Journal of Kerbala University , Vol. 10 No.4 Scientific . 2012

Laboratory Investigation on Efficiency of Models Stone and Lime Column Groups

بحث مختبري عن كفاءة نماذج من الاعمدة الحجرية وأعمدة النورة

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Abstract :

The efficiency of a group (E_g) of stone or lime columns is defined as the ratio between the capacity of each stone or lime column in the groupto the capacity ofsingle stone (lime) column. In this study, the group efficiency of 16 model stone and lime columns installed in soft clay arecalculated. These groups consist of 2, 3 and 4 columns. The tests were conducted on stone and lime columns with length to diameter ratio (L/D) of 9.A special compression machine was manufactured for carrying up these tests. The foundation steel plate have 120 mm diameter and 5 mm thickness. The spacing between all columns equals twice the stone or lime column diameter (D), center to center.

The stone (lime) column capacity is taken as the load corresponding to a settlement equals to 50% of the diameter of stone (lime) column. The results illustrated that the group efficiency decreases with increasing the number of stone columns, also the stone columns provided higher efficiency than lime columns in the soil of shear strength (cu= 8 kpa), but the lime columns provided higher efficiency than stone columns in soil of cu= 14 kPa.

الخلاصة

تعّرف كفاءة مجموعة الاعمدة الحجرية او اعمدة النورة بانها " النسبة بين قابلية تحمل كل عمود داخل مجموعة الاعمدة الى تحمل العمود المفرد. تم في هذه الدراسة احتساب كفاءة المجموعة لستة عشر نموذجا مختبريا من الاعمدة الحجرية وأعمدة النورة. هذه المجاميع تتألف من اثنين وثلاثة وأربعة اعمدة على التوالي. اجريت الفحوصات المختبرية على الاعمدة الحجرية واعمدة النورة بنسبة طول العمود (L) الى قطره (D)أي (L/D)مساويالى تسعة, ولقد تم تصنيع جهاز انضغاط خاص لغرض اداء تلك الفحوصات. استخدم لوح فولاذي بقطر 120 mm وسمك 5 mm كأساس.

ولقد اخذت قابلية تحمل العمود الحجري او عمود النورة بأنها الحمل الذي يسبب هبوطا مقداره 50% من قطر العمود الحجري او عمود النورة. بينت النتائج بان كفاءة المجموعة تقل عند زيادة عدد الاعمدة ولقد وضحت النتائج ايضا بان الاعمدة الحجرية اعطت كفاءة اعلى من اعمدة النورة في التربة ذات مقاومة القص المساوية الى 8 kPa لكن اعمدة النورة ابدت كفاءة اعلى من الاعمدة الحجرية في التربة ذات مقاومة القص المساوية الى 14 kPa.

Introduction

The Stone Column Approach Stone columns and sand compaction piles represent the most known column-type technique for improving soft soils. They possess high compressive strength and stiffness relative the soft soil. They do not only serve the function of reinforcement and drainage, but they also increase the bearing capacity and reduce the settlement of the soft ground. Depending on the type of installation method, the soil around the column is compacted due to the displacement of the soil during installation, and hence improved stiffness of the soil.

Various installation methods are used world-wide, for instance, the vibro-replacement method, the vibro-compaction method, the vibro-composer method and ramming by dropping hammer (15 to 20 kN)[1].

Bearing capacity of a single column

Stone columns may undergone failure in one of the following forms as shown in Figure(1). : bulging, shear, or punching failure [1].

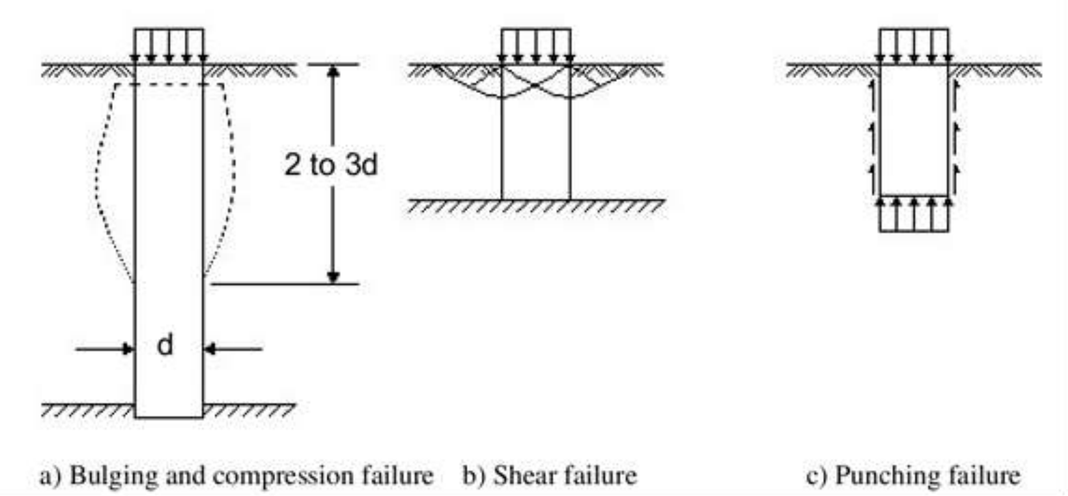

Figure (1) :Failure mechanism of a single gravel column in soft soil

Bulging or compression failure.

Analogue to the effective shear parameters in a specimen in a triaxial test, the maximum effective pressure on the column can be expressed by:

$$\sigma'_{v,max} = tan^2\left(45+\frac{\varphi_c}{2}\right)\cdot\sigma'_{h,max} = K_{p,c}\cdot\sigma'_{h,max} \qquad \text{……………………(1)}$$

Where:

$\sigma'_{v,max}$ = maximum vertical effective pressure on the column,

$\sigma'_{h,max}$ = maximum horizontal effective pressure on the surrounding soil,

φ_c = angle of internal friction of the column material,

$K_{p,c}$ = the coefficient of the passive earth pressure of the column material in Rankin's special case

Shear failure . This type of failure can be examined by taking an axis symmetrical composite column-soil unit cell system with a cone type of rupture surface as shown in Fig. 1 . Ignoring the shear stresses on column skin and the shear de-formation along the rupture surface and assuming a constant volume, the maxi-mum effective vertical pressure $\sigma'_{v,\max,}$ on the column can be estimated from:

$$\sigma'_{v,max} = c_u\cdot\left[\frac{\sigma}{c_u}+\frac{2}{sin(2\cdot\delta)}\right]\cdot\left[1+\frac{tan\,\delta_c}{tan\,\delta}\right]\cdot tan^2\,\delta_c, \quad mit \quad \delta_c = 45+\frac{\varphi_c}{2} \qquad \text{…………(2)}$$

where σ is the applied external pressure on the improved soil.

Punching failure of a floating column .

The resistance of the column against punching arises from the skin friction and the base resistance. Ignoring the weight of the column, the minimum length of a column required to avoid a punching failure is given by:

$$L_{min} = \frac{1}{2}\cdot R_c\cdot\left(\frac{\sigma_{v,0}}{c_u}-9\right) \qquad \text{……………(3)}$$

The longer the column the smaller will be the base resistance. The maximum length of the column at which th e base resistance will no more exists may be calculated from:

$$L_{max} = \frac{1}{2} \cdot R_c \cdot \frac{\sigma_{v,0}}{c_u} \quad \ldots\ldots\ldots\ldots\ldots(4)$$

where $\sigma_{v,o}$ is the vertical stress on the top of the column and R_c is the radius of the column. A length of column beyond the maximum length will not have any advantage. Hence, the optimum length of the column lies between these extreme values, i.e. $L_{\min} \le L \le L_{\max}$.

The Lime Column Approach

The Deep Mixing Method (DMM) is a common technique for an in situ soil treatment technology whereby the soil is blended with cementitious and/or other materials. These materials are widely referred to as "binders" and can be introduced in dry or slurry form. They are injected through hollow, rotated mixing shafts tipped with some type of cutting tool [2]. Other variant of the DMM was lime-column method (LC). The limecolumn method was formed by injecting the dry or wet lime under preferable pressure into soil in-situ [3].

The lime-column technique has been applied successfully in recent years to improve the physical and mechanical properties of the soils. This technique would increase soil bearing capacity and reduces soil settlement owing to improving of soil strength and stiffness. Hence, this technique was preferable for soft soil improvement [4].

A study carriedby [5] on full-scale model showed that the stiffness of the improved soil using lime-column increased more significantly than that of lime-cement column.

Ref. [6] carried out a case and theoretical studies on lime and stone columns and proved that both ground improvement methods are able to provide increases in strength and stiffness of the soil mass and the resulting increase in undrained shear strength gain after the ground treatment was higher than the theoretical prediction.

Ref. [7] studied the changes in the microfabric of long-term cured lime-stabilized kaolinite clay using X-ray diffraction pattern, scanning electron microscope and unconfined compressive strength (UCS). The UCS of pure kaolinite was originally 125 kPa, which increased to 1,015 kPa after 1 month.Ref. [8]conducted a series of unconfined compression and static cone penetration (CPT) tests on system of soil-lime column. The test results showed that the LC contributes to enhance the soil strength inradial direction up to 4D from the center of LC and the soil strength tends to increase with time.Ref. [9] used X-ray Diffraction (XRD) technique to study permeability coefficient (k) in the marine clay stabilized with single and lime columns. The results showed a enormous improvement in k up to 23 times.

Testing program

The total of 16 model tests of soil treated with stone and lime columns were carried out in cylindrical container to study the efficiency of stone and lime column groups beside two model tests of untreated soil for comparison purpose . Load tests were carried out on single column and groups of 30 mm diameter. The length to the diameter (L/D) ratio of stone and lime column were taken equal to 9.

Materials Used

I. Soil Used

Soil samples were collected from a depth of (0.5- 1.5) m from the soil surface of a site in the vicinity of Al-Musaib Technical Institute in Babylon Governorate. The soil was subjected to routine laboratory tests to determine its properties. These tests include:

1- Grain size distribution (sieve analysis and hydrometer tests) according to ASTM D422[10] specifications.
2- Atterberg limits (liquid and plastic limits) according to ASTM D423 and D424 specifications[10].

The test results show that the soil consists of 13% sand, 35 % silt, and 52 % clay. According to the unified soil classification system, the soil is inorganic sandy silty clay designated as (CL). Table (1) shows the physical properties of the soil.

II. **Crushed Stone**

The natural calcium carbonate, $CaCo_3$(limestone), crushed stone was used as a backfill material. The size of the crushed stone was chosen in accordance with the guidelines suggested by [11], where the particle size is about (1/6 to 1/7) of the diameter of stone columns. The minimum particle size is 2 mm and the maximum particle size is 10 mm.

Steel Container

The model tests were carried out in a test cylindrical test tank manufactured of steel with dimensions of 300 mm in diameter and 350 mm in height, made of steel plates (6 mm in thickness) . The container is sufficiently rigid and exhibited no lateral deformation during the preparation of the bed of soil and during the tests. The thickness of soil bed inside the container was 270 mm.
The foundation square plate have 120 mmof side length and 5 mm of thickness. Figure (2) shows details of the complete set up which consists mainly of steel container, loading frame, dial gauges and accessories.

Table (1): Physical properties of the treated soil.

Property	Value
Liquid limit (LL)	44%
Plastic limit (PL)	22%
Plasticity index (PI)	22%
Specific gravity (GS)	2.71
% Passing sieve No. 200	87%
Sand content	13%
Silt content	35%
Clay content <0.005 mm	52%
Maximum dry unit weight kN/m^3	18.5
Symbol according to Unified Soil Classification System	CL

Model Preparation and Testing Preparation of the Bed of Soil

Prior to the preparation of the bed of soil, a relationship was obtained between the water content and the undrained shear strength of the soil.The shear strength was measured using unconfined compression.Following this stage, the bed of the soil was prepared as follows:

- The natural soil was first crushed with a hammer to small sizes and then left for (24) hours for air-drying. Further crushing was carried out using a crushing machine.
- The air-dried soil was divided into 2 kg groups. Each group was mixed gradually and thoroughly with sufficient amount of water corresponding approximately to the water content range of (22-35) % to get the specified values of shear strength ranged between 8 kPa and14 kPa.
- After mixing with water, the soil was placed in layers inside the steel container and each layer was tamped with a special tamping hammer. The final thickness of each layer was about 40 mm. The procedure was continued until the final thickness of 270 mm of the soil bed.
- After the completion of the preparation of the bed of soil, it was covered tightly with nylon sheets and left for four days as a curing period.

Construction of Stone and lime Columns

At the end of curing period, the following steps were used in construction of the stone columns:

(1) The top of the soil bed was leveled.
(2) The position of the stone or lime column(s) to be placed was properly marked with respect to the

loading frame. Auger of 30 mm of diameter is fully penetrated in soil to the stone or lime column or L/D = 9 and, (the critical length is usually about four times the column diameter,[12]). The auger was then slowly withdrawn.

(3) The soil was removed from the auger and samples of the soil at different depths were taken for water content measurement.

(4) The lime was dried in Furnacewith degree of 600^0.

(5) The crushed stone or lime poured into the hole in layers and each layer was compacted gently using a (10 mm) in diameter tamping rod. The unit weight of the compacted crushed stone and dry lime were measured to be 17.5 kN/m^3 and 7 kN/m^3 respectively.

(6) The stone and lime columns were left 24 hour before carrying out the loading tests.

Model Testing Procedure

The model tests were carried out according to the testing program as follows:

1. The footing assembly (120 mmof side length) is placed in position so that the center of the footing coincides with the center of the hydraulic jack.
2. The *electronic load cell*with capacity of 50 kPais attached to the hydraulic jack.
3. The *displacement transducer*with capacity of 50 mm is fixed in position to measure the settlements of the plate.[figure 2]
4. Loads were then applied through a loading disk in the form of load increments of 50 N.
5. During each load increment, the readings of theload cell and were recorded from the (*5 channels digital unit*) with accuracy of 0.001 kN for load and
6. The settlement readings corresponding to the *displacement transducer*were recorded at the end of the period of each load increment from the same(*5 channels digital unit*)with accuracy of 0.001 mm.
7. Each load increment was left for (2.5) minutes.
8. The load increments were continued until the total settlement reached 40 mm (133% of the *stone* and *limecolumns* diameter).
9. For comparison purposes, the loading tests were performed in the container for the untreated soil only.

The testing was carried out on single column or on group of 2, 3 and 4 columns installed in soil bed.
Figure(3) present different shapes of stone and columns models before and after the completion of the tests.

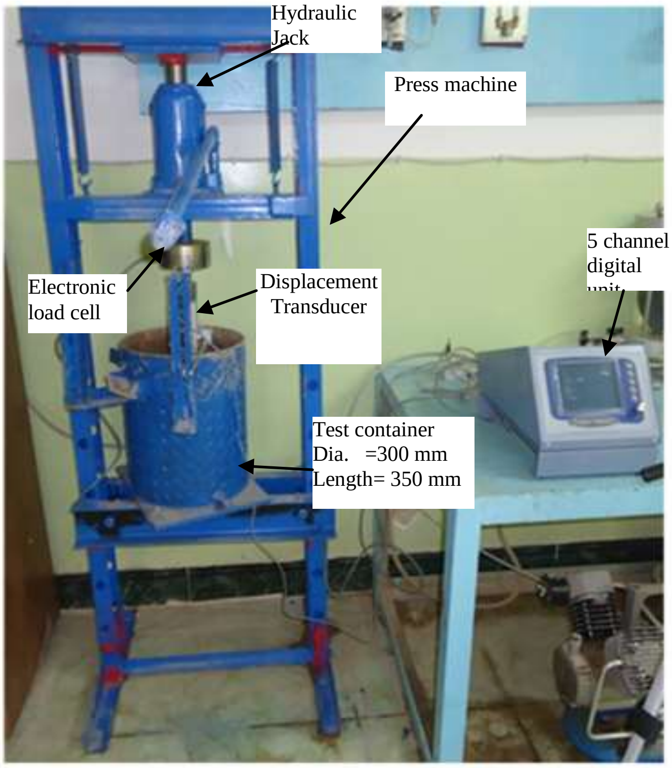

Figure (2) : the experimental set-up

Figure (3) : Stone (Lime) columns before and after tests

Results

Figures (4, 5, 6, 7) relate the bearing ratio (q/cu),where q represented the applied stress with the deformation ratio (S/B), where the S represented the settlement and B represented the width of footing, for untreated soil and soil treated with single, two, three and four stone(lime) columns having (L/D) ratio of 9. The surrounding soil was prepared at undrained shear strength of (cu=8kPa, and 14kPa), respectively. These models were tested 24 hours after preparation. The figures demonstrate that the stone (lime) column in all bearing ratios shows significant difference in the behaviour corresponding to (S/B) ratio.

The efficiency of a group (Eg) of stone or lime columns is defined as the ratio between the capacity of each stone or lime column in the groupto the capacity of the single stone (lime) column. The net load taken by the columns was taken as difference between the load taken by the column supported plate (treated) and unsupported plate (untreated) or by the following formula:

Net load on stone column = Ultimate load on treated soil - Ultimate load on untreated soil

$$= P_{treated} - P_{untreated} \qquad \text{……(5)}$$

The efficiencies of the 2, 3 and 4 stone (lime) groups were calculated according to Ref.[13].

$$\text{Efficiency } (E_g) = \frac{\text{Load (single)}}{\text{(Load (group)/ No. of columns)}} \qquad \text{……(6)}$$

Figures (8) and (9) demonstrate the relation between the number of stone (lime) columns with ultimate load on composite material [soil-stone(lime) column], load on soil, load on group of columns and load on single column. It can be noticed from these figures that soil of shear strength of 8 kPa, treated with stone columnscould carry higher load than the soil treated with lime column i.e., the stone column carried more load the lime column but when the shear strength increases the lime column carried higher load than stone column.

Tables (2 and 3) with figure (10) show the calculations of group efficiency for all 16 model tests. In all model tests, the capacity is taken as the load corresponding to a settlement equals to 0.125 times the diameter of loading plate or 50% times the diameter of stone column. It can be seen from these tables that the group efficiency is decreased with increasing the numbers of stone columns. The group efficiency of two, three and four stone columns are (0.98, 0.98 and 0.92) respectively for soil having(cu = 8kPa) treated with stone columns. The results also show that the group efficiency values are (1.00, 0.87 and 0.85) respectively in soil treated with two, three and four lime columns at shear strength of soil is 14 kPa.

These tables demonstrate that when the shear strength decreases, the group efficiency increases. These tables also illustrated that the crushed stone provided higher efficiency than lime column in the low shear strength but the lime column provided the largest efficiency in the high shear strength.

The results obtained from tables (2) and (3) are in agreement with [13], [14], [15] and [16].

Conclusions:

The following points are drawn from the tests:

(1) The crushed stone provided the group efficiency of (0.98, 0.98 and 0.92) in two, three and four stone columns respectivelyat shear strength of soil of 8 kPa .

(2) The lime provided the group efficiency of (0.88, 0.78 and 0.65) in two, three and four lime columns respectivelyat shear strength of soil of 8kPa .

(3) The soil treated with stone column carried higher load than the soil treated lime column but when the shear strength is increased the soil-lime system behaved in contrary way.

(4) The group efficiency decreases with increasing the numbers of stone or lime columns.

(5) The group efficiency of stone columnsgroup,Eg, decreases with increasing the shear strength of the treated soil, while the lime columns group efficiency acted in a different way.

Table (2): Summary of group efficiency (Eg) from various modeltests (cu = 8 kPa).

Stone columns

No. of columns	Ultimate load (N)	Load on soil (N)	Load on group of stone columns (N)	Load on single stone column (N)	Group Efficiency
single	937	716	221	221	
two	1152	716	436	218	0.98
three	1367	716	651	217	0.98
four	1529	716	813	203	0.92

Lime columns

No. of columns	Ultimate load (N)	Load on soil (N)	Load on group of stone columns (N)	Load on single stone column (N)	Group Efficiency
single	920	716	204	204	
two	1076	716	360	180	0.88
three	1191	716	475	158	0.78
four	1248	716	532	133	0.65

Table (3): Summary of group efficiency (Eg) from various modeltests (cu = 14 kPa).

Stone columns

No. of columns	Ultimate load (N)	Load on soil (N)	Load on group of stone columns (N)	Load on single stone column (N)	Group Efficiency
single	1550	1300	250	250	
two	1700	1300	400	200	0.80
three	1870	1300	570	190	0.76
four	2050	1300	750	187.5	0.75

Lime columns

No. of columns	Ultimate load (N)	Load on soil (N)	Load on group of stone columns (N)	Load on single stone column (N)	Group Efficiency
single	1550.0	1300.0	250.0	250.0	
two	1800.0	1300.0	500.0	250.0	1.00
three	1950.0	1300.0	650.0	216.7	0.87
four	2150.0	1300.0	850.0	212.5	0.85

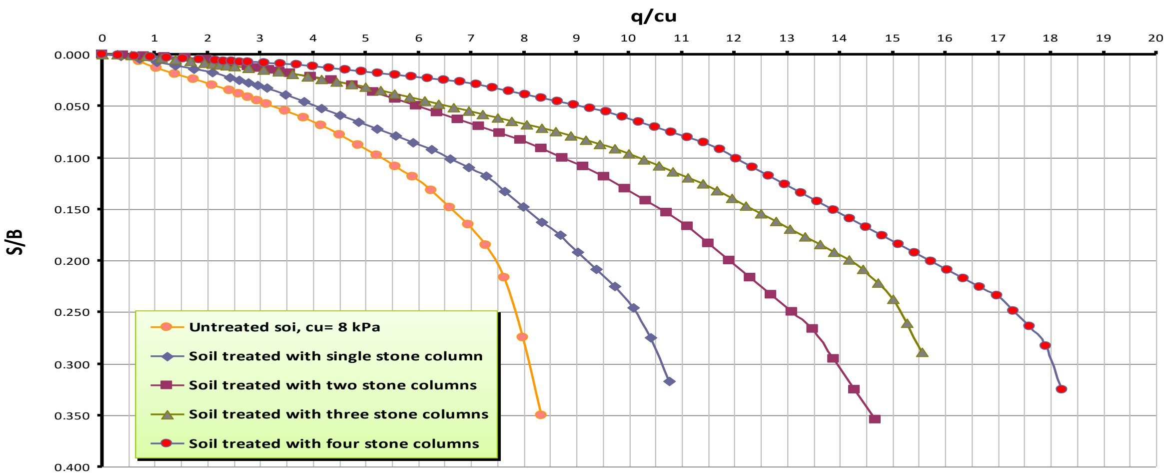

Figure (4): q/cu versus S/B for the soil treated with stone column, cu= 8 kPa.

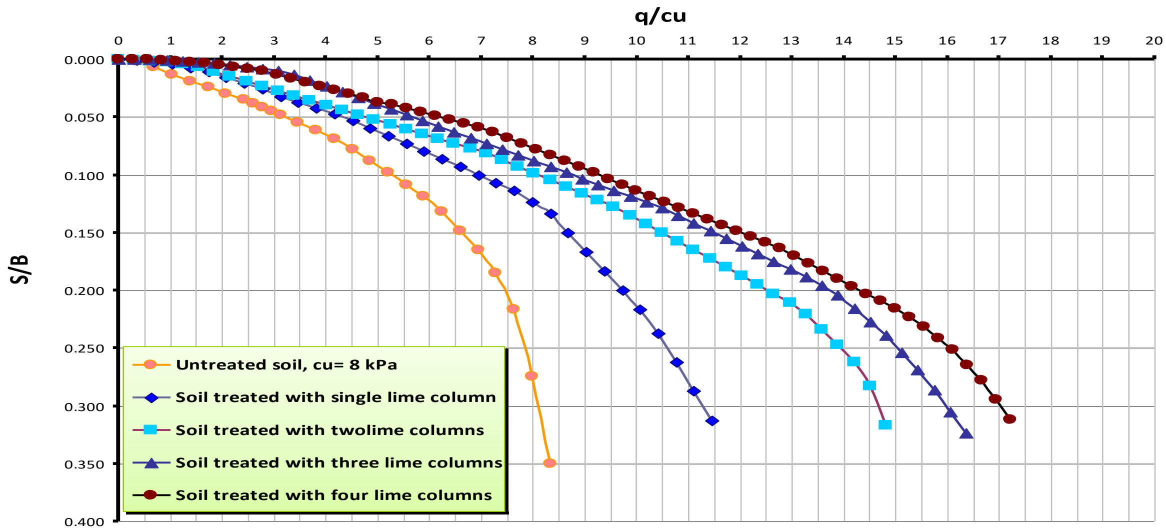

Figure (5): q/cu versus S/B for the soil treated withlime column, cu= 8 kPa.

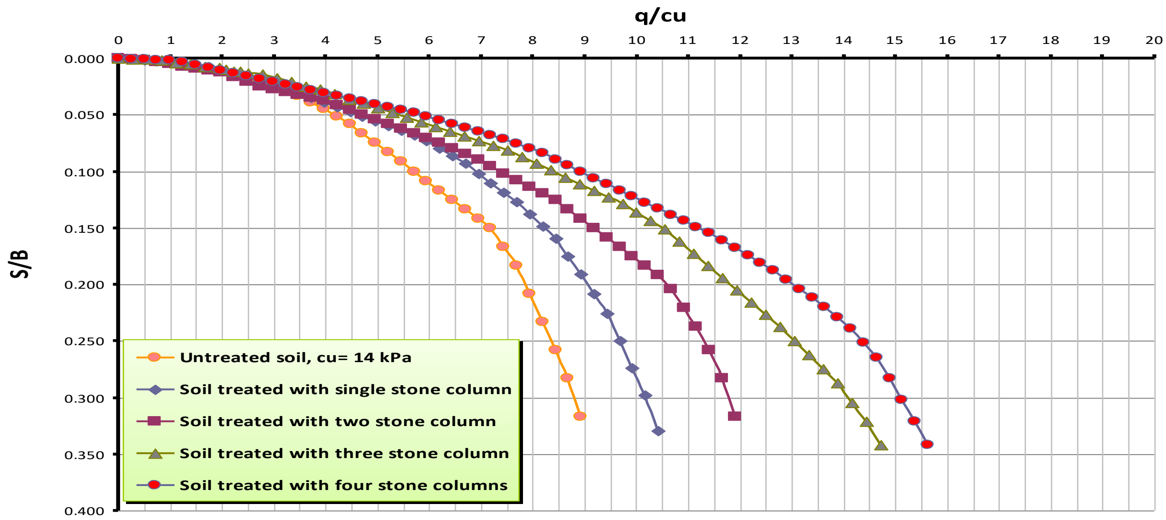

Figure (6): q/cu versus S/B for the soil treated with stone column, cu= 14 kPa.

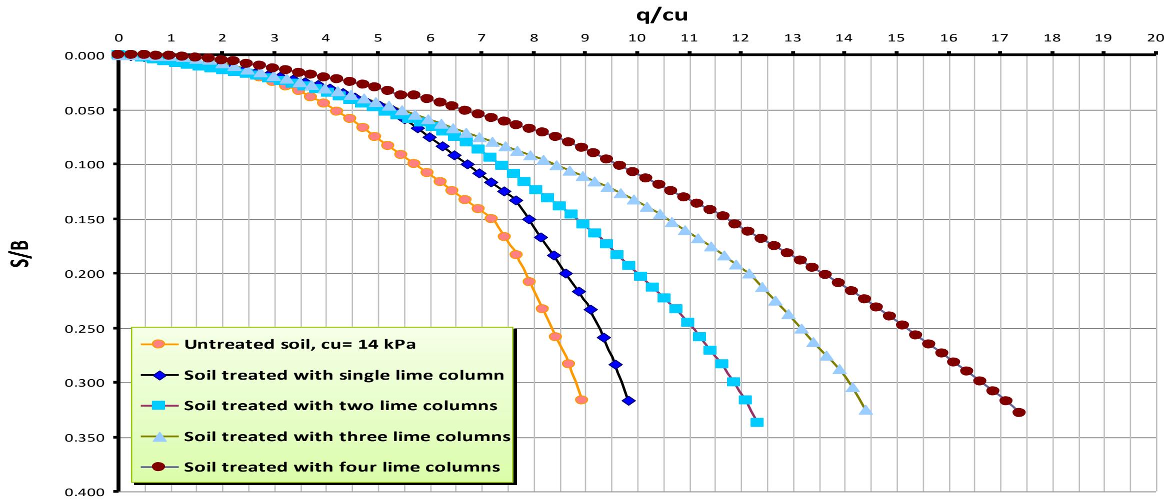

Figure (7): q/cu versus S/B for the soil treated withlime column, cu= 14 kPa.

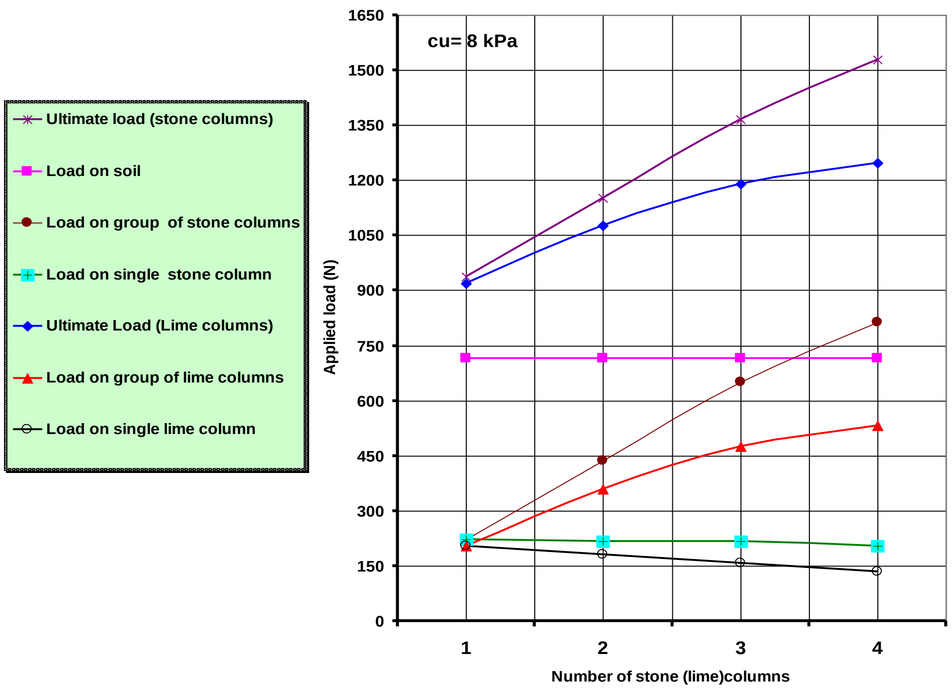

Figure (8) : Number of stone (lime) columns versus (ultimate, load on soil, load on group of columns and load on single column), cu= 8kPa.

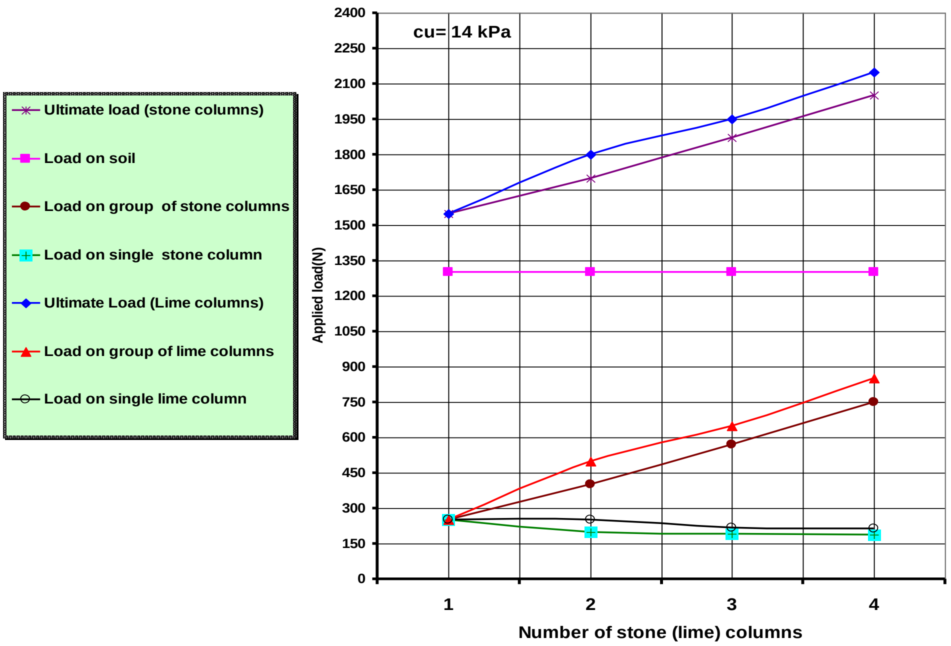

Figure (9) : Number of stone (lime) columns versus (ultimate, load on soil, load on group of columns and load on single column), cu= 14kPa.

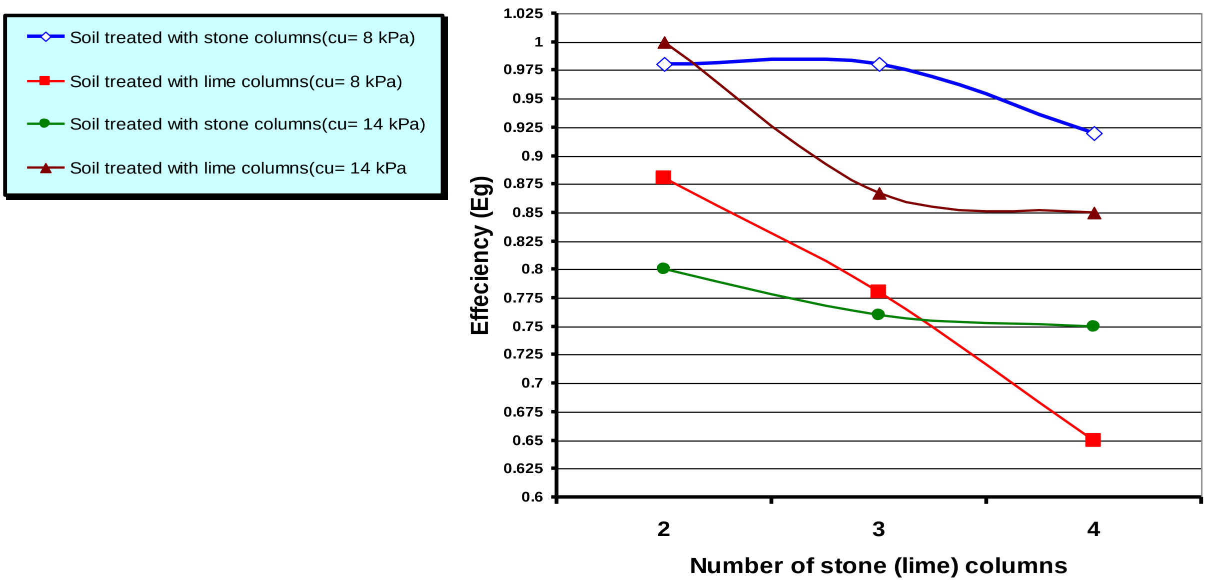

Figure (10) : Number of stone (lime) columns versus Efficiency

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