The paper was published in the proceedings of the 11th Australia New Zealand Conference on Geomechanics and was edited by Prof. Guillermo Narsilio, Prof. Arul Arulrajah and Prof. Jayantha Kodikara. The conference was held in Melbourne, Australia, 15-18 July 2012.

Effect of Lime Column Group Configuration on Total Shear Strength of Clay Based on Experimental Modelling

S. Pahlevanzadeh[1]

[1] Griffith School of Engineering, Griffith University, Gold Coast Campus, QLD 4222, Australia; PH (0061) 7-5552 7608; FAX (0061) 7-5552 8803; email: s.pahlevanzadeh@griffith.edu.au

ABSTRACT

Lime column stabilisation has been frequently employed as a preferred ground improvement technique in clayey soils. The response of the reinforced soil by lime columns is a function of different factors, the effects of some of which, such as lime content, curing time and water content, have been widely explored in the literature. The present study focuses on the geometrical effect, i.e. the arrangements of lime columns. A series of large direct shear tests (500mm wide, 500mm long and 250mm high) have been conducted on experimental models of lime columns with different spacing, diameter, number and group configuration using Barican clay from North West of Tehran, Iran. Based on an experimental configuration sensitivity study, the relationship between gain in total shear resistance and influencing parameters has been established. The results indicate that the total shear strength of the reinforced soil can increase between 40% and 120% due to lime column installation, depending on total area, spacing ratio and the configuration of columns. Optimum area and spacing ratio are accordingly defined and relevant guidance on choosing appropriate lime column configuration is provided which can be of practical use in engineering design of lime column reinforced soils.

Keywords: lime column, ground improvement, shear strength, clay, experimental modelling

1 INTRODUCTION

Clay soils are the most common type of soils which exhibit a variety of engineering properties and behaviours, such as excessive heave, settlement and low shear strength. One of the most effective and economic methods for making improvement in clay engineering properties is the use of lime columns. Broms and Bowman (1977) brought out the concept of lime columns. Lime columns are constructed in-situ by mixing quicklime with the natural soils using a giant egg-beater auger. To construct a column the auger is drilled into the soil to the required depth, the direction of rotation is reversed and the auger is slowly withdrawn. As the auger is withdrawn, powdered quicklime is pneumatically pumped into the soil.

Bruce et al. (1999) reported an overview of international practice of lime columns which indicated considerable improvements in the engineering properties of stabilised soils. Many investigators supported the stabilisation mechanisms and recommended lime stabilisation in improving the soil characteristics. The stabilisation process provided by lime columns is controlled mainly by the lime migration. The soil properties around lime columns will change due to consolidation, densification, and hardening resulted by the chemical reaction between lime and soil. Muntohar and Jiun (2003) presented the investigation result for the application of lime column technique on expansive soft clay. The research studied the strength distribution surround the installed lime column in the radial and vertical direction from the centre of column. Researchers such as Shen et al. (2003) and Tonoz et al. (2003) studied separately the strength of the soil surrounding the lime-column. 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; however, all methods of assessing column parameters have limitations. These are caused by uncertainties in empirical factors as well as testing a small proportion of the lime column volume and determining whether it is representative of the strength of the entire column.

Limited research has been carried out on the effect of lime column group configuration on total shear strength of stabilised soil. In this study, factors such as diameter of each column, D, spacing between the columns, S and group configuration of lime columns in the model test have been reported. Barican Clay from a frequent-land-sliding region in North West of Tehran, Iran was used for all the tests. In total, seventeen large direct shear tests carried out on stabilised specimens utilising large direct shear box (500mm x 500mm x 250mm), and the results of the tests from the stabilised and un-stabilised specimens are compared. Improvement of the engineering properties of the Barican Clay is discussed. The established principles are able to provide the effect of location, group configuration and size of lime columns in relation with total shear strength of soil.

2 APPARATUS AND TEST PROCEDURE

2.1 Shear Box and Loading System

Figure 1 shows the large direct shear apparatus and one of the samples after the test. The specimen has been confined in a metal box (known as shear box) of square cross section (500mm x 500 mm) split horizontally at mid-height (total height 250mm). A vertical force, F_v is applied to the specimen through a loading plate and shear force, F_h is gradually applied on a horizontal plane by a horizontal loading system causing the two halves of the box to move relative to each other in a constant velocity. Direct shear tests have been conducted according to ASTM D3080 and the shear force, F_h being measured together with the corresponding horizontal displacement, D_h.

2.2 Model Lime Column

Since the lime column stabilisation 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 (2002) used the ASTM C977-98 method to determine the lime required for stabilisation which is in a broad agreement with Muntohar and Jiun (2003) who determined simple method to define the amount of lime by using correlation between plasticity index, PI and lime content.

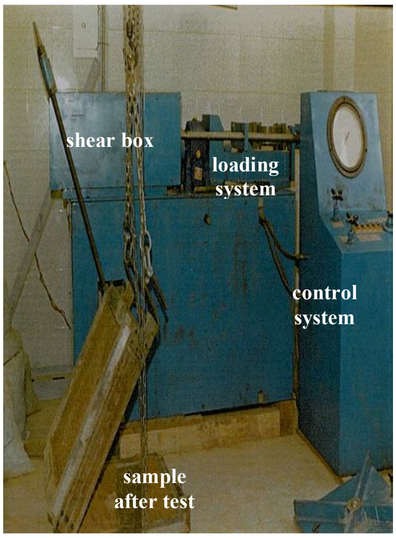

Figure 1: View of the large direct shear apparatus

Utilising similar method for Barican Clay, mixing with 7% lime verified to be appropriate for the purpose of the strength improvement. The plan view of the installed lime-columns is shown in Figure 2. In the laboratory, the field application is simulated by the technique in which the natural soil has been oven-dried, and then mixed with water. Desired number of Poly-ethylene pipes has been placed in the shear box with designated diameter, spacing and group configuration. The box has been filled and compacted with moisturised soil in three layers such that no soil entered inside the pipes. Then, the Poly ethylene pipes have been pulled out and the column holes were filled with the natural soil mixed with powder type quicklime in three successive layers and each layer was separately compacted.

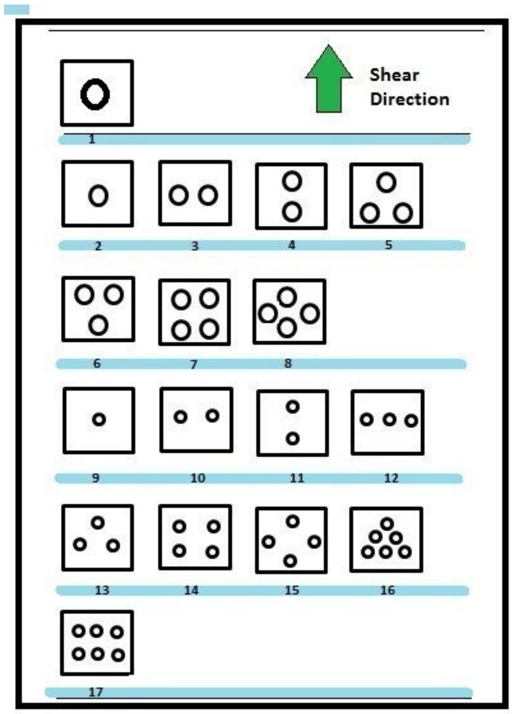

Figure 2: Configuration numbers

2.3 Clay Properties

The results from identification tests conducted to distinguish the natural (un-stabilised) properties of Barican Clay from in North West of Tehran, Iran are as summarised in Table 1.

2.4 Testing Condition

Testing condition for all seventeen tests was consistently defined. Water content and dry density considered equal to the optimum water content (i.e. $w_{opt.}$ = 14 %) and the maximum dry density ($\gamma_{d\text{-}max}$ = 0.18 t/m^3) obtained from compaction test. Speed of shearing, set to be 0.5mm/min. Curing time was 7 days from the end of sample preparation to the start of applying the shearing force. Percentage of lime mixed with the soil for making the lime columns, determined 7% of weight of dry soil.

Table 1: Identification test results on un-stabilised (natural) Barican Clay

Identification tests	**Result**
Water content, w_{av} (%)	23.5
Liquid limit, LL (%)	28.5
Plastic limit, PL (%)	20.6
Plastic index, PI (%)	7.9
specific gravity, G_s	2.65
<u>Particle size distribution:</u>	
Fine aggregate (%):	74
Coarse aggregate (%):	26
<u>Compaction test:</u>	
w_{opt} (%)	14
$\gamma_{d\text{-}max}$ (t/m$^{3)}$	0.18

3 TEST RESULTS AND DISCUSSION

Table 2 presents the test results on one natural un-stabilised (sample No.0) and seventeen large direct shear tests on stabilised (samples No.1 to No.17). To enable rapid practical estimates of column-soil behaviour, it is extremely useful to have available dimensionless parameters from which the effects of variations in lime column group configuration on soil strength can readily be determined. Therefore, lime columns area ratio, A_r is defined as:

$$A_r = N\pi\left(\frac{D}{2}\right)^2 / (500 \times 500) \quad (1)$$

Where, N is the number of lime columns in the sample and D is the diameter (mm) of each lime column in the sample.

Table 2: Large direct shear test results

Group Configuration Number [1]	N [2]	S [3] (mm)	D [4] (mm)	A_r [5]	S_r [6]	R_t [7] (MPa)	I_p [8] (%)	η [9] (%)
No.0	0	0	0	0.000	0.000	4.85	-	-
No.1	1	0	150	0.071	0.000	7.94	63.71	-
No.2	1	0	100	0.031	0.000	7.34	51.34	-
No.3	2	66.5	100	0.063	0.665	8.06	66.18	54.905
No.4	2	66.5	100	0.063	0.665	8.85	82.47	60.286
No.5	3	92.5	100	0.094	0.925	9.57	97.32	43.460
No.6	3	92.5	100	0.094	0.925	9.05	86.60	41.099
No.7	4	150	100	0.126	1.500	9.25	90.72	31.505
No.8	4	76.5	100	0.126	0.765	9.70	100.00	33.038
No.9	1	0	50	0.008	0.000	6.75	39.17	-
No.10	2	116.5	50	0.016	2.330	7.41	52.78	54.889
No.11	2	116.5	50	0.016	2.330	8.20	69.07	60.741
No.12	3	75	50	0.024	1.500	8.72	79.79	43.062
No.13	3	142.5	50	0.024	2.850	8.85	82.47	43.704
No.14	4	200	50	0.031	4.000	8.53	75.87	31.593
No.15	4	126.5	50	0.031	2.530	8.92	83.92	33.037
No.16	6	89.5	50	0.047	1.790	11.02	127.22	27.210
No.17	6	75	50	0.047	1.500	9.97	105.57	24.617

1 group configuration number as indicated in Figure 2
2 number of columns in model test
3 spacing between columns in model test
4 diameter of each column in model test
5 Lime columns Area Ratio as defined in Equation (1)
6 Lime columns Spacing Ratio as defined in Equation (2)
7 Total shear strength of clay stabilised with lime columns
8 Improvement percentage as defined in Equation (3)
9 Group efficiency as defined in Equation (4)

Lime columns spacing ratio, S_r is defined as:

$$S_r = S / D \quad (2)$$

Where, S is the centre to centre distance between two lime columns (mm). Improvement percentage, I_p is defined as:

$$I_p = R_t / R_{t_0} \quad (3)$$

Where, R_t is the total shear strength of column group and R_{t0} is the total shear strength of un-stabilised (natural) soil. Group efficiency, η is then defined as the ratio of the total shear capacity of the group to the sum of shear capacity of the single columns:

$$\eta = 100 \times R_t / (N \times R_{t_1}) \quad (4)$$

Where, R_{t1} is the total shear strength of the model test using only a single lime column with the same diameter.

3.1 Comparison Between Stabilised and Un-stabilised (Natural) Total Shear Strength

Regarding the calculated improvement percentage, I_p from Table 2, the relative improvement in total shear strength due to lime column installation is between 40% (sample No.9) and 120% (sample No.16), based on results from large direct shear tests.

3.2 Effect of Spacing Ratio, S_r on Total Shear Strength, R_t

Figure 3 shows total shear strength, R_t versus spacing ratio, S_r .The R_t has an upward trend from S_r~0 to S_r~2 and after this point any increase in S_r, decreases the total shear strength, R_t. It appears to be an optimum value of S_r=2 which can be used as a design principle in lime columns application. This has been emphasized in Figure 3 that more or less spacing between lime columns would not result to greater total shear strength, R_t.

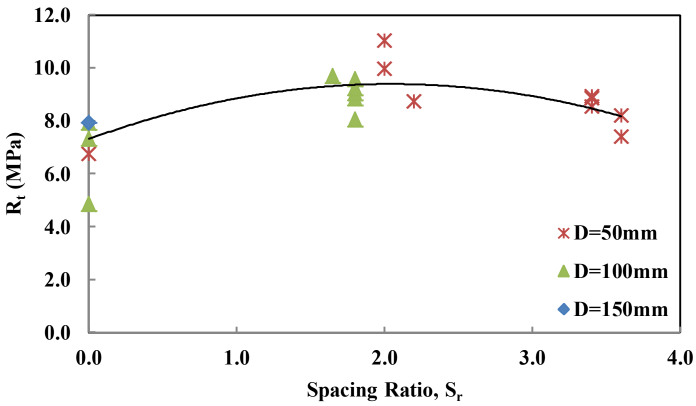

Figure 3: Total shear strength, R_t versus spacing ratio, S_r

3.3 Effect of Area Ratio, A_r on Total Shear Strength, R_t

Figure 4 demonstrates the total shear strength, R_t versus area ratio, A_r. It can be observed that any increase in area ratio with constant lime column diameter, D, results greater total shear strength, R_t (dashed curves in Figure 4). However, the solid trend line for all data in Figure 4 represents an optimum value for area ratio, A_r ~ 0.06 to 0.08, which can be utilised as a principle for design purposes in lime column application. Therefore, in an optimum condition, approximately 6 to 8 % of the total area should be covered by the lime columns.

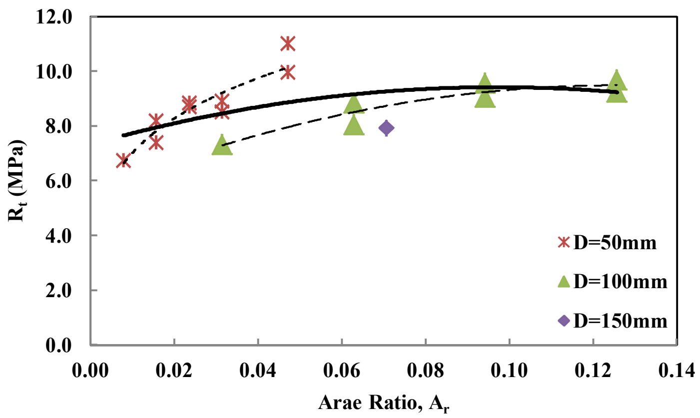

Figure 4: Total shear strength, R_t versus area ratio, A_r

4 CONCLUSION

Experimental small scale testing on samples made of Barican Clay, from a frequent-land-sliding region in North West of Tehran, Iran has been conducted. Comparison between the results from the tests on stabilised and natural (un-stabilised) specimens indicates that the total shear strength of the stabilised samples, increased between 40% and 120% due to lime column installation. Direct application to field scale may not be valid. Discussing the improvement of the engineering properties of the Barican Clay also illustrates that:

- There is an optimum value for area ratio, i.e. A_r=0.06~0.08 which results to maximum total shear strength and it could be used as a design principle in lime column application.
- Spacing ratio, S_r has an optimum value S_r=2.0, which can be used as a principle for designing purposes to obtain the greatest total shear strength, R_t.
- Diamond-shape group configuration of four lime columns results higher total shear strength, R_t in comparison to rectangular group configuration.
- Triangular group configuration results higher shear strength in comparison to the rectangular group configuration.
- Application of lime columns in a row parallel to the shearing force alignment will result to higher total shear strength, R_t in comparison to the application of same lime columns in a row perpendicular to the shearing force alignment.
- Application of lime columns in a triangular group configuration should be in a way that the front row consists of more lime columns in comparison to the rear rows.

REFERENCES

Broms, B.B., Bowman, P. (1977) “Stabilisation of Soil with Lime Columns.” Design handbook, Department of Soil and Rock Mechanics. Royal Institute of Technology, Stockholm.

Bruce, D.A., Bruce, M.E.C., DiMillio, A.F. (1999) “Dry mix method: a brief overview of international practice.” International conference on dry mix methods for deep soil stabilisation, Stockholm, Sweden

Muntohar, A.S., Jiun-Liao, H. (2003) “Strength Distribution of Soft Clay Surround Lime-Column.” International Conference on Civil Engineering, Malang, Jawa Timur, Indonesia

Rogers, C.D.F., Glendinning, S. (2002) “Lime requirement for stabilisation.” Transportation Research Record No. 00-0604, National research Council, pp. 9-18.

Shen, S.L., Miura, N., Koga, H.D. (2003) “Interaction mechanism between deep mixing column surrounding clay during installation.” Canadian Geotechnical Journal, Vol. 40, 293-307.

Tonoz, M.C., Gokceoglu, G., Ulusay, R. (2003) “A laboratory-scale experimental investigation on the performance of lime in expansive Ankara (Turkey) clay.” Bulletin Engineering Geology & Environmental, Vol. 62, 91-106.