Comparison between Sand Columns and Sand Columns Stabilized with Lime or Cement with Stone Columns Embedded in Soft Soil

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Received on: 13/3/2016 & Accepted on:29/12/2016

ABSTRACT
Sand and stone columns are used to improve bearing capacity of soft clayey soils because of their stiffness which is higher than the soil was replaced, the compacted columns produce shearing resistances which provide vertical support for overlying structures or embankments. Also the sand and stone columns accelerate the settlement in the native surrounding soil and improve the load settlement characteristics of foundation. The technique consists of excavating holes of specific dimensions and arrangement in the soft soil and backfilling them with either sand or stone particles.

The present work investigates the behavior of soft soil reinforced with group of stone columns, sand columns and sand columns stabilized with lime or cement. The percentage of lime and cement used in this research, were determined previously in papers of single sand column stabilized with lime and cement, 11% by weight lime and 9% by weight cement. The model tests were carried out on a soil with undrained shear strength ranging between 16-18 kPa. The models consist of eight columns at area replacement ratio of (0.196) in square pattern, the holes 50 mm in diameter and 300 mm in length were excavated in a bed of soft soil. The holes were backfilled with stone, and sand stabilized with lime or cement particles. Each group of columns was loaded gradually through a rectangular rigid footing, its dimensions 400×200 mm with 50 mm thickness, up to failure with continuous monitoring of the settlement. The test results are analyzed in terms of bearing improvement ratio and settlement reduction ratio for all columns and in terms of the stress concentration ratio and stiffness ratio.

The results show that the improvement in bearing capacity was about 70% and 62% for sand columns stabilized by lime and cement respectively, and the improvement in bearing capacity was about 42% and 34% for sand columns stabilized by lime and cement compared with stone columns respectively.

Keywords: Sand column, stone column, lime stabilized sand column, cement stabilized sand column.

INTRODUCTION
Iraq is among the countries where nearly 30 to 40 % of its area is characterized as soft saturated silty clay. This soft soil exists along the alluvial plain, beginning from north of Baghdad and extending south to the Arabian Gulf. The area is expected to experience rapid development in its infrastructure and hence ground improvement becomes a major task for construction industry (Al-Saoudi et al.,2015). Stone or sand columns have been widely applied internationally as a successful,

https://doi.org/10.30684/etj.34.15A.3
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sustainable and efficient technique for improving the load carrying capacity and controlling the settlement of soft soils and in many cases considered as an economic alternative to deep foundation. Stone or sand columns are composed of stone or sand inserted into the soft clay foundation by displacement method. The term "Stone or sand columns" refers to the component of stone and/or sand columns. The ground that improved by stone or sand columns is termed as composite ground. When loaded, the pile deforms by bulging into the subsoil strata and distributes the stresses at the upper portion of the soil profile rather than transferring the stresses into the deeper layers, thus causing the soil to support it. As a result, the strength and bearing capacity of the composite ground can be increased and compressibility reduced (Bergado et al., 1996).

In present work, the percentage of lime and cement determined as an optimum percent of previous studies, the optimum percent of lime is the maximum percent in this study 11% by weight of column (Al-Gharbawi, 2013) and the optimum percent of cement is 9% by weight of column after seven days curing (Rajab, 2013). And the stone columns result was taken from previous study, eight ordinary stone columns at loose state R.D 23%, (Al-Baiaty, 2012).

Laboratory Model Tests

Material properties

Soil used

The soil was brought from a site located at east of Baghdad city. The soil consists of 3.3% sand, 31.7% silt and 65% clay as shown in figure (1). Atterberg limits revealed LL = 42 and PI = 22. According to the Unified Soil Classification System (USCS), the soil is classified as CL (clay of low plasticity). The soil was prepared at undrained shear strength between 16 -18 kN/m^2.

Sand used

The sand was brought from Al-Ekhether city south of Baghdad city. The grain size distribution consists of 10 % gravel, 89 % sand and 1 % fines with D_{10}, D_{30} and D_{60} are 0.28 mm, 0.79 mm and 2 mm respectively, revealing coefficient of uniformity 7.14 and coefficient of curvature 1.11, which classified as well graded sand as shown in figure (2) and its specific gravity is 2.65. The dry unit weights used in the construction of sand columns is 17 kN/m^3 corresponding to relative density 15 %.

Stone used

The crushed stone was brought from a crushing stone factory, white in color and angular in shape. D_{10}, D_{30} and D_{60} are 4.9 mm, 5 mm and 5.2 mm respectively revealing coefficient of uniformity 1.06 and coefficient of curvature 0.98, classified as poorly graded stone as shown in figure (3) and its specific gravity is 2.62. The dry unit weights used in the construction of stone columns is 13 kN/m^3 corresponding to relative density 23 %.

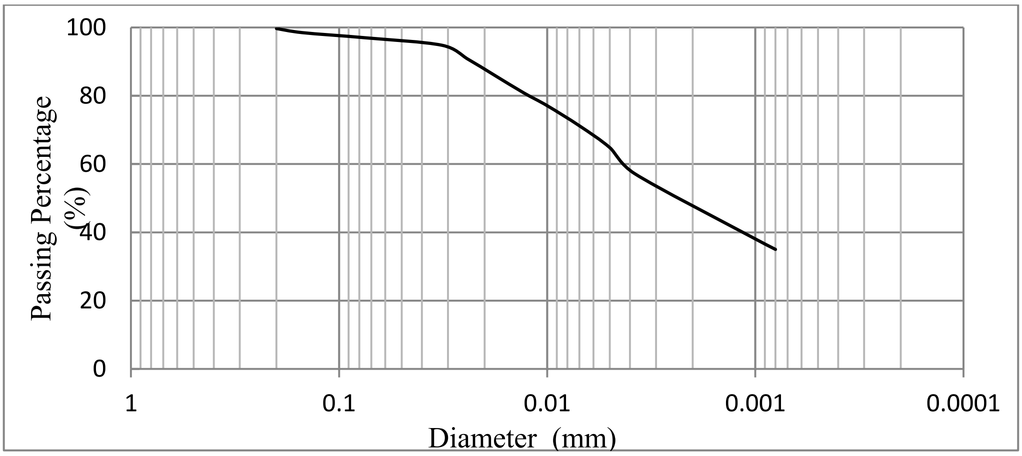

Figure (1): Grain size distribution of the soil used

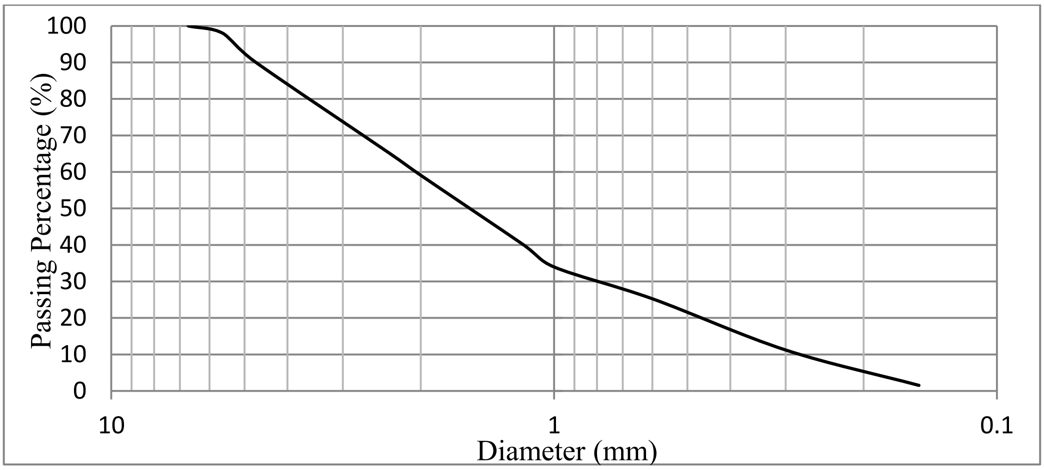

Figure (2): Particle size distribution of sand used

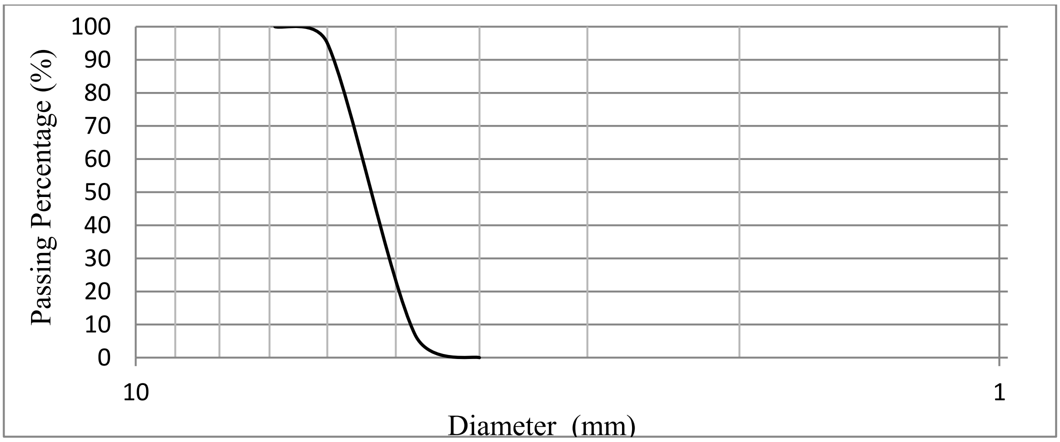

Figure (3): Particle size distribution of crushed stone used (Al-Baiaty,2012)

Lime

The type of lime was used Turkish hydrated lime exposed to heat in laboratory to convert it to quick lime. The physical and chemical properties was tested in The National Center for Construction Laboratories and Research (NCCLR), Ministry of

Construction and Housing, and the physical and chemical properties are shown in table (1) according to ASTM specifications.

Table (1): Physical and chemical properties of lime

Index Property	Index value
Physical Properties	
Retained on Sieve # 30 (% by weight)	0
Retained on Sieve # 200 (% by weight)	10
Chemical Properties	
CaO Content (%)	93.34
Free Water Content (%)	0.08
IR (%)	2
SO_3 Content (%)	0.07
L.O.I (%)	25.24

Cement

The cement that used in the model tests is sulfate resistant cement, which manufactured by Tasluja cement factory. The physical and chemical properties was tested in The National Center for Construction Laboratories and Research (NCCLR), Ministry of Construction and Housing, and the physical and chemical properties are shown in Table (2).

Table (2): Physical and chemical properties of the cement

Index property	Index value
Compressive strength after 3 days (MPa)	17
Compressive strength after 7 days (MPa)	26
Time of initial setting (minute)	93
Time of final setting (hour)	4.28
SiO_2 %	19.79
CaO %	63.8
MgO %	3.19
SO3 %	2.15
C_3A %	3.27
LOI %	0.89

Model preparation and testing

Beds of fully saturated soil were prepared inside steel containers 1000 mm * 400 mm * 700 mm in depth. The dry soil was mixed thoroughly with the required amount of water to obtain soil of undrained shear strength between 16 – 18 kN/m^2.The lumps of soil were placed in layers inside the container and each layer was tamped gently to remove any entrapped air. The process continues till the thickness reaches 500 mm. After completion of the final layer, the top surface was scraped and leveled to get as near as a flat surface. The models consist of eight columns at area replacement ratio of (0.196) in a square pattern the configuration of the columns shown in figure (4). PVC tube (50 mm in diameter and 500 mm in height) was inserted vertically to the required depth (300 mm from the top surface) and the soil was removed completely inside the tube. The sand or stone was carefully charged into the hole in three layers to achieve the loose state of density of 17.0 kN/m^3 for sand and 13 kN/m^3 for stone. The additives to sand column, lime or cement, was mixed before adding into the hole, the cross section of the models is shown in figure (5). After completion of the construction of the sand or stone columns and after seven days curing for sand columns stabilized with lime or cement, the container was moved along therails and fixed in position in such a manner that the center of the footing coincided with the center of the bed of the model, a steel rigid footing 400 mm * 200 mm with 50 mm thickness was applied gradually through the hydraulic jack which operates at a controlled displacement of 0.05mm/sec, the process continues up to failure. The loading assembly is shown in figure (6).

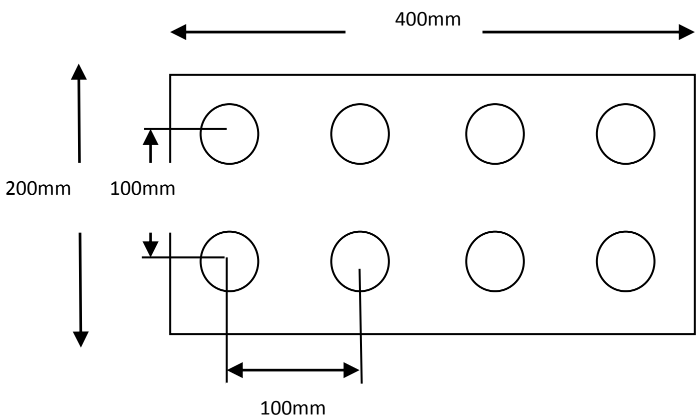

Figure (4): Configuration of columns

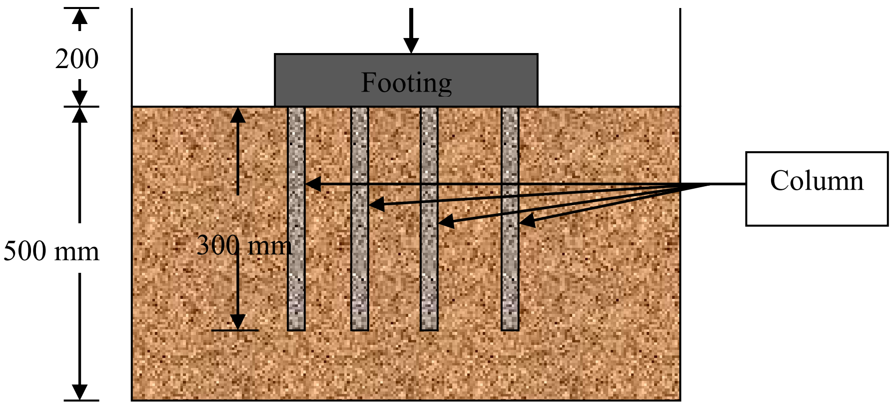

Figure (5): Cross section in the model

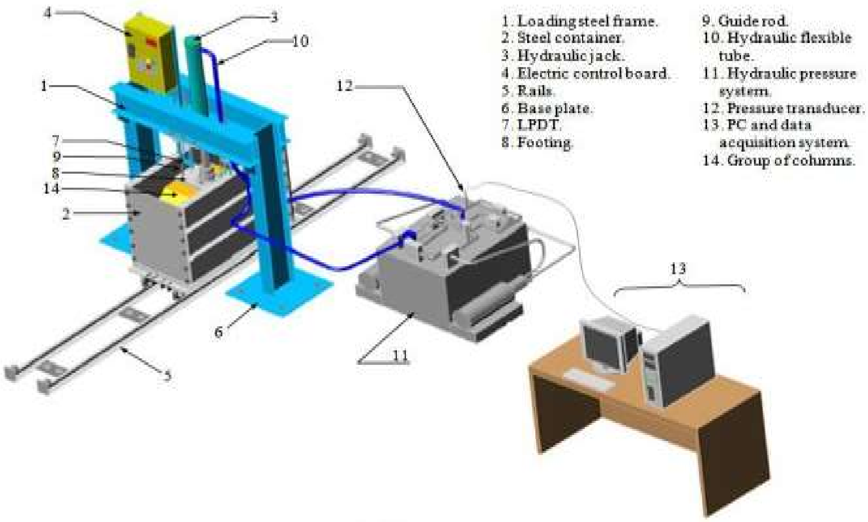

Figure (6): The apparatus (Rahil, 2007)

Analysis And Discussion of Results

The following terms are used in the evaluation of improvements achieved by stone, sand or sand stabilized with lime or cement columns. The bearing ratio q/c_urepresents the ratio of the applied stress to the undrained shear strength. Failure of model tests is defined as the stress required to causes settlement corresponding to 10% of the footing width dependig on the proposal given by (Terzaghi, 1947).

The bearing improvement ratio $(q/c_u)_t$ / $(q/c_u)_{unt}$, represents the ratio of the bearing ratio of the treated soil to the bearing ratio of the untreated soil .The settlement reduction ratio S_t/S_{unt} represents the ratio of the settlement of the treated soil to the settlement of the untreated soil.

Untreated soil

A model was tested; the thicknesses of the soft soil layer used are 500 mm. Figure (7) demonstrates the gradual development of the relationship between the bearing ratio and the settlement ratio. Considering the failure criteria at 10% settlement ratio, the bearing ratio (q/c_u) at the failure is 4.

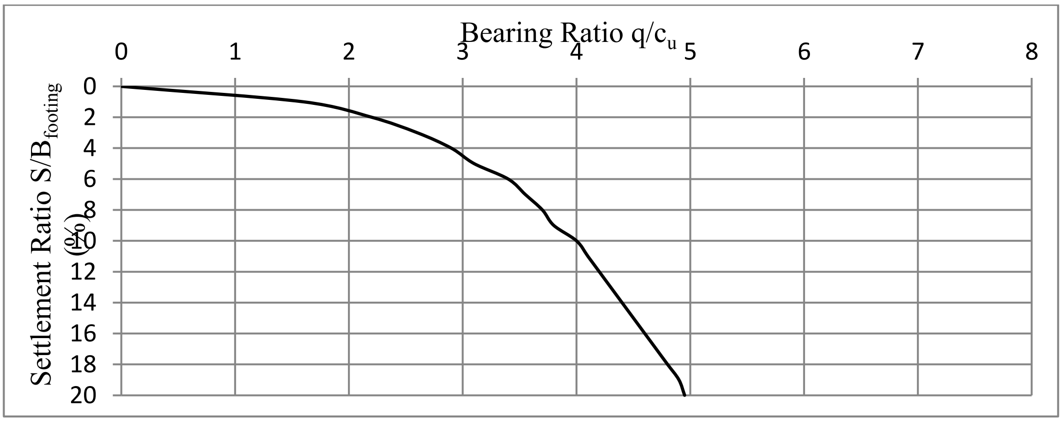

Figure (7): Bearing ratio versus settlement ratio of untreated soil

Stone columns

Eight ordinary stone columns reinforced soft soil at loose state (R.D 23%) was taken from pervious study (Al-Baiaty,2012). Figure (8) demonstrates the relationship between the bearing ratio with the settlement ratio for the untreated soil and stone columns. Considering the bearing ratio (q/c_u) at failure is 4.8 for stone columns.

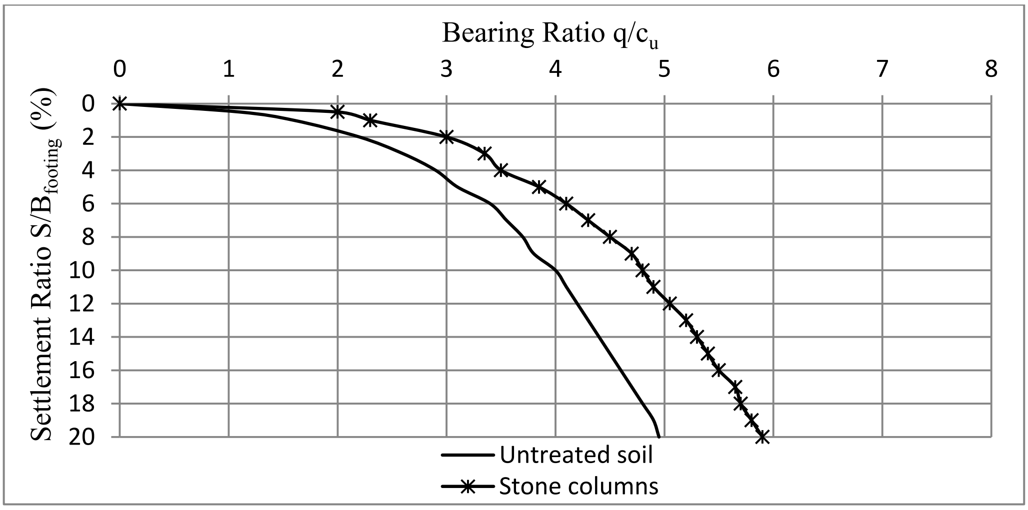

Figure (8): Bearing ratio versus settlement ratio for stone columns at loose state

Sand columns

Loose state of sand columns reinforced soft soil (R.D 15%). Figure (9) demonstrates the relationship between the bearing ratios with the settlement ratio for sand columns. Considering the bearing ratio (q/c_u) at failure is 5.3.

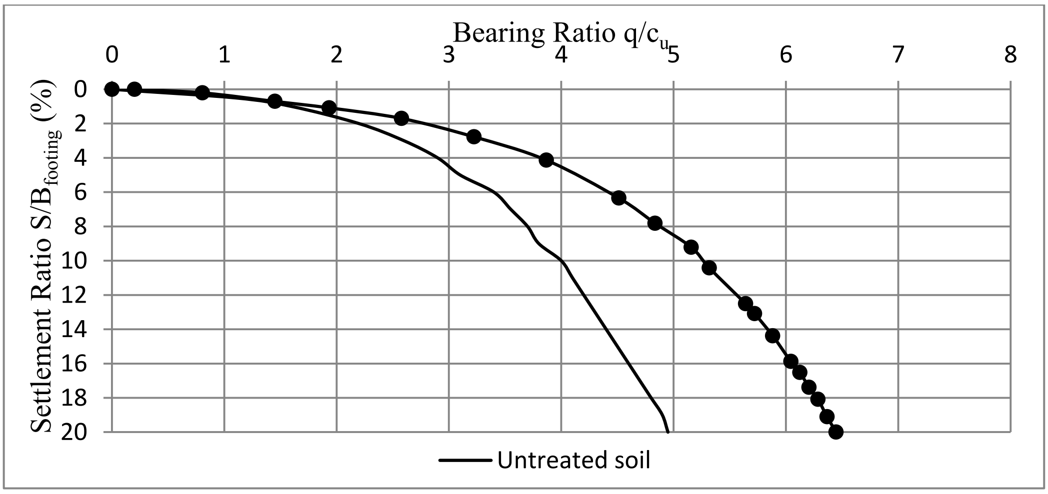

Figure (9): Bearing ratio versus settlement ratio for sand columns

Sand columns stabilized with lime or cement

Loose state of sand columns reinforced soft soil (R.D 15%) stabilized the sand columns, the optimum ratio of lime and cement, 11% by weight lime or 9% by weight cement. Figure (10) demonstrates the relationship between the bearing ratio with the settlement ratio for stone, sand columns and sand columns stabilized with lime or cement. Considering the bearing ratio (q/c_u) at failure are 6.8 and 6.45 for sand columns stabilized with 11% lime and sand columns stabilized with 9% cement respectively.

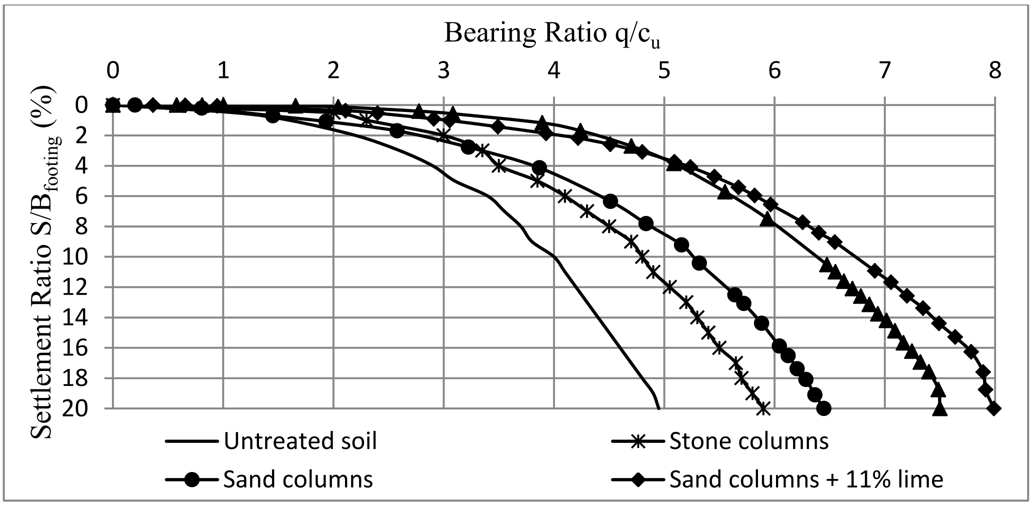

Figure (10): Bearing ratio versus settlement ratio for stone columns, sand, sand stabilized with 11% lime and sand stabilized with 9% cement

Figure (11) & (12) show the bearing improvement ratio versus settlement ratio and settlement reduction ratio versus bearing ratio respectively, in figure (11) the bearing improvement ratio at 10% settlement ratio are 1.2, 1.33, 1.7 and 1.62 for stone columns, sand columns, sand columns stabilized by lime and sand columns stabilized by cement respectively. In figure (12), the general trend of sand columns with 11% lime and sand columns with 9% cement indicates a steep reduction in S_t/S_{unt} up to q/c_u= 2 then leveled off gradually up to q/c_u= 5, revealing a final settlement reduction ratio 0.6, 0.4, 0.19 and 0.17 for stone columns, sand columns, sand columns stabilized by lime and sand columns stabilized by cement respectively.

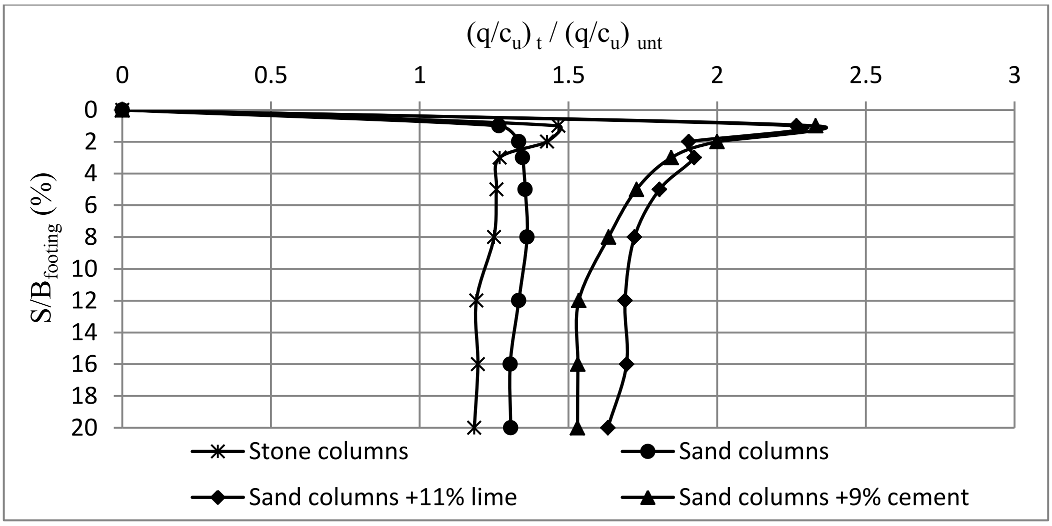

Figure (11): Bearing Improvement Ratio versus Settlement Ratio

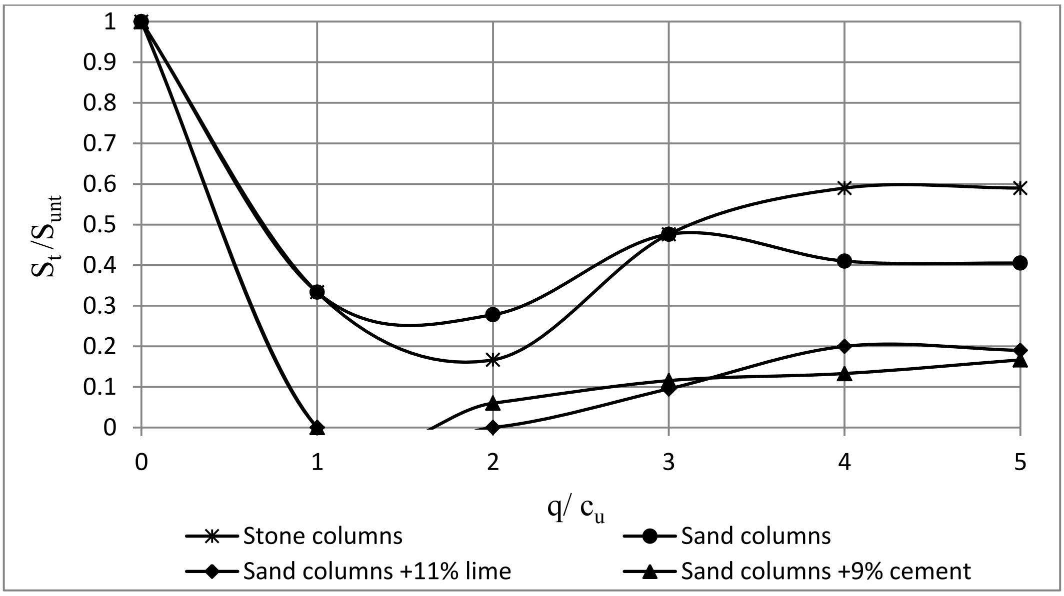

Figure (12): Settlement Reduction Ratio versus Bearing Ratio

Stress Concentration Ratio and Stiffness

When a uniform load is applied to composite soil reinforced with stone or sand columns, the stress concentrates on the columns due to the difference in the deformation characteristics or stiffness between the columns and the surrounding soil (Aboshi et al., 1979). The stress concentration factor for stone or sand columns in a cohesive soil matrix is defined as follows

$$n = \frac{q_s}{q_c} \quad ...(1)$$

$$q = q_s * a_s + q_c(1 - a_s) \quad ...(2)$$

$$q_c = q/ [1 + (n-1) a_s] = \mu_c * q \quad ... (3)$$

$$q_s = nq / [1 + (n-1) a_s] = \mu_s * q \quad ... (4)$$

Where:

q : the average applied stress.

q_s : the applied stress on the column.

q_c : the applied stress on the clay.

a_s : the area replacement ratio.

n : the stress concentration factor.

μ_c : the ratio of stress in cohesive soil to average applied stress.

μ_s : the ratio of stress in column to average applied stress.

To estimate the ratio of the stiffness of the column to the stiffness of the cohesive soil, (Watts et al., 2000) as proposed in equation (5).

$$E_{eq}=(E_s . A_s + E_c . A_c)/(A_s + A_c) \quad ... (5)$$

Where:

E_{eq} : Young's modules of the treated soil.

E_s : Young's modules of the stone or sand column.

E_c : Young's modules of the clay soil.

Since the settlement reduction ratio at any stress level is proportional to the Young's modulus, the values of E_{eq}/ E_c are the reciprocal of S_t/S_{unt}.
The equation (5) can be rewritten as

$$\frac{E_{eq}}{E_c} = \frac{\frac{E_S}{E_C} * A_S + A_C}{A_S + A_C} \qquad \dots (6)$$

From equation (6) we can determine the ratio of E_S/E_C. The ratio E_S/E_C is a good indicator of the improvements achieved in terms of settlement reduction ratio and bearing improvement ratio. The stress at failure of the composite soil defined as the stress ratio corresponding to settlement ratio S/B = 10 % and the undrained shear strength between 16 – 18 kPa, from figure (10) and by using the above equations can illustrate the values of $(q/c_u)_f$, q_f, q_c, q_s, n, μ_c, μ_s, S_t/S_{unt} and E_s/E_c, as shown in Table (3). The table also demonstrates that sand with percentages of additives columns exhibit high stiffness ratio compared to other columns.

Table (3): Stresses at failure, stress concentration factors and stiffness ratio

Column type	$(q/c_u)_f$	q_f (kN/m²)	q_c (kN/m²)	q_s (kN/m²)	n	μ_c	μ_s	S_t/S_{unt}	E_s/E_c
Stone	4.8	81.6	68	100.3	1.5	0.83	1.22	0.6	1.7
Sand	5.3	90.1	68	108.8	1.6	0.75	1.21	0.4	2.5
Sand +11% lime	6.8	115.6	68	136	2	0.59	1.18	0.19	5.5
Sand +9% cement	6.3	107.1	68	127.5	1.8	0.63	1.19	0.17	6

CONCLUSIONS

This research shows the importance of the type of backfill material used in the construction of granular columns in soft soil. Currently, no guidelines are available yet in the literature regarding to the type, gradation and other geotechnical properties of the backfill material. The common practice is using crushed stone as a backfill material due to its satisfactory stiffness but the sand columns and sand columns with lime or cement gave more stiffness than stone columns. Sand columns with additives are considered as an accepted alternative due to the increase in improvement ratio and its economic consideration.

The results show that the improvement in bearing capacity was about 70% and 62% for sand columns stabilized by lime and cement respectively, and the improvement in bearing capacity was about 42% and 34% for sand columns stabilized by lime and cement compared with stone columns respectively.

The results show that the improvement in stiffness was from 1.7 to 5.5 and 6 for stone columns compared with sand columns stabilized with lime and cement respectively.

RECOMMENDATIONS

1- Study the scale factor and its effect in size particles and to use this research in field.
2- Study the stiffness ratio in laboratory and compare its results with the equations results that used in this research.

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