

Effect of Geotextile Encapsulation on Lime Column Axial Stress in Pontian Marine Clay

Siaw Yah Chong^{1, a}, Khairul Anuar Kassim^{2, b*} and Kenny Tiong Ping Chiet^{1, c}

¹PhD Candidate, Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, Johor, Malaysia.

²Professor, Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, Johor, Malaysia

^acsyah84@yahoo.com, ^bkanuar@utm.my, ^ckennytiongpc@gmail.com

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Abstract. Previous researchers reported that problematic soft clay can be improved by deep lime stabilization. However, due to low confining pressure of surrounding soil, problems often occurred at top part of column which reduced the performance of lime column, such as: crushing at column head and higher settlement for surrounding soil at the upper part of column. Geotextile encapsulated lime column (GELC) was proposed in this study. The stresses on column are essential in the analysis on columnar improved soil. Multi-stage loading test was conducted on lime column and GELC stabilized Pontian marine clay aged 14 days, 28 days and 56 days in order to investigate axial stress on lime column and GELC stabilized Pontian marine clay. Geotextile encapsulation increased the compressive strength of lime column about 70 percent at axial strain of 8 percent.

Introduction

Based on previous researches, problematic soft clay can be significantly improved by deep lime stabilization, such as lime column, lime pile and lime slurry pressure injection. Deep lime stabilization is widely applied in Sweden, Japan and United States [1,2,3]. However, as lime column performance is greatly influenced by confining pressure of surrounding soil, problems usually occurred at top part of column, such as: crushing at column head and higher settlement for the surrounding soil at upper part of column [4,5,6]. Geotextile encasement successfully increased the performance of granular column on settlement reduction, by increasing the confining pressure on column [7,8,9]. Therefore geotextile encapsulated lime column (GELC) was proposed in this study. Axial stress on column and stress strain relationship are essential to understand the consolidation behaviour and settlement prediction for columnar improved soil [10,11]. Thus axial stress on column and stress strain relationship of lime column and GELC stabilized Pontian marine clay with different ages were investigated. Other than that, effect of geotextile encapsulation on stress strain behaviour and lime column strength in composite system was evaluated.

Sample Preparation

Oven-dried Pontian marine clay passing 2 mm sieve, with liquid limit of 62 percent and plastic limit of 30 percent was selected in this test. The initial consumption of lime for Pontian marine clay was 4.40 percent. Hydrated lime from Limetreats, Pasir Gudang in Johor was selected as the stabilizer whereas TenCate Polyfelt® PE50 from Tencate Geosynthetics Malaysia Sdn Bhd was selected for the geotextile encapsulation. Remoulded Pontian marine clay was prepared by consolidation of Pontian marine clay slurry with initial moisture content of 1.2 times of liquid limit, under 49 kPa for 3 days. A very soft to soft marine clay bed of 210 mm diameter and 200 mm height with vane shear strength about 20 kPa was formed; Inspection Vane Tester, Geonor H-60 was used to verify the vane shear strength. Lime column has a lime content of 10 percent, moisture content of 37 percent and bulk density of 1.74 Mg/m³, based on 95 percent maximum density on the wetter side of

compaction curve. Strength properties of lime stabilized Pontian marine clay, which were obtained from unconfined compression test on laboratory samples, are shown in Table 1.

Table 1 Strength properties of lime stabilized Pontian marine clay

| Age [day] | Lime Content [%] | Unconfined Compressive Strength, q_u [kPa] | Failure Strain [%] | Young Modulus, E_{50} [MPa] |
|-----------|------------------|--|--------------------|-------------------------------|
| 14 | 10 | 264 | 1.85 | 17.512 |
| 28 | 10 | 362 | 1.30 | 31.187 |
| 56 | 10 | 389 | 1.20 | 40.056 |

The lime-soil mixture was compacted in 3 layers into PVC tube with inner diameter of 53 mm in order to form a lime column with a diameter of 53 mm and height of 200 mm. GELC has the same composition with lime column, except it was encapsulated with a geotextile sleeve. The geotextile sheet was sewn into 53 mm diameter and 200 mm sleeves by overlapping 2.5 mm wide section of geotextile and sewing with prayer seam and 101 type of chain-stitch. Then, the geotextile sleeve was placed into a PVC tube and soil-lime mixture was compacted in three layers into the geotextile sleeve, in order to form a GELC with a diameter of the 53 mm and height of 200 mm. The column installation method was different from the method at site. In this study, column was pre-fabricated and then installed in the marine clay bed. This method was chosen as it could provide a uniform and quality column. This study focused on axial stress on column with respect to settlement of column, the quality control at site was not the objective of this investigation. A hollow, sharp end of cylindrical steel tube together with a plastic tube as a casing was pushed into the middle of Pontian marine clay bed. Then, the soil was extracted and replaced with prefabricated column. Final height of sample was 210 mm, which included a 200 mm height column at middle and a 10 mm thick soil pressure gauge on the column. The column stabilized samples were cured at room temperature for 14, 28 and 56 days before tested.

Physical Modelling: Multi-Stage Loading Model Test

Multi-stage loading model test was designed based on unit cell concept, which simulated a group of column with area ratio of 0.064 and column diameter of 53 mm, installed vertically in triangular pattern at same spacing on a Pontian marine clay layer. They sat on a hard layer and were subjected to uniform vertical loads. Experiment setup for multi-stage loading model test is shown in Fig. 1, which was similar to the test procedure of previous test [12]. The test equipment consisted of a 15 mm thick Perspex cylindrical mould with a 210 mm internal diameter and 400 mm height, with a rigid permeable plate each placed at top and bottom of the sample to provide drainage. No lateral drainage and displacement was allowed. Only top and bottom drainages were allowed. In order to ensure similar and uniform settlement on both column and surrounding soil, a rigid piston with a vertical shaft and the assistance of piston guide was used to apply load onto the sample, using air pressure from compressor with assistance by cylinder and controller. Two small earth pressure gauges were installed on column and surrounding soil surface, in order to detect the pressure acting on column and surrounding soil. A 100 mm linear variable differential transducer was also installed to monitor settlement of the composite system throughout the test whilst data logger was used to collect data. The sample was loaded in stages as in oedometer test. A piston with supply of air pressure was used to load the sample; load was maintained for 4 days until the settlement was less than 1 mm within 24 hours in each loading stage. Time, settlement, pressure on column and pressure on surrounding soil were monitored throughout the test. Sample tested were Pontian marine clay, lime column stabilized Pontian marine clay and GELC stabilized Pontian marine clay with different ages.

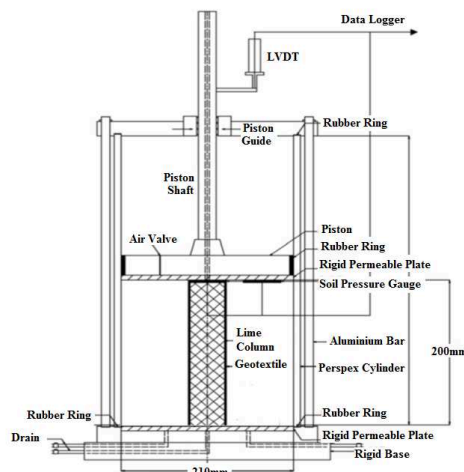


Fig.1 Multi-Stage Loading Test Equipment and (from Chong and Kassim, 2014)

Axial Stress on Lime Column

Axial stresses on column respect to applied loadings for lime column stabilized sample with different ages are shown in Fig. 2. Stress at column increased with applied loading. Other than that, higher load concentration was found on lime column at higher age which had higher stiffness. The final stress on lime column aged 14 and 56 days under applied loading of 196 kPa was 640 kPa and 709 kPa, respectively. However, final stress on lime column aged 28 days was extremely low, which was near to the stress on unstabilized Pontian marine clay. This might be due to the failure of column during installation which reduced column stiffness and therefore reduced the load concentration on column. Fig. 3 displayed the stress-strain curves for lime column at different ages. Axial stress on column increased with strain. Axial stress on column at 8 percent strain for lime column stabilized sample at age 14, 28 and 56 days observed was 510 kPa, 140 kPa and 615 kPa, respectively. The axial stress on column for sample aged 14 days and 56 days was 1.9 and 1.6 times of unconfined compressive strength for lime stabilized marine clay at respective age. The axial stress on column for sample at age 28 days was extremely low, which was only 0.4 times of unconfined compressive strength for lime stabilized marine clay at age 28 days; this might be due to the failure of column during installation which had reduced the strength of lime column.

Axial Stress on GELC

Axial stresses on column respect to applied loadings for GELC stabilized sample with different ages are shown in Fig. 2. The effective stress on column increased with applied loading. GELC with the elder ages had higher load concentration on column. The stress-strain curves of GELC in Pontian marine clay is shown in Fig. 3. It was observed that strength of GELC increased with curing duration. Axial stress on column at 8 percent strain observed for GELC stabilized sample at age 14, 28 and 56 days was 790 kPa, 1015 kPa and 1135 kPa, respectively. The axial stress on column for GELC stabilized sample aged 14, 28 and 56 days were about 3 times of unconfined compressive strength for lime stabilized marine clay at respective age. The increase of strength with strain was still on-going after 8 percent strain was reached.

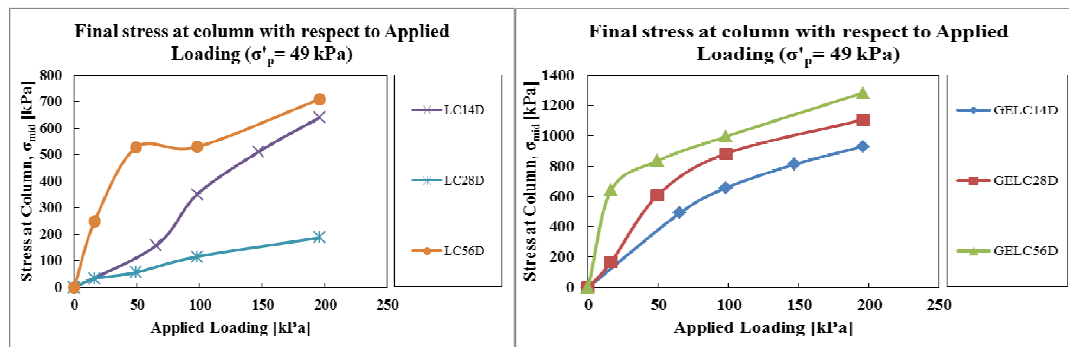


Fig. 2 Effects of curing duration on the final stress on lime column and GELC with respect to applied loading

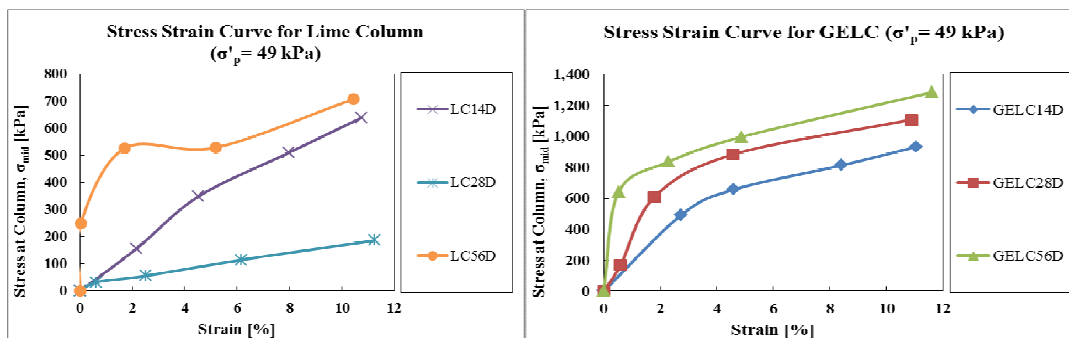


Fig. 3 Stress-strain curves for lime column and GELC with different ages in Pontian marine clay

Comparison between Axial Stress on Lime Column and GELC

Both lime column and GELC stabilized marine clay had higher load concentration at mid of sample where the columns were located. However, under similar applied loading, GELC stabilized sample had higher stress concentration on column compared to lime column stabilized sample. Other than that, stress on column was higher for lime column with geotextile encapsulation at particular strain. This meant that GELC could sustain a greater stress at the same deformation, compared to lime column. A visible yield point was observed on lime column aged 56 days which had a higher stiffness compared to column at younger ages, as shown in Fig. 2. However, with geotextile encapsulation, yield point was eliminated and the lime column could sustain a greater load at same deformation compared to lime column. From Table 2, the strength of GELC and lime column in Pontian marine clay at 8 percent strain was about 2.9 and 1.8 times of lime column unconfined compressive strength, respectively. At axial strain of 8 percent, GELC strength was about 1.7 times of lime column strength. Therefore it was suggested that geotextile encapsulation effectively increased the compressive strength of lime column.

Table 2 Stress on column at 8 % strain versus unconfined compressive strength of column material

| Unconfined Compressive Strength, UCS [kPa] | Stress on Column at 8 % Strain, $\sigma_{mid @8}$ [kPa] | | $\sigma_{mid @8} / \text{UCS}$ | |
|--|---|------|--------------------------------|------|
| | LC | GELC | LC | GELC |
| 264 | 510 | 790 | 1.9 | 3.0 |
| 362 | - | 1015 | - | 2.8 |
| 389 | 615 | 1135 | 1.6 | 3.0 |
| Average | | | 1.8 | 2.9 |

Conclusion

Higher axial stress was observed on geotextile encapsulated lime column compared to lime column at similar settlement. For surrounding soil pre-consolidated under 49 kPa, the column strength for lime column and GELC was about 1.8 times and 2.9 times of the unconfined compressive strength of lime stabilized soil, respectively. It was suggested that confining effect by geotextile encapsulation successfully increased lime column strength. At 8 percent axial strain, geotextile encapsulation increased the lime column strength at about 70 percent.

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