Behavior Of Soft Clay Soil Stabilized With Lime Columns

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Abstract— **Soft clays cause a lot of problems to structures due to low shear strength and high compressibility. Its properties can be improved by several techniques. In this paper, the effect of lime columns on the shear strength behavior of soft clay soil has been studied. A series of large direct shear box tests have been carried out using different parameters such as number of columns, spacing between columns and the curing time. The results show that, the shear stress of soft clay soil is improved well and increased by 250%, 300% and 327% with increasing the number of columns to 4, 5 and 6 columns respectively. For stabilized soil with a group of 4 lime columns with diameter/length (D/L) ratio equals 0.28, at curing time of 7, 14 and 28 days, the shear stress increased by 250%, 273% and 293% respectively compared with unstabilized soil.**

Keywords— Soft clay; Stabilization; Lime columns, Shear strength.

I. INTRODUCTION

Structures that constructed on soft clay soils face a lot of problems such as high compressibility and low shear strength. The traditional stabilization techniques are very expensive due to raw material prices and the machines cost for executing the project. To solve these problems, a technique that features economy and give an acceptable improvement can be used. Columns insertions in soft formation are used widely because of its good improvement of soft soils. The lime columns are one of the columns types which are used to stabilize the shear strength of the soil and reduce its compressibility. It is considered an economic technique and gives an acceptable stabilization than any other techniques. The stabilization process with lime column is mainly depending on the soil, lime type and curing time. Quick lime can stabilize the soft clay shear strength by consuming the water content during hydration process in addition to the occurred chemical reaction which is increased with increasing the curing time and the resulted compounds due to these reactions can fill the voids between soil particles and consequently the shear strength is increased and the soil compressibility is decreased. Many researchers carried out different studies to understand the behavior of soft clay stabilized with lime columns technique. Charpit (2010) [6], carried out a series of shear box tests on lime-cement column improved kaolin clay. The tests were conducted with several patterns, single columns and two rows of overlapping columns. The test results indicated that the unstabilised soil failed at a shear stress of about 4.4 kPa and a horizontal displacement of about 10 mm. Single lime/cement columns did not contribute much to the shear resistance. They failed at shear stress equals 6 kPa and a horizontal displacement of about 18 mm. The test results also showed that, the overlapping of 12 columns in two rows significantly increased the shear resistance. They failed at shear stress equals 8 kPa and a horizontal displacement of about 25 mm. Ashok and Reddy (2015) [1], carried out an experimental study to examine the geotechnical improvement of clay soil properties using lime pile technique. The treated soil block properties were investigated at different curing periods (28, 60, 90 and 120 days). It was observed that, there are significant changes in the compaction characteristics and strength of treated soil due to the clay lime reactions. The test results indicated that these reactions have remarkable effects on the lime pile treated soil which produce strong inner particle ponds and increase the unconfined compressive strength of the soil. This can be attributed to the migration of Ca^{2+} and Mg^{2+} ions from the lime piles into the soil, flocculation of particles, and Pozzolanic reactions. Khan et al. (2016) [8], carried out a comparative Study of ground Improvement by lime and stone columns. They investigated the effects of floating columns in clay soil with silty deposits by developing small scale laboratory models. A comparison is made among lime and granular columns whereby the results of the treated ground are compared to the untreated ground. The obtained results showed that, the soil treated with lime column has a higher load carrying capacity than the treated soil with stone column. Jose, and Rajamane (2018) [7], presented the preliminary results of the small laboratory model test of lime column technique on clay soil to investigate load-settlement characteristics in laboratory. The test results showed that, the load-settlement relationship before installation of lime column led to a mode of failure which is likely can be defined as general shear failure. The bearing capacity of the soil was found to be increased after the lime column was installed and this increase of the bearing capacity was found to be increased with the increase of the curing time.

Based on the above-mentioned literature review, it has been found that the investigation of the effect of a group of lime columns on the shear strength of soft clay soil is limited and there is lack of knowledge in this regard. Therefore, in this paper, a series of large-scale direct shear box tests carried out to study the effect of a group of lime columns with different numbers on the shear strength behavior of soft clay after different curing times. Meanwhile, a parametric study has been done to evaluate the influence of different parameters such as number of lime columns, spacing between columns and the curing time on the shear strength of the treated soft clay.

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II. Material and Methodolgy

A. *Soft clay*

In the current study, soft clay used was artificial clay which prepared from kaolinite in powder form brought from the company of El Basateen for Industry, Cairo-Egypt. This powder was mixed with 25% water content to form a soft clay soil that can be used to simulate the natural soft clay. Different tests were performed on the prepared soft clay to study its properties. These test results are shown in Table 1.

Table 1: Soft clay properties

Property	Value
Liquid limit, L.L (%)	***29.4***
Plastic limit, P.L (%)	***15***
Plasticity Index, P.I (%)	***14.4***
Specific gravity, Gs	***2.7***
Maximum dry density, γdry (kN/m^3)	***14.22***
Optimum moister content, O.M.C (%)	***19.9***

B. *Lime*

Quick lime (Calcium oxide, CaO) was used in this study in order to make use of the hydration process and the resulted emitted heat during this process in decreasing the water content and improving the shear strength properties of the treated soft clay soil.

C. *Large-scale direct shear test box*

A series of experimental tests were carried out using a large-scale direct shear box test apparatus as shown in Fig. 1 with internal dimensions of (30cm x 30cm x 20cm). The direct shear box test was performed at a strain rate of 1 mm/min until reaching a horizontal displacement of 45 mm (15 percent of the tested soil width) or until the failure of the tested soil. A normal pressure of 11kPa was applied on the tested soil throughout the test. Horizontal load and displacement were recorded throughout the test.

Fig. 1: *Large-scale direct shear box test apparatus*

III. Experimental Test Program

A series of large-scale direct shear box tests was carried out on the soft clay soil stabilized with lime columns to study the improvement in the shear strength behavior of the stabilized soft clay soil. The studied parameters which are used in this experimental testing program are shown in Table 2.

IV. Results And Analysis

A. *Shear stress-strain behvior for different number of columns*

The test results illustrate that, increasing the number of columns increase the shear strength of the stabilized soft clay soil from 3 columns to 6 columns as can be seen in Fig. 2 which shows the variation of shear stress and shear strain of unstabilized and stabilized soft clay with different number of lime columns at constant (D/L) ratio equals 0.28. This can be attributed to that, the lime columns that surrounded by the soft clay can absorb the water from the clay and react with clay minerals with time resulting in more stiffer clay soil with high shear resistance. The maximum shear stress of the soft clay is increased by 250% and 300% when using 4 and 5 columns with (D/L) ratio equals 0.28 respectively compared to unstabilized soil. The maximum increase in the shear stress reached to 327% when using 6 lime columns compared to the unstabilized soil. Meanwhile, the shear strain of the stabilized soft clay is decreased with increasing the number of columns from 3 to 6 columns. The shear strain is decreased by 69% and 72% when using 4 and 5 lime columns respectively. The maximum reduction in shear strain was in the case of using a group of 6 columns. The shear strain in this case is decreased by 75% compared to the unstabilized soil.

Table 2: Studied Parameters in the experimental testing program

Series	Constant Parameters	Variable Parameters	No. of tests
S1	***D = 5.5 cm, D/L = 0.28, σ = 11kPa, Curing time 7 days***	***Number of columns, N = (3, 4, 5, 6)***	***4***
S2	***N = 4, D = 5.5 cm , D/L = 0.28 σ = 11kPa, Curing time = 7 days***	***S/D = (1,1.5, 2, 2.5, 3, 3.5, 4)***	***7***
S3	***D = 5.5 cm, N = 4, D/L = 0.28, σ = 11kPa***	***Curing time (7, 14 and 28) days***	***3***
Total number of tests			**14**
L: column length, D: column diameter, N: number of columns, S: spacing between columns from center to center, σ: Vertical stress.			

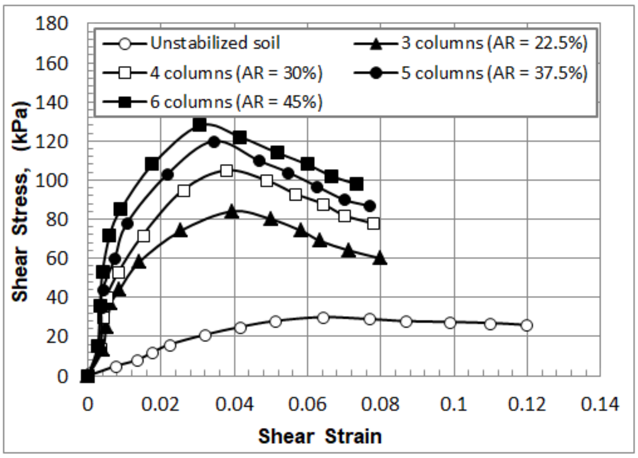

Fig. 2: *Shear stress-strain relationship for the unstabilized and stabilized soft clay with different number of lime columns at constant (D/L) ratio equals 0.28 and (S/D) ratio equals 2*

B. Shear stress-strain behavior for different spacing between lime columns

The effect of the group of lime columns on improving the shear strength behavior of soft clay soil with changing the spacing between the columns (S) has been studied. A series of experimental tests were carried out using a group of 4 lime columns with constant diameter/length ratio (D/L) equals 0.28. Experimental tests were carried out with different ratios for (S/D equals 1, 1.5, 2, 2.5, 3, 3.5 and 4). Fig. 3 illustrates the improved area of soil around columns with changing the (S/D) ratio. From this figure it is found that, in case of (S/D) equals 1 and 1.5 the columns were very close to each other and consequently an overlap was noticed between the improved areas of the soil around the columns. So, the other parts of the soft clay soil at the edges of shear box still unimproved. While, in the case of (S/D) equals 3, 3.5, and 4, the lime columns were somewhat far from each other and as a result, the improved areas of the soft clay around the columns began to be spaced apart. So, unimproved areas of the clay soil appeared between the columns and these areas were expanding with the increase of (S/D) ratio. From this figure It can be said that, each column in this case acts as a separate single column, not as a group of columns. The shear stress-strain relationship for unstabilized and stabilized soft clay soil for different (S/D) ratios is studied and presented in Fig. 4. From this figure it is found that (S/D) ratio smaller than 2 and larger than 2.5 does not give a significant improvement in the soil shear strength behavior. The maximum reduction in the shear strain was the same and equals to 69% at (S/D) equals 2 and 2.5. So, it can be concluded that the optimum value of (S/D) ratio is ranging from 2 to 2.5.

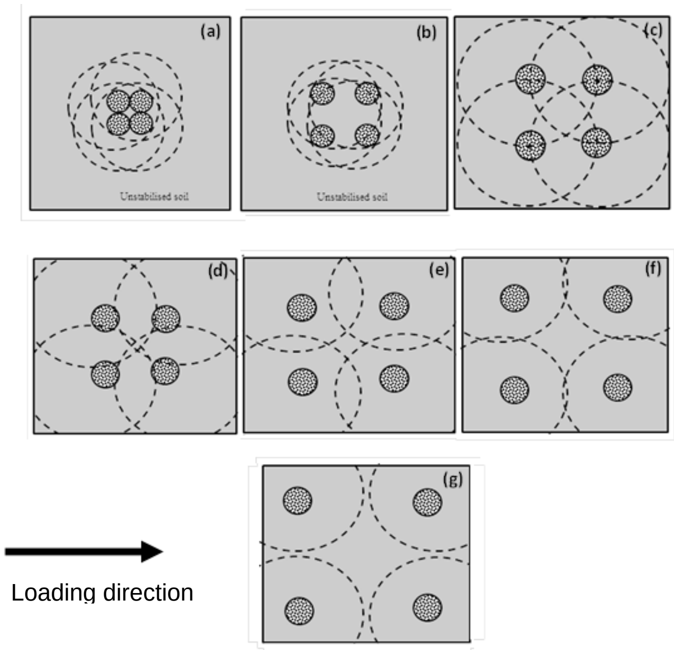

Fig. 3: *Variation of improved area of soil surrounding lime columns with changing the S/D ratio, (a) S/D = 1, (b) S/D = 1.5, (c) S/D = 2, (d) S/D = 2.5, (e) S/D = 3, (f) S/D = 3.5, (g) S/D = 4*

(The improved area of the stabilized soil)

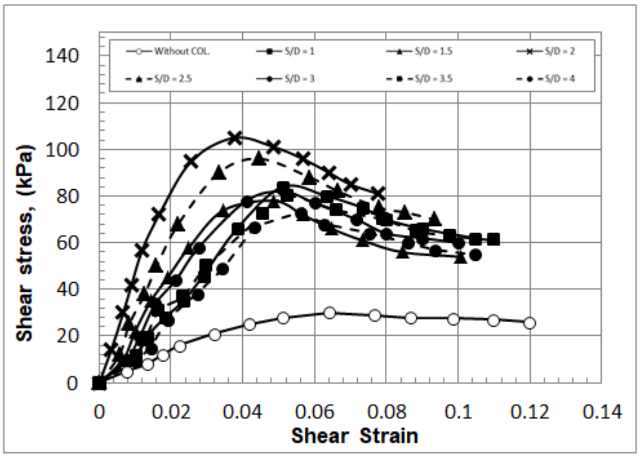

Fig. 4: *Shear stress-strain relationship of unstabilized and stabilized soft clay soil with a group of 4 lime columns for constant (D/L) ratio equals 0.28 and different (S/D) ratios*

C. Stress-strain behavior at different curing times

In this part of study, the effect of increasing curing time on the shear strength behavior of lime columns stabilized soft clay has been investigated. Experimental tests were carried out at different curing times (7, 14 and 28 days). Fig. 5 shows the stress-strain relationship for unstabilized and stabilized soft clay soil with 4 lime columns for different curing times. From this figure, it can be clearly seen that, at curing time 7 days and 14 days the shear stress of stabilized soil increased by 250% and 273% respectively compared to unstabilized soft clay soil. While after 28 days of curing, the shear stress was found to be increased by 293%. From the other hand, the shear strain of the stabilized soil is found to be reduced with increasing the curing time reaching 69% and 71% after 7days and 14 days of curing respectively. While, after curing time of 28 days the reduction of shear strain has reached to 76%. From these results it can be concluded that with longer curing time, the resulted formation of the compounds from the reactions between lime and clay minerals is increased.

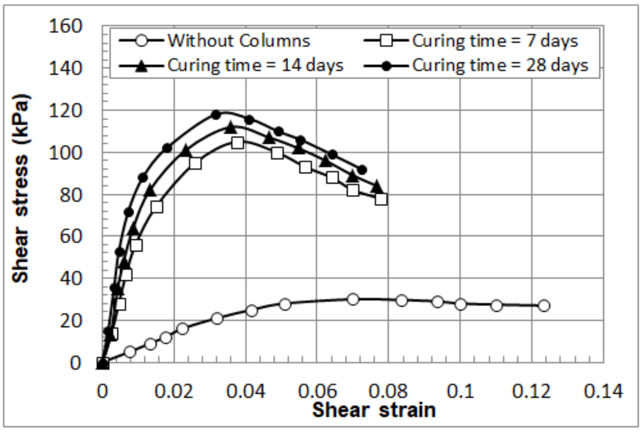

Fig. 5: *Shear stress-strain relationship of unstabilized and stabilized soft clay soil with a group of 4 lime columns at constant (D/L) ratio equals 0.28 for different curing times*

V. CONCLUSIONS

This study was performed to investigate the effect of using lime columns technique in improving the shear strength behavior of soft clay soil. From the experimental test program which is carried out the following conclusions can be drawn: -

I. The inclusions of lime columns with sufficient numbers can be considered as a good technique in order to obtain the optimum effect in improving the shear strength behavior of the stabilized soft clay.

II. Increasing the number of lime columns leads to more increase in the shear stress and more reduction in the shear strain of the stabilized soft clay soil.

III. The shear stress was found to be increased by 250%, 300% and 327% when using a group of 4, 5 and 6 lime columns respectively compared to the unstabilized soil.

IV. Using a group of columns with (S/D) ratio less than 2 or more than 2.5 does not give a significant improvement in the shear strength of the stabilized soft clay.

V. The lime column stabilization technique is a time dependent technique. The shear stress of the stabilized clay soil with a group of 4 lime columns was found to be increased by 293% after 28 days of curing time compared to the unstabilized soil.

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