

Geotextile Encapsulation as Protection to Lime Column under Shear Load

Siaw Yah Chong^{1*}, Khairul Anuar Kassim², Min Lee Lee³, and See Hung Lau¹

¹Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Jalan Sungai Long, Bandar Sungai Long, Cheras, 43000 Kajang, Selangor, Malaysia

²Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

³Department of Civil Engineering, Faculty of Engineering, University of Nottingham Malaysia, 43500 Selangor, Malaysia

Abstract. Deep lime stabilization such as lime column, can effectively improve the problematic soft clay through stabilization, settlement reduction and embankment stabilization. Nevertheless, the reduction of lime column load capacity was often encountered due to the column lateral displacement which was induced by high lateral earth pressure in embankments and deep excavation. In order to protect and enhance the mobilization of lime column strength, geotextile encapsulation was proposed for lime column. In this study, large shear box tests were conducted on lime column and geotextile encapsulated lime column (*GELC*) stabilized Pontian marine clay samples with different column sizes and curing ages, in order to investigate the performance of geotextile encapsulation on lime column in Pontian marine clay under shear loading. It was found that geotextile encapsulation effectively increased the horizontal shear resistance of lime column and protected the column from defect due to lateral displacement, especially at early age when modification was still in process. Geotextile encapsulation also successfully protected lime column from shear and bending failure under lateral load.

1 Introduction

Deep lime stabilization such as lime column improves the problematic soft clay through stabilization, settlement reduction and embankment stabilization [1- 6]. Shear failure and bending failure were normally observed on lime column under lateral load [7- 11]. The lateral displacement significantly reduced lime column load capacity, especially for embankments with low stability and deep excavation which had high lateral pressure [1]. Geosynthetic encasement provides additional confining pressure to the granular column and effectively increased its performance in the soft clay [2, 3]. In order to protect and enhance

* Corresponding author: chongsiawy@utar.edu.my

the mobilization of lime column strength, geotextile encapsulation was proposed for lime column in this study.

This paper aimed to investigate the performance of geotextile encapsulation on lime column under shear load, including shear resistance and failure mechanisms. Physical modelling, namely large shear box tests were conducted. The samples tested are Pontian marine clay stabilized with lime column and *GELC* at different ages. Column with different sizes are also tested. The horizontal shear resistance and failure mode were observed. Improvement ratio was used to evaluate the performance of geotextile encapsulation on lime column stabilized Pontian marine clay under lateral load. Parameters which influenced the performance of geotextile encapsulation on lateral force resistance for lime column were investigated, including curing duration and area ratio.

2 Material and methods

2.1 Materials

Pontian marine clay obtained from Sg Penerok T/Kiri in Johor, Malaysia was selected as the soil specimen in this study. The sampling site is geographically located at coordinates of N 01°22.457' and E 103°25.702'. The area is part of the coastal plain of southwestern region of Johor which is predominantly underlain by marine clay, silt and the paludal peat deposit of Holocene age [4]. Pontian marine clay has liquid limit of 62 % and plastic limit of 30%. It was classified as clay with high plasticity (*CH*), based on the British Soil Classification System (*BSCS*). The soil has a specific gravity of 2.48 Mg/m³ and with the initial consumption of lime of 4.40%. The stabilizer selected was hydrated lime supplied by Limetreats, a lime product manufacturer based in Pasir Gudang, Johor whereas the geotextile selected for encapsulation on the lime column was TenCate Polyfelt® PE50 from Tencate Geosynthetics Malaysia Sdn Bhd.

2.2 Samples preparation

First, Pontian marine clay was mixed with water to form slurry with moisture content of 1.2 times the liquid limit. Then, the slurry was poured into a cylinder with internal diameter of 210 mm. An overburden pressure of 50 kPa was applied onto the slurry for 3 days in order to form a 200mm thick clay bed with vane shear strength about 20 ±2 kPa.

Lime columns of 200 mm in height were formed in 3 different diameters, i.e. 40 mm, 53 mm and 60 mm by compacting lime-soil mixtures into *PVC* tubes of the selected diameters in 3 layers at a bulk density of 1.74 Mg/m³. The lime content of the lime-soil mixture was 10%, while the water content was controlled at 37%. From the preliminary tests, the 14-day, 28-day and 56-day unconfined compressive strength of the lime columns was 264 kPa, 362 kPa, and 389 kPa, respectively [15].

For *GELC*, the geotextile sheet was seamed into the required diameters and 200 mm sleeves. The soil-lime mixture with similar properties as those of the normal lime column was then compacted in three layers into the *PVC* tubes that covered with the geotextile sleeve to form the *GELC* [16].

A hollow, sharp-ended cylindrical steel tube that attached to a *PVC* casing was pushed into the center of the clay bed. Soil in the tube was removed and the pre-casted lime column was subsequently pushed into the hole to replace the soil extracted. Pontian marine clay sample with lime column and *GELC* were cured under room temperature for different curing periods, namely: 14 days, 28 days and 56 days before being tested.

2.3 Large shear box test procedures

A series of large shear box tests were performed to evaluate the performance of the geotextile encapsulation on lime column under shear stresses. The testing setup was designed based on the unit cell concepts to simulate a number of columns installed at an identical spacing, in a triangular pattern. The area ratios (a) for the specimens were 0.036, 0.064 and 0.082.

Fig. 1 shows the schematic diagram of the large shear box. The shear box consisted of 2 separated shear rings with an inner diameter of 210 mm. Fig. 2 shows the photograph of the shear ring taken from the top view. The upper part of the shear ring was fixed while the bottom part was unrestrained from any movement. The sample was sheared laterally until the lateral displacement exceeded 20 % of the sample diameter. The strain rate applied was 1 mm/ min. The sample was subjected to a normal stress of 8.65 kPa throughout the test. The shear stress was measured by using load cell whereas the lateral displacement was measured by using linear variable differential transducer (*LVDT*). Data acquisition system was used to record and retrieve the data for subsequent analysis. Upon completion of the shear tests, the samples were extruded and bisected to observe their failure pattern and deformation characteristics.

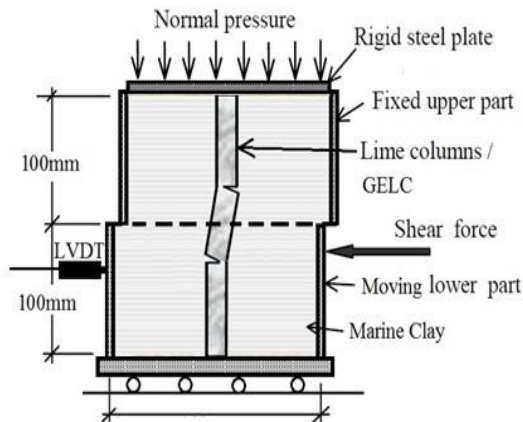


Fig. 1. Large shear box test setup

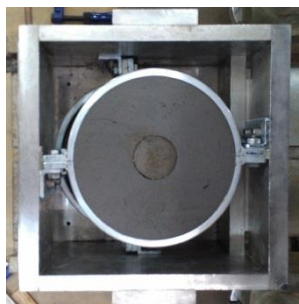


Fig. 2. Top elevation of big shear box

3 Results and discussion

3.1 Horizontal Shear Resistance Improvement Ratio (HSR)

The peak shear stress obtained from the large shear box tests was defined as the horizontal shear resistance (*HSR*). The performance of geotextile encapsulation on lime column stabilized Pontian marine clay was evaluated by comparing the horizontal resistance shear improvement ratio (*IR*). Horizontal shear resistance improvement ratio is defined as the ratio of horizontal shear resistance of *GELC* stabilized sample (HSR_{gelc}) to that of normal lime column stabilized marine clay (HSR_{lc}). The results for both *HSR* and *IR* are summarized in Table 1.

The *HSR* of lime column stabilized samples at age of 14 days with column diameter of 40mm, 53mm and 60mm was 11.70 kPa, 13.28 kPa and 14.90 kPa, respectively. Then, the *HSR* for the sample at age of 56 days increased to 17.36 kPa, 19.42 kPa and 19.83 kPa, respectively. It was observed that the lime column stabilized marine clay had a greater increase in *HSR* from age 14 to 28 days than from age 28 to 56 days. This was because the lime-soil mixture was still in modification process in which the lime column is still in the process of gaining strength; the lime column at 14 days was still weak. This was supported by the results of unconfined compression test which also exhibited a similar trend.

Table 1. Horizontal shear resistances and improvement ratios of Pontian marine clay with lime column and *GELC*.

Column Diameter, ϕ_{col} (mm)	Area Ratio, a (in fraction)	Age, t (day)	Unconfined Compressive Strength, $q_{u\ col}$ (kPa)	HSR_{gelc} (kPa)	HSR_{lc} (kPa)	<i>IR</i> (in fraction)
40	0.036	14	264	17.27	11.70	1.48
40	0.036	28	362	16.11	15.77	1.02
40	0.036	56	389	17.08	17.36	0.98
53	0.064	14	264	17.51	13.28	1.32
53	0.064	28	362	20.39	18.60	1.10
53	0.064	56	389	18.16	19.42	0.94
60	0.082	14	264	18.55	14.90	1.25
60	0.082	28	362	20.44	19.69	1.04
60	0.082	56	389	21.25	19.83	1.07

The enhancement in *HSR* of lime columns that encapsulated with geotextile was further evaluated by assessing their *IRs*. Two parameters which may affect the performance of the geotextile encapsulation were examined, namely curing duration and column size.

Fig. 3 presents the correlation between curing duration and *IR* of *GELC* stabilized Pontian marine clay with different column diameters. For samples aged 14 days, the *HSR* of *GELC* samples with column diameters of 40 mm, 53 mm and 60 mm were improved by 48%, 32%, and 25%, respectively. However, the *IR* decreased as the curing duration increased. The *IRs* were close to unity for the samples aged 56 days. A higher *IR* was observed for samples at a younger age as the lime column was still weak and in modification process, especially for samples at the age of 14 days. It was anticipated that the geotextile could provide additional bonding to these weak columns. When the samples

reached the age of 28 days, the lime column had almost achieved the optimum unconfined compressive strength and hence the improvement ratio for samples aged 28 days were relatively close to those of 56 days. From the foregoing results, it was found that geotextile encapsulation was effective in enhancing the short term performance of the lime columns stabilized soil during the early construction stage. An empirical correlation between horizontal shear resistance improvement ratio (*IR*) due to geotextile encapsulation and sample curing duration (*t*, in day) was developed:

$$IR = 2.3t^{-0.2} \tag{1}$$

It should be noted that the correlation may only be valid for *GELC* with lime content of 10% and other testing parameters as set in the present study. A larger sample size with different testing configurations is required to further validate the empirical equation.

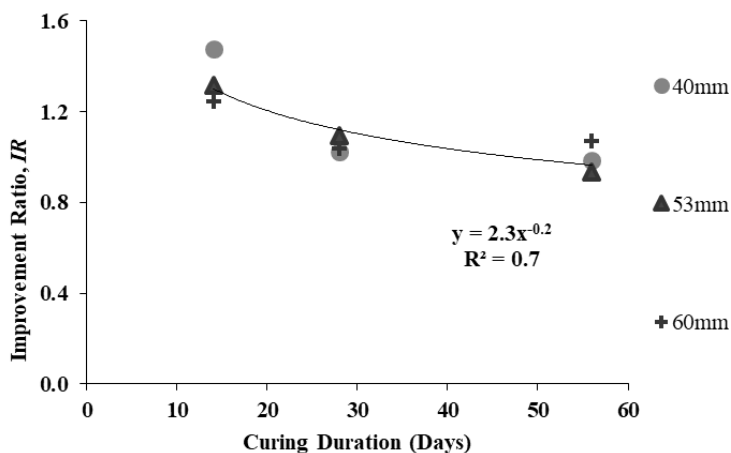


Fig. 3. Relationship between horizontal shear resistance improvement ratio and curing duration for *GELC* with different diameters

The effect of area ratio on *IR* for samples at different ages is shown in Fig. 4. It was observed that for columns aged 14 days, the *IR* decreased as area ratio increased (the *IR* for *GELC* with area ratios of 0.04, 0.06 and 0.08 were 1.48, 1.32 and 1.25, respectively). However, for columns aged 28 days and 56 days, the *IR* did not exhibit clear relationship with area ratio. The *IR* was close to unity, ranging from 0.94 to 1.10. This showed that geotextile encapsulation was more effective on young aged lime column with smaller area ratio.

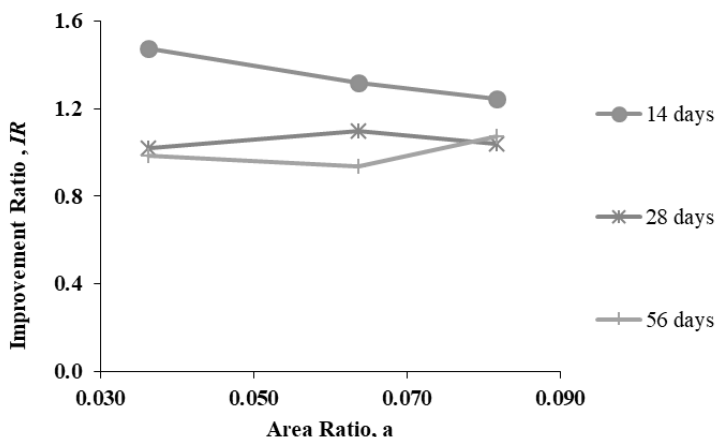


Fig. 4. Horizontal shear resistance improvement ratio due to geotextile encapsulation for sample at different ages versus area ratio

3.2 Failure patterns

Bisected samples of lime column stabilized Pontian marine clay upon completion of large shear box tests are shown in Figs. 5 to 7. Similar failure patterns were observed for lime column stabilized samples at the same age, regardless of the column size. Shear failure was observed for the lime column stabilized Pontian marine clay aged 14 and 28 days. Both column and surrounding soil failed along the pre-determined surface. This was because lime columns at a young age had lower strength and stiffness. Bending failure with 2 plastic hinges was observed for lime columns aged 56 days. The samples failed as the resistant capacity of the column against bending moment was exceeded. The plastic hinges were located at 25 mm above and below the shearing plane. When the lime column strength and moment resistance is relatively high, the column behaves as a pile or dowel in which the number of plastic hinges formed is dependent on the location of slip surface compared to the column length [5]. However, the surrounding soil experienced shear failure at the pre-determined surface

Bisected samples for the GELC stabilized Pontian marine clay after the large shear box tests are shown in Figs. 8 to 10. It was observed that all the GELC stabilized samples had a similar failure mode, regardless of the column size and curing duration. No crack or failure was observed in the column itself. However, the column failed by rotation as the lateral resistance of surrounding soil exceeded. Kivelo and Brom found that for short columns with slip surface at half of the column length, and constant surrounding soil strength to depth, the column will rotate as a rigid mass [5].

Geotextile encapsulation had significantly influenced the failure mode of lime column under shear load test. From the testing results, it can be concluded that the columns without geotextile encapsulation failed by either shear or bending of the column materials. Geotextile encapsulation successfully protected lime columns and improved their shear and bending capacity. As the result, The *GELC* failed by rotation as a rigid body due to the exceeded lateral resistance of surrounding soil.

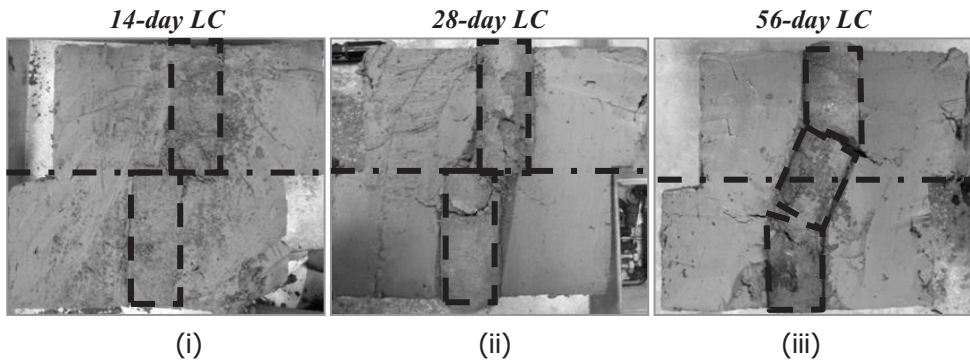


Fig. 5. Bisected Pontian marine clay sample with 40 mm lime column

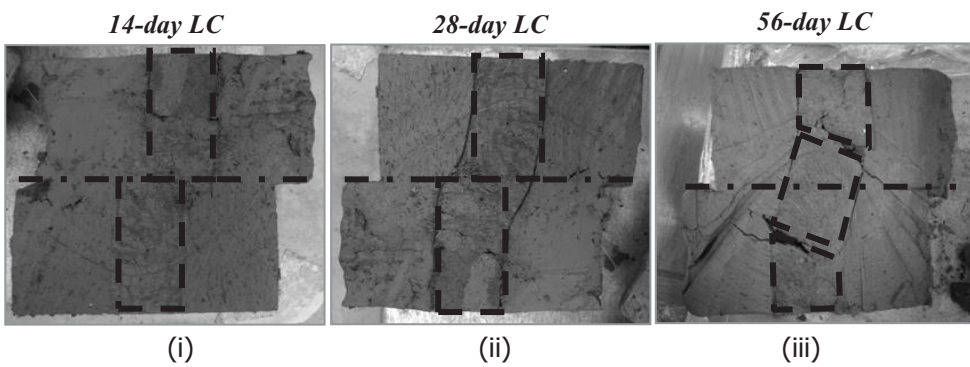


Fig. 6. Bisected Pontian marine clay sample with 53 mm lime column

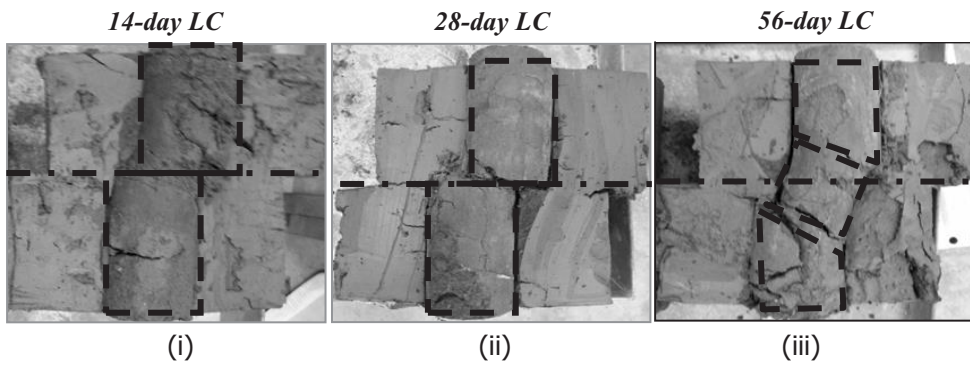


Fig. 7. Bisected Pontian marine clay sample with 60 mm lime column

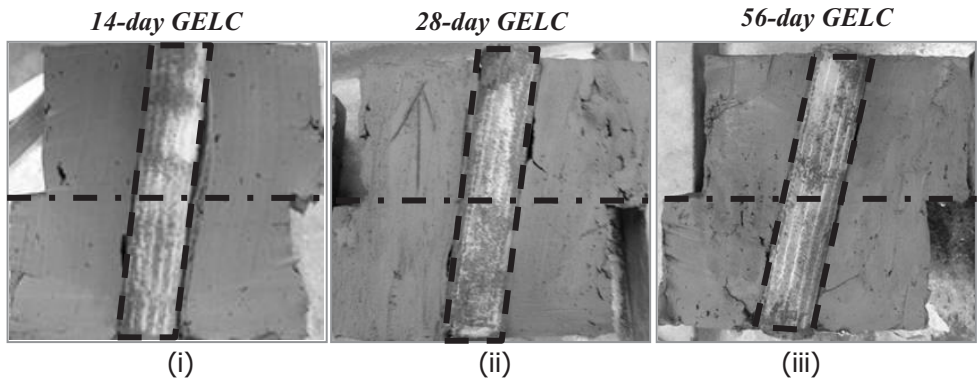


Fig. 8. Bisected Pontian marine clay sample with 40 mm *GELC*

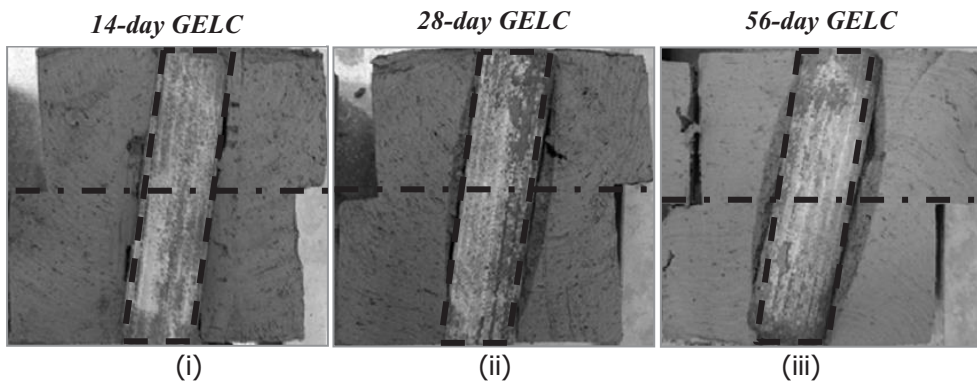


Fig. 9. Bisected Pontian marine clay sample with 53 mm *GELC*

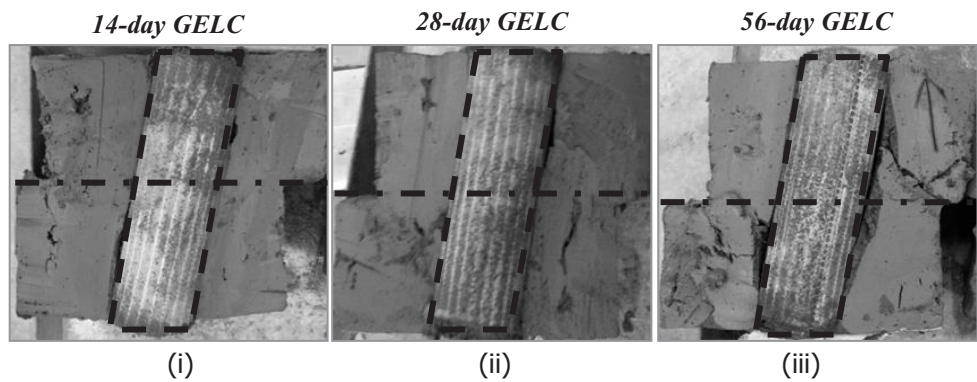


Fig. 10. Bisected Pontian marine clay sample with 60 mm *GELC*

4 Conclusions

In conclusion, geotextile encapsulation effectively improved the horizontal shear resistance of lime column stabilized Pontian marine clay, especially for lime column with smaller sizes at younger ages, which was still in modification phase when the column strength was still low. A 48% increment was observed for lime column stabilized Pontian marine clay sample with area ratio of 0.036, at age of 14 days. Meanwhile, the improvement ratio was near to 1 for sample at age of 56 days when the lime column was in stabilization phase.

In terms of failure pattern, lime column at younger ages, namely 14 and 28 days, had shear failure. Whereas lime column at age of 56 days has bending failure with 2 plastic hinges. GELC at all ages had failure due to lacking of lateral resistance by the surrounding soil; the column was rotated. No crack was found on lime column with geotextile encapsulation. Geotextile encapsulation had protected lime column from shear and bending failure at early ages, which might lead to cracking and lateral displacement that reduced the load capacity of lime column.

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