

Strength distribution of soft clay surround lime-column

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ABSTRACT: This paper presents the investigation result of the application of lime-column (LC) technique on expansive soft clay. The research studied the strength distribution surround the installed lime-column in the radial and vertical direction from the center of column. In this research, the LC was designed as single column with 50 mm in diameter (D), and the depth was $4D$ ($= 200$ mm). The soil strength surrounds the LC is determined by unconfined compression strength (UCS) test and static cone penetration (CPT) test. The test results show that the LC contributes to enhance the soil strength in radial direction up to $4D$ from the center of LC. Higher strength occurs near the LC and decreases with the distance from the LC center. It was also observed that soil strength tends to increase with time. The CPT results also showed that the installation of LC affected the soil strength to a depth of $4xD$ beneath the bottom of LC. This research also confirms that after installation of LC the water content of soil decreased near the LC, but beyond the distance of $4D$ in radial direction the water content remained its original value.

1. INTRODUCTION

Lime column technique has been applied successfully in recent years to improve the physical and mechanical properties of the soils. Both the dry and wet lime mixing are carried out by injecting a preferable pressure into soil and form a lime-column in-situ (Rogers & Glendinning, 1997). This technique increases soil bearing capacity and reduces soil settlement owing to improving of soil strength and stiffness. A study carried by Baker (2000) on full-scale model showed that the stiffness of the improved soil using LC increased more significantly than that of lime-cement column. Researchers such as Shen et al (2003), Tono et al (2003), and Budi et al (2003) studied separately the strength of the soil surrounding the LC. They reported that the soil strength increased near the column to a distance up to 2 to 3 times of the column diameter in radial direction. But, the effect of strength change beneath the bottom of LC was not studied. It is reasonably to assume that the lime will flow easily downward into soil in vertical direction and the soil strength may also increase with the availability of lime.

After LC has been installed, the lime or calcium ions migrate into soil surround the LC. The soil properties around LC will change due to consolidation, densification, and hardening resulted by the chemical reaction between lime and soil. For an efficient stabilization, calcium and hydroxyl ions should migrate through the clay, because hydroxyl ions cause highly alkaline conditions in clay soil. Highly alkaline conditions give rise to the slow solution of aluminosilicates which are then precipitated as hydrated cementitious reaction products. These reaction products contribute to flocculation by bonding adjacent soil particles together and when curing is allowed the clay soil is strengthened. This mechanism will control the strength of the soil surround the LC. The soil strength around the LC will vary with the distance from the center of the LC both in radial and vertical direction. So far, based on the strength characteristics, the migration zone of the calcium ion of lime can be predicted. The lime – soil reaction takes place within 24 – 72 hours after installation and the soil properties are modified. Such pozzolanic reactions are time dependent. So is the development of soil strength, After that, the soil undergo a permanent change in mechanical properties and the strength develop gradu-

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ally over a long period (Bell 1996; Sivapullaiah et al., 2000; Muntohar, 2003).

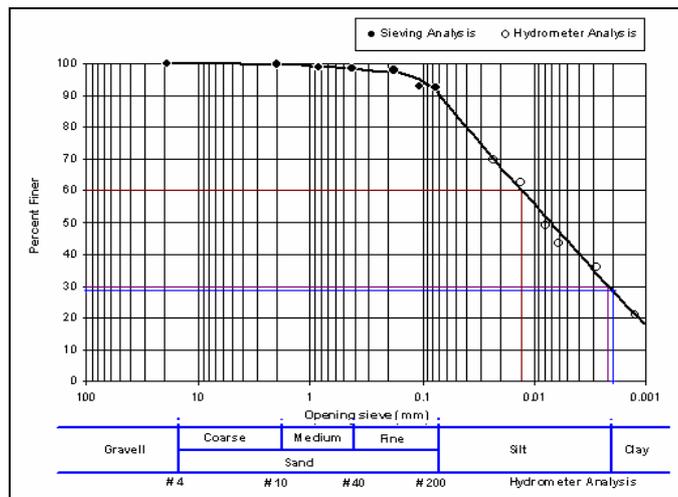


Figure 1 Particle size distribution of the soil used.

Since the LC ground improvement method is highly related to the chemical reaction between lime and soil, it is necessary to consider the amount of lime that should be added or mixed with the soil. Roger and Glendinning (2003) used the ASTM C977-98 method to determine the lime required for stabilization. Muntohar (2003) determined simple method to define the amount of lime by using correlation between plasticity index and lime content. For expansive soft clay, mixing with 6% lime was sufficient for the purpose of the compressive strength improvement.

2. EXPERIMENT METHOD

2.1 Soil Used

The index properties of test soil are as follows:

- Specific gravity (G_s) = 2.64
- Liquid limit (LL) = 73%
- Plasticity index (PI) = 36%
- Fines fraction ($< 7.5 \mu$) = 89%
- Clay size fraction ($< 2 \mu$) = 29%

The particle size distribution of the soil sample is shown in Figure 1.

2.2 Laboratory Test

Lime columns of 50 mm in diameter and 200 mm in length were installed in the test tanks of 120 x 120 x 100 cm in dimension (Figure 2). The clay prepared in the tank is saturated by controlling the water level at the ground surface for 3 – 4 months. It results in a degree of saturation about 90%-98%.

Consolidation test for the soil sample indicates that the soil undergoes a higher stresses before compared with the current stress and can be considered as OC clay. The compressibility coefficient (C_c) and swelling index (C_s) are 0.7 and 0.085 respectively.

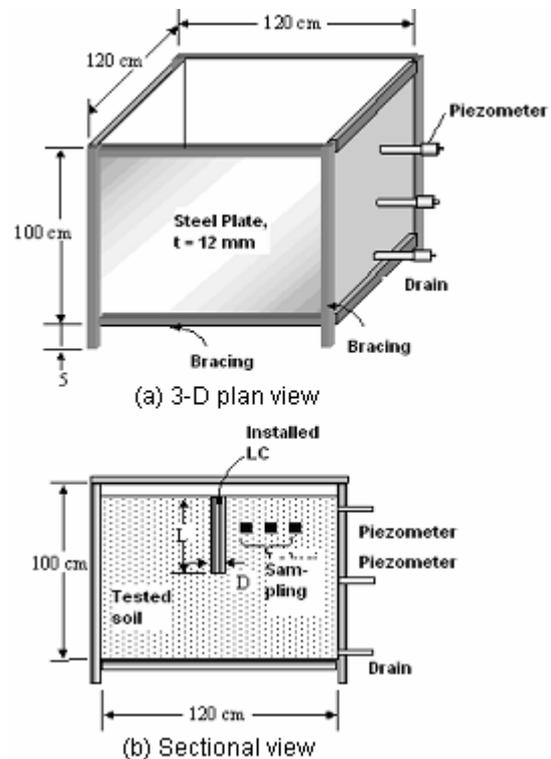


Figure 2 Test tank used in this study.

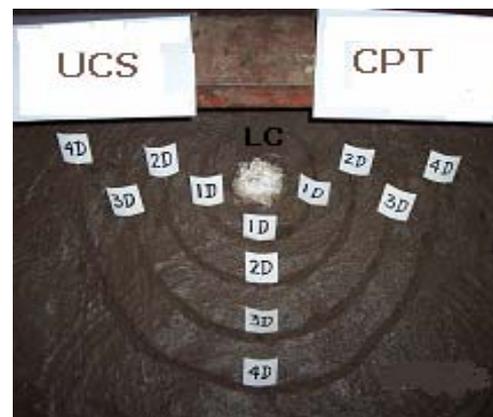


Figure 3. Plan view of the installed LC.

In the field application, a hollow tube is pushed into the soil to the required depth and quicklime is then forced into the pile or column by air pressure as the tube is withdrawn. In the laboratory, the field application is simulated by the technique in which the column hole was filled with the powder type quicklime in four successive layers and each layer was separately compacted. The plan view of the installed LC is shown in Figure 3.



Figure 4 Installation of CPT and SPT equipment.

Laboratory tests conducted are unconfined compressive strength test (UCS) and cone penetration test (CPT). The UCS test was performed at varying distance from the installed LC i.e. 50, 100, 150 and 200 mm in radial direction. To avoid much disturbance and sampling difficulties, the UCS samples were taken at depth of 100 mm (one-half of LC length). The CPT or sounding test was performed also at radial direction. The cone resistance (q_c) was recorded every 20 cm of depth. The installation of CPT is shown in Figure 4.

3. TEST RESULTS

3.1 Unconfined Compressive Strength (UCS)

Figure 5 shows the development of unconfined compressive strength of soil surround LC at different ages after installation. The effect of lime on the strength of soil depends on numerous factors such as type of soil and lime, curing period, moisture content, temperature, etc. In this study, the unconfined compressive strength of the soil treated with the lime column has also been determined in order to compare the variation in unconfined compressive strength with the distance from the lime column.

Fourteen days after installation, the soil strength around LC is higher than that of 3 and 7 days after installation. It implies that ageing factor has effect on the soil strength surround LC. Similarly, the strength of LC will also increase with time due to pozzolanic reaction.

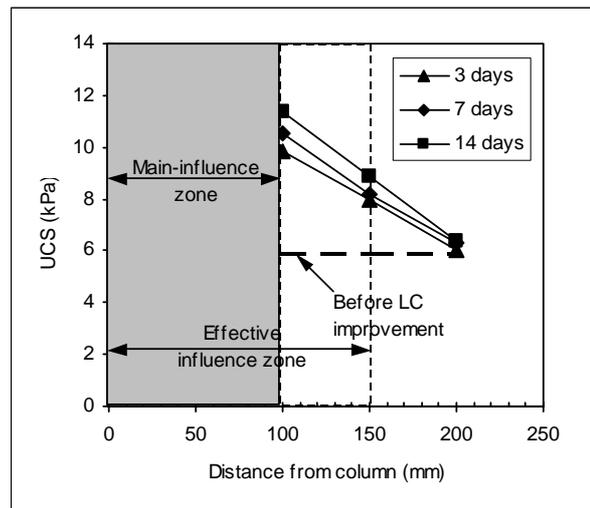


Figure 5. Unconfined compressive strength of soil surrounding LC.

Most of the strength increase concentrates at the soil near the side surface of the LC. It is up to 50 mm or $1 \times D$ in radial direction from column. The soil strength decays associated with distance from LC. The soil strength in the distance of twice time of diameter ($2 \times D$) does not decrease very much in between 5%-7%. This influenced distance may be noted as main influenced zone. However, the lime migrates effectively to a radial distance of 3 times of the column diameter ($3 \times D$). It has been indicated by the higher soil strength than that before improvement. This zone may be called as effective influence zone within which the strength is decreased in the range of 24%-28%. Interestingly, after a distance of $4 \times D$, the soil strength is approximately same as the soil strength before LC improvement. The migration distances are small in clayey soils because the soil has low to very low permeability. The coefficient of hydraulic conductivity of the clay soil used in this study ranges in between 2.6×10^{-6} to 8×10^{-8} cm/sec. Other researchers, Rao and Rajasekaran (1996) wrote that the lime migration takes place in 7 to 15 days after installation to penetrate into soil up to $5D$ in radial direction.

During migration, the lime reacts with the surrounding soil. This reaction consumes some amount of water and produces reaction product as cementation compound materials. This phenomenon is illustrated in Figure 6, it can be seen that the water content decreases due to the lime reaction with water especially in the influenced zone.

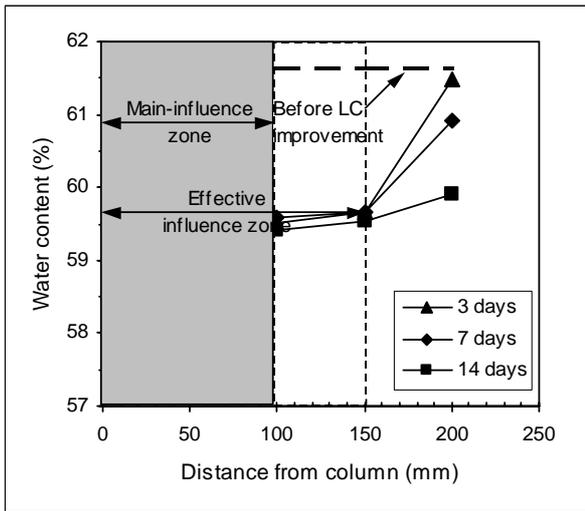


Figure 6. Variation of water contents from the LC.

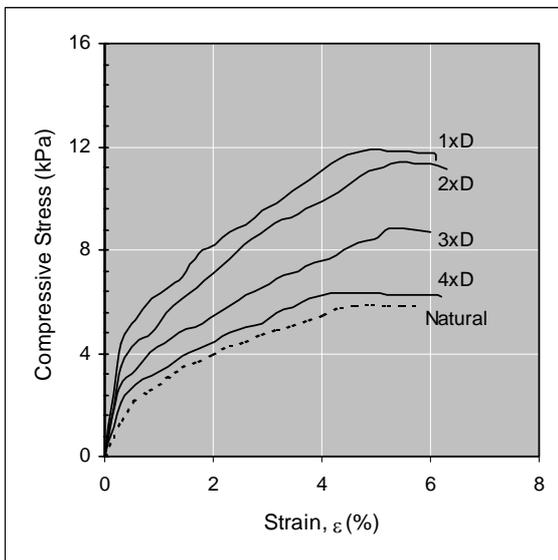


Figure 7. Stress and strain relationship from UCS test after 14 days.

As shown in Figure 7, no clear peak is observed at the stress–strain curves for the natural samples. In comparison, the stress–strain curves of the lime-treated samples shown in Figure 7 have slight peaks due to cementation of soil particles resulted by the pozzolanic compounds from lime reactions. It indicates that soil becomes stiffer and behaves in a slightly brittle manner after lime treatment.

3.2 CPT Test

Cone penetration test is commonly used to determine the soil strength. Its cone-tip resistance q_c will vary with soil layer and soil properties. Figure 8 presents the CPT results 14 days after installation. It is shown that the lime column not only improves the soil strength in radial direction but also in verti-

cal direction beneath the column. Similar to the UCS results, the CPT result confirm that the q_c reaches higher value near the lime-column and decreases with distance from column.

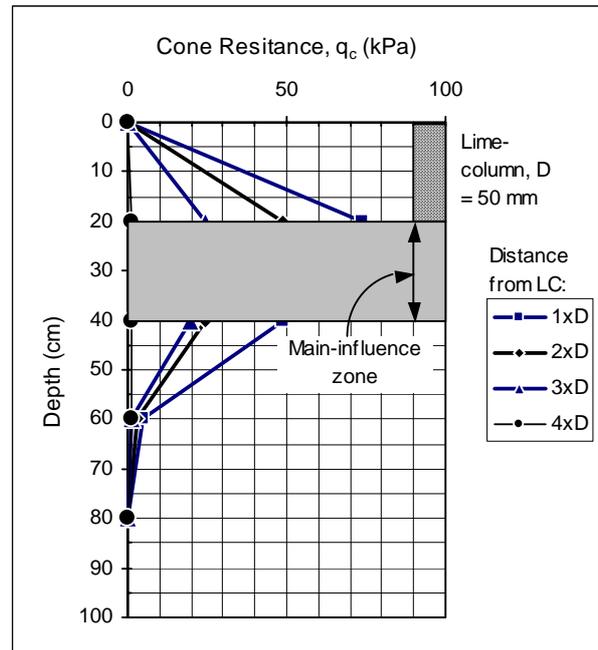


Figure 8 CPT results taken 14 days after installation.

In vertical direction, higher q_c value is obtained near the base of column decreases gradually to a depth of 40 cm to 60 cm underneath column. In other words, the lime can penetrate into soil about 8 to 12 times of column diameter beneath the column. The influenced zone in vertical direction is wider than in radial direction. The lime migration in vertical direction is helped by the gravity force to be able to migrate more rapidly and wider. It is found In this investigation that the main migration zone can reach up to 4 times of column diameter beneath the column tip (Figure 8).

However, it should be noted that due to the variability of in-situ soil is relative high in vertical direction, the range of lime migration In the field may be different from the laboratory results,.

4. CONCLUDING REMARKS

The following conclusions can be drawn from the above research findings.

1. The installation of lime-column in the soil can improve the strength of the soil surrounding the column in both vertical and radial directions. Higher strength attained near the column and

- decreased gradually with the distance from the column.
2. The increased soil strength is a result of the lime migrates into and reacts with soil. The lime can penetrate into soil up to $4 \times D$ in radial direction and $8 \times D$ in vertical direction. But, the main influenced zone is within $2 \times D$ in radial direction and $4 \times D$ beneath column in vertical direction.
 3. The water content of surrounding soil decrease after installation of the lime-column owing to the imbibing of water for chemical reaction between lime and soil. The amount of water content decrease reduces with the distance from the column edge.

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