Cement stabilization of clay in Singapore: Field and laboratory comparison

Siau Chen Chian[1], X.L. Goh[1], Z. He[2], and K.W. Leong[2]

[1] Department of Civil and Environmental Engineering, National University of Singapore, Block E1A #07-03, 1 Engineering Drive 2, Singapore 117576, Singapore.
[2] Keller Foundations (S.E.Asia) Pte Ltd, Tradehub 21, #04-104, 18 Boon Lay Way, Singapore 609966, Singapore

ABSTRACT

Cement stabilization is a well-established technique to enhance the soil's properties such as strength and compressibility. Production of cement is highly deleterious to the environment. Judicious dosage of cement in soft clayey soils is hence key in reducing waste, time and cost. In order to encourage optimization of cement dosage, a comprehensive suite of laboratory tests on cement treated Singapore marine clay were carried out over a wide range of water-clay-cement proportions and curing ages. In order to put the strength predictive model to good use, the predicted strength according to the field mixing ratios and curing duration was compared with unconfined compressive strength results from field core samples. Results showed that the predictive strength fall along the lower bound of the field results. By adopting a COV of 0.4 onto the predicted strength, more than 95% of the field data was observed fall either within or above the predicted range. These findings were persistent for two construction sites adopting different cement type at almost opposite ends of the Singapore mainland at Bedok and Punggol, where the underlying geological formation are different. In view of the matching results between laboratory and field results, the potential for direct field application is promising to optimize cement dosage as well as a means of quality control to detect defective mixing.

Keywords: cement stabilization; marine clay; unconfined compressive strength

1 INTRODUCTION

Ground improvement using cement stabilization is commonly adopted in many construction projects in Singapore, particularly at locations with deep marine clay deposits within the Kallang Formation, to enhance the soil's properties such as strength and compressibility. A minimum unconfined compressive strength is often stipulated in the performance specifications, failing which requires the ground improvement contractor to rectify at considerable cost and time. Due to lack of confidence on the performance of cement stabilization, this results in contractors adopting excessive cement dosage into the ground to ensure compliance to the specification. Such practice is costly, time consuming and deleterious to the environment. Optimization of dosage of cement in soft clayey soils is hence key in addressing these issues in this growingly environmental conscious modern society. In order to encourage optimization of cement dosage, comparison of insitu and predicted strength has to be carried out to offer the confidence to contractors to adopt a more aggressive approach towards lower cement dosage, while still satisfying the minimum contractual performance required. A strength predictive model developed based on a comprehensive suite of laboratory tests on cement treated Singapore marine clay over a wide range of water-clay-cement proportions and curing ages (Chian et al. 2015) was therefore used for the comparison. Through such studies, three objectives can be achieved: 1) compare performance of laboratory and field strength of cement-treated soil, 2) assess feasibility of using an established strength predictive model, and 3) highlight limitations and recommend future work to enhance strength prediction.

2 NATURE OF KALLANG FORMATION MARINE CLAY

The Kallang Formation in Singapore is the youngest deposit consisting of sediments with marine, alluvial, littoral, and estuarine origins that have been laid down from late Pleistocene to Holocene period. It can be found up to about 55m deep and generally low lying less than 4m above sea level. Marine clay is very soft and highly compressible. It can appear in two layers; softer upper layer overlaid by a stiffer layer separated by fluvial deposits. In general, the shear strengths of the upper and lower marine clay are typically in the range of 10 to 30 kPa and 30 to 60 kPa respectively (Liu et al. 2008). Table 1 shows the typical physical properties of upper Singapore marine clay. Large consolidation settlement is expected when subjected to additional loads or water drawdown due to its inherent high water content. Therefore, it is often essential to conduct ground stabilization to improve the soil condition where very deep foundations are not possible.

Table 1. Physical properties of upper Singapore marine clay (Lu et al. 2011)

Property	Value
Liquid limit (%)	70-90
Plastic limit (%)	36-56
Specific gravity	2.62-2.69
Clay fraction (%)	>50
Sand fraction (%)	<5

3 SOIL STABILIZATION IN PRACTICE

It is common practice that contractors apply a constant cement dosage across the soil depth profile despite differing type and properties of the soil. As a result, variation in strength is often observed due to these difference in soil condition, thereby making subsequent excavation and trimming challenging.

One of the most common cement stabilization mixing method is deep soil mixing. In this method, the shaft with mixing blades rotates and penetrates into the soil till the desired depth is reached. The shaft is then withdrawn from the ground while pumping wet slurry grout into the soil. The mixed soil is left to cure so hydration and hardening of the cement-treated soil would take place insitu (Fig. 1). For performance verification, samples are cored after curing for considerable age and tested in the laboratory for their unconfined compressive strength.

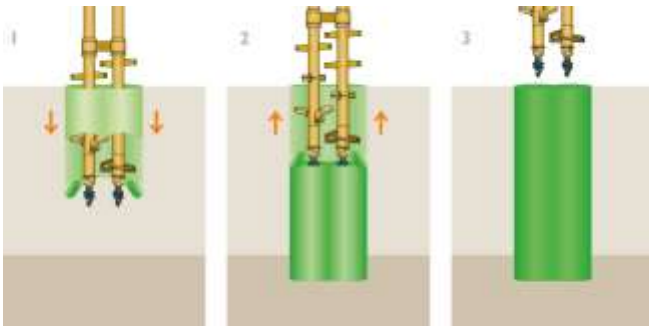

Fig. 1. Wet soil mixing process

4 LABORATORY EXPERIMENTS AND STRENGTH PREDICTIVE MODEL

The strength of cement treated soils is dependent on the properties of the reactants, reaction conditions and sample preparation. Chian et al. (2015) compiled an extensive suite of laboratory experiments with different types of soil, cement, mix proportions and curing time so as to produce a broad guide on the optimisation of cement to achieve a target strength. Specific to Singapore marine clay, they sieved the raw Singapore marine clay for removal of stones and shell pieces before mixing with cement and water to form slurry which were then transferred to cylindrical moulds of 50mm and 100mm in diameter and height respectively. The specimen was compacted in three layers by manual tamping to minimise entrapped air voids. Next, the specimens were fully immersed in water until the desired curing age for testing of unconfined compressive strength. An empirical strength predictive model for cement-treated clays was developed to reflect the key parameters such as water-to-cement (w/c) and soil-to-cement (s/c) ratios as well as curing days as shown in Eq. (1):

$$q_u = \frac{X}{Y^{w/c}} \ln(t) = \frac{a + b(s/c)}{Y^{w/c}} \ln(t) \tag{1}$$

where a and b are the y-axis intercept and slope of parameter X versus s/c respectively. The proposed model requires 3 constants (a, b, Y) to be calibrated from experimental data. Fig. 2 shows Eq. (1) fitting the full range of tests in the present study. The a, b and Y constants used are 3700, -75 and 1.35 respectively for Singapore marine clay treated with Portland Blast Furnace Cement.

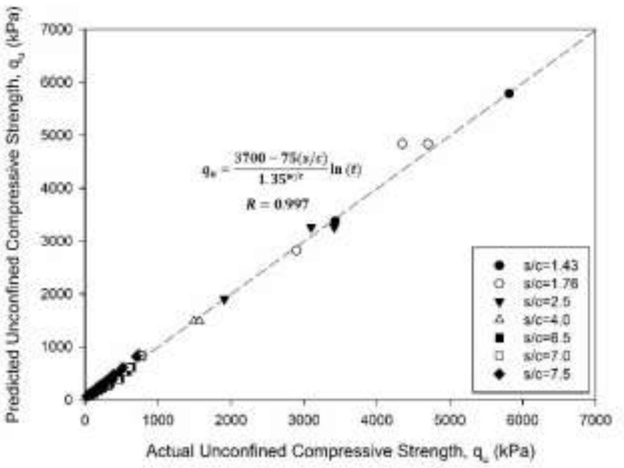

Fig. 2. Predicted versus actual laboratory unconfined compressive strength of cement treated Singapore marine clay (Chian et al. 2015)

5 CASE STUDIES AT BEDOK AND PUNGGOL

Bedok Site

The Bedok site was a mass rapid transit (MRT) station construction along the Thomson-East Coast Line. The site was a land reclaimed in late 1960s. The soil profile consists of several types of soil, the Fill, Kallang formation and Old Alluvium. Underlying the reclaimed fill was a 10m thick soft marine clay which had to be treated. The deep soil mixing stabilizing additive was Portland Blast Furnace Cement (PBFC).

The five areas requiring stabilization at the Bedok site are shown in Fig. 3. The purpose of cement stabilization is to improve the soil bearing capacity to a minimum unconfined compressive strength of 0.6MPa and modulus to 150MPa. Treatment was targeted at the softer soil layer at depths 5 to 6m below the ground surface where 10 to 14m thick of soft marine clay were found (denoted as “mixing length” in Fig. 4). These depths were also where the future MRT station structure would be constructed.

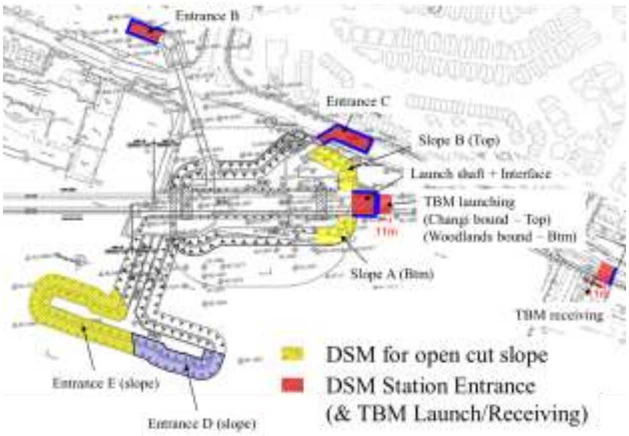

Fig. 3. Plan of deep soil mixing at Bedok Site

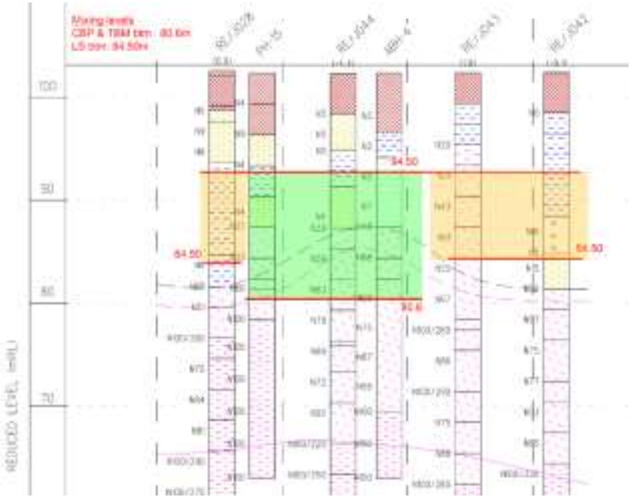

Fig. 4. Deep soil mixing soil profile at Bedok site

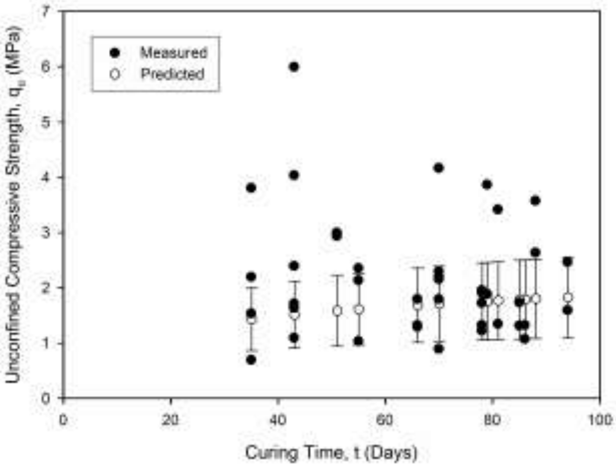

Fig. 5. Comparison of predicted and measured unconfined compressive strength over time at Bedok site

Based on a total of 139 field core samples at different locations and depths of the site, results showed that the predictive model proposed by Chian et al. (2015) was able to provide good estimates of these core sample unconfined compressive strength with 96.5% of the field data points above the lower bound of a COV of 40%, which is typical for such soils in practice. Fig. 5 shows a predicted versus measured strength development of cement treated Singapore marine clay with PBFC over time at the section with most extensive cement stabilization in that construction site.

Punggol Site

In the case of the Punggol site, the soil profile contained a 15m thick soft marine clay which was treated with Ordinary Portland Cement (OPC) using the deep soil mixing technique. The site was a construction project adjacent to the waterway. The soil along Chainage Ch.3759 to Ch.3900 in Fig. 6 was the location of the waterway requiring cement stabilization.

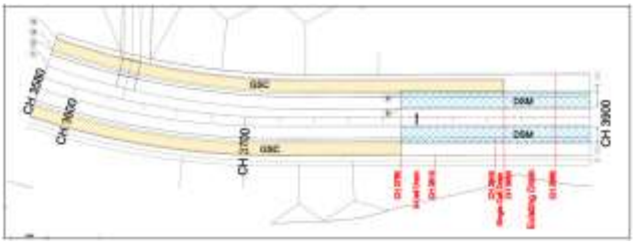

Fig. 6. Deep soil mixing location at Punggol Site

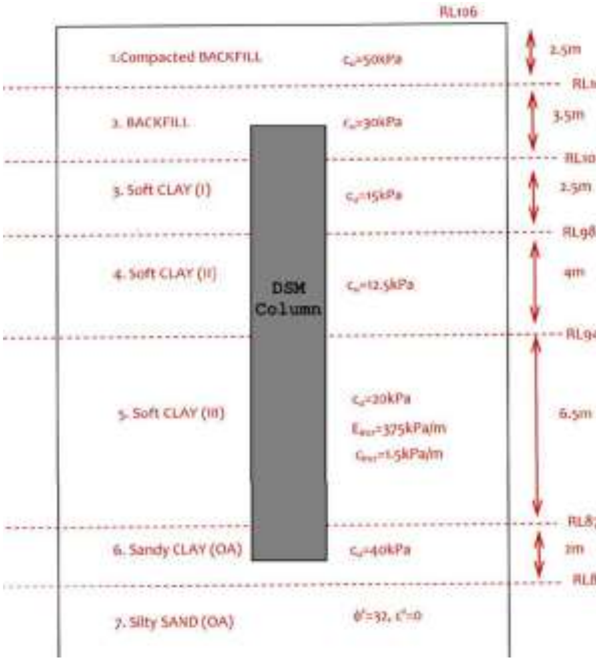

Fig. 7. Depth of the cement mixed pile in the soil profile

Fig, 7 shows a typical soil profile and the depth of soil treated with cement. The target area for ground improvement was about 5.5 meters below ground level and final depth of the cement treated pile of about 14.1m. Similar to the stabilization of slopes in Bedok, a rectangular grid-like pattern was adopted to stabilize the ground as indicated in Fig. 8.

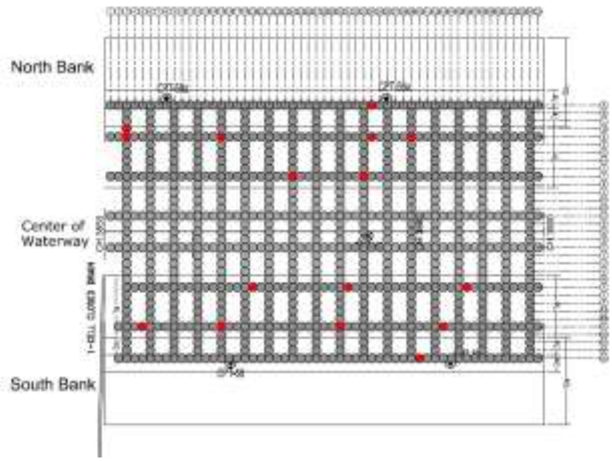

Fig. 8. Plan view of the cement mixed pile configuration

A total of 48 field samples were obtained and compared with the empirical prediction with consideration to the differing soil and cement type such as liquid limit, sand content and composition of the cement. Fig. 9 shows a plot of predicted versus measured strength development of cement treated Singapore marine clay with OPC over time at the Punggol site, demonstrating persistently good estimates of lower bound values of unconfined compressive strength obtained in the field. This confirms the applicability of using laboratory developed strength predictive model to estimate field performance.

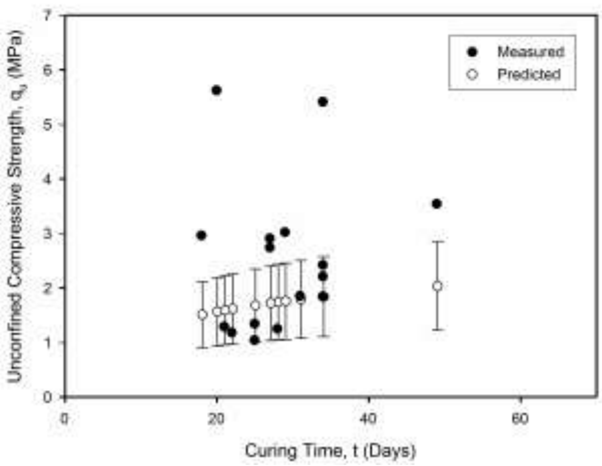

Fig. 9. Comparison of predicted and measured unconfined compressive strength over time at Punggol site

6 CONCLUSION

A comparison between laboratory prepared and field samples were carried out on two construction sites in Singapore with presence of Singapore marine clay. It is observed that empirical strength predictive models such as Chian et al. (2015) can provide consistent estimates of the lower bound of the expected field performance. This opens up the potential of optimizing cement dosage in cement stabilization of soft soils with assurance of not falling below contractual requirement of minimum strength performance.

REFERENCES

Chian, S.C., Nguyen, S.T. & Phoon, K.K. (2015). Strength and Stiffness Development of Cement Mixed Clay. 16th European Conference on Soil Mechanics and Geotechnical Engineering, Edinburgh, pp. 3129-3133.

Liu, S.Y., Zhang, D.W., Liu, Z.B., and Deng, Y.F. (2008). Assessment of unconfined compressive strength of cement stabilized marine clay. Marine Georesources and Geotechnology, 26, 19-35.

Lu, Y., Tan, T.S., and Phoon, K.K. (2011). Accelerated testing of cement treated Singapore Marine Clay cured under elevated temperature. Technical report. National University of Singapore, Centre for Soft Ground Engineering, Singapore.