Single Sand Column Stabilized by Lime Embedded in Soft Soil

Dr. Namir K.S. Al-Saoudi
Building and Construction Engineering Department. University of Technology/Baghdad
Dr. Hasan H. Joni
Building and Construction Engineering Department, University of Technology/Baghdad
Ahmed S.A. Al-Gharbawi
Building and Construction Engineering Department, University of Technology/Baghdad
E-mail: ahmedsgharbawi@yahoo.com

Received on: 16/6/2013 & Accepted on: 5/12/2013

ABSTRACT

The behavior of isolated sand columns stabilized with lime and embedded in bed of soft soil of untrained shear strength c_u between 16 – 19 kPa, is investigated. Holes in the form of columns 50 mm in diameter and 300 mm in length were excavated in a bed of soil and backfilled with sand mixed with various percentages of lime and cured for 7 days. A rigid circular footing 64.6 mm in diameter was placed on each column and loaded axially up to failure. The analysis of the model test results showed encouraging improvements of the load carrying capacity of the columns and significant reduction in the settlement over the conventional stone columns.

Keywords: Lime Stabilization of Soft Soil, Sand Columns, Sand Compaction Piles, Improvement of Soft Soils.

الاعمدة الرملية المنفردة المثبتة بواسطة النورة المغروزة في التربة الناعمة

الخلاصة

يهدف البحث الى دراسة تصرف الاعمدة الرملية المثبتة بالنورة والمغروزة في تربة طينية ذات مقاومة قص بين 16 – 19 كيلوباسكال. لقد تم عمل حفر على شكل اعمدة بقطر 50 ملم وطول 300 ملم في طبقة التربة الطينية وملئها بالرمل الممزوج بنسب مختلفة من النورة. لقد تركت طبقة الطين والاعمدة الرملية مغطاة باحكام لفترة انضاج سبعة ايام . تم وضع قرص دائري بقطر 64,6 ملم على كل عمود ومن تحميله محوريا لحين الوصول الى حالة الفشل . ان تحليل الفحوص اعطت نتائج مشجعة من ناحية مقدار التحسن في قابلية تحمل الاعمدة و في مقدار النقصان في الهبوط .

INTRODUCTION

As an improvement technique, stone or sand columns are implemented in soft soil to reduce the compressibility of soft soils, to accelerate the rate of consolidation and to improve the carrying capacity of soil. The common practice is to use crushed stone as a backfill material. Stone columns have proved to be a successful technique used for different applications such under embankment fill support for highways and bridge abutments as well as for other different structures.

https://doi.org/10.30684/etj.32.4A.16
2412-0758/University of Technology-Iraq, Baghdad, Iraq

The technique has been extensively used in Europe, USA, Canada and many countries in South East Asia (Bergado et al., 1996)[1].

Clean well graded sand has also been used as an alternative backfill material. The sand columns or compaction sand piles are similar in principles to the stone columns; the only difference is that sand columns are compacted in the field by vibrating closed end pipe (FHWA, 1983)[2]. The idea of sand column was developed in Japan in 1957 by Murayama as described by Mitchell in 1981[3]. Sand columns or sand compaction piles have been extensively used in Japan, commonly constructed by driving a steel casing down to the desired elevation using a heavy, vertical vibratory hammer located at the top of the pile. As the pile is being driven, the casing is filled with sand. The casing is then repeatedly extracted and partially retrieve using the vibratory hammer. By the time, the sand compaction pile has been completed the casing has been completely removed from the ground. (Aboshi et al., 1979[4], FHWA, 1983). Using sand column instead stone column is a good choice for its economic (Al-Zuhairi, 2000)[5].

The degree of improvement in carrying capacity and reduction in settlement achieved by the presence of sand columns depends on the type of sand and degree of compaction. Maximum improvements are achieved by stiffer sand columns made of well graded sand compacted at high relative density (Al-Gharbawi, 2013)[6]. Currently, there are many attempts to increase the stiffness of stone columns as well as sand columns by mixing additives with the backfill material or by using different patterns of encasement.

The present work tends to evaluate the use of lime as an additive to increase the stiffness of sand columns. It is true that sand is not recommended as a stabilizer for sandy soil in highway construction but in sand columns, the case is different as lime will be in contact with the clay along the base and the circumferential area of the column.

Aim of Study

The present article aims to evaluate the improvements in load carrying capacity and settlement reduction ratio of lime stabilized sand columns over the conventional sand columns.

EXPERIMENTAL INVESTIGATION

Selection of soil

The remolded soil used was brought from Al- Nahrawan city. The soil consists of 16 % sand, 34 % silt and 50 % clay. Atterberg limits revealed LL = 44 and PI = 25. According to the Unified Soil Classification System (USCS), the soil is classified as CL (clay of low plasticity). Other physical and chemical properties of the soil are summarized in Table (1). From direct shear test the cohesion of the soft soil (c) is 35 kN/m^2.

Table (1) Physical and chemical Properties of Natural Soft Soil.

Index Property	Index Value
Liquid Limit (%) (L.L)	44
Plastic Limit (%) (P.L)	19
Shrinkage Limit (%) (S.L)	14.1
Plasticity Index (%) (P.I)	25
Activity (A_t)	0.96

Specific Gravity (Gs)	2.69
Gravel (%) (G)	0
Sand (%) (S)	16
Silt (%) (M)	34
Classification (USCS)	CL
Cohesion (kN/m^2) (c)	35
Organic Material (%) (O.M)	0.39
Calcium Oxide (CaO) (%)	0.36
SO_3 Content (%)	0.52
Total Dissolved Salt % (TDS)	1.02
pH Content (%)	9.17

Note: all tests were performed according to the ASTM (2003)[7].

Sand

The sand used as a backfill material was brought from Al-Ekhether city. The grain size distribution showed 40 % gravel, 59 % sand and 1 % fines classified as well graded sand. The physical and chemical properties of sand are shown in Table (2). From direct shear test at dry unit weight 16 kN/m^3, the angle of internal friction (ϕ) is 44^o.

Table (2) Physical and Chemical Properties of Sand.

Index Property	Index Value
Max. Dry Unit Weight (kN/m^3)	20.5
Min. Dry Unit Weight (kN/m^3)	16.5
D_{10} (mm)	0.28
D_{30} (mm)	0.79
D_{60} (mm)	2
Coeff. of Uniformity (C_u)	7.14
Coeff. of Curvature (C_c)	1.11
Gravel (%) (G)	40
Sand (%) (S)	59
Fines (%)	1
Classification	SW
Specific Gravity (Gs)	2.65
Organic Material (%) (O.M)	0.09
Total Dissolved Salt (%) (TDS)	0.3
SO_3 Content (%)	0.15

Lime

The physical and chemical properties of lime are shown in Table (3).

Table (3) Physical and Chemical Properties of Lime.

Index Property	Lime
Retained on Sieve # 30 (% by weight)	0
Retained on Sieve # 200 (% by weight)	17
CaO Content (%)	83.55
Free Water Content (%)	0.1

EXPERIMENTAL SETUP FOR LOAD TEST

Steel Container

The model tests were performed inside a steel container of internal dimensions 600 mm x 600 mm x 500 mm. The steel container is made of steel plates of 4mm in thickness.

Model footing

Circular steel model footing 64.6 mm in diameter and 10 mm in thickness was used in all model tests.

Loading Assembly

The main features of the load assembly consist of the steel container and a loading frame. The loading frame consists of a steel rod with several attachments that host the loading weights. The whole assembly is capable to apply static vertical loads on the footing. Details of the main features of the loading assembly are shown in Figure (1).

Figure (1) Steel Container and Loading Assembly.

Preparation of soft clay bed

Beds of fully saturated soil were prepared at undrained shear strength between 16 to 19 kPa. This value was achieved after several trials of natural drying and mixing with continuous measurements of undrained shear strength. The soil was placed in five layers inside the steel container. Each layer was tamped gently with a wooden tamper 75 mm*75 mm to remove any entrapped air. After completing the final layer, the top surface was scraped, leveled and covered with a polythen sheet and a wooden board of the same size was placed with 5 kPa seating pressure. The bed of soil was left for a period of two days to regain its strength by self weight consolidation. The top surface of the bed soil was marked into four equal quarters and a column was constructed in the center of each quarter by inserting a vertical hollow plastic PVC pipe with external diameter of 50 mm to a depth of 300 mm. The soil inside the column was carefully removed by a hand auger. The sand-lime mixture was then poured into the hole in layers. After pouring all the specific amount of the mixture, the full depth of the hole was filled at dry unit weight of 15 kN/m^3, after the completion of the preparation of the bed of soil, a seating load 5 kN/m^2 was placed for 24 hours, it was covered with a nylon sheet to prevent any loss of moisture and left for curing period at seven days.

Following the curing days for the columns, the static loading system was placed and fixed in position and the footing was incrementally loaded with continuous measurements of the footing up to failure.

RESULTS AND DISCUSSION OF MODEL TESTS

Prior to the discussion of the model test results, it is important to clarify that the failure is considered as the load corresponding to settlement 10 % of the footing diameter. The discussion is divided into two sections; the first is devoted for discussing the results concerning the improvements in bearing capacity due to the presence of sand columns and sand- lime columns. The increase in bearing capacity is determined using the term “bearing improvement ratio” defined as the ratio of the bearing ratio q/c_u of the treated soil divided by q/c_u of the untreated soil, simply given the notation $(q/c_u)_t /(q/c_u)_u$. The second section of the discussion is devoted to the reduction in settlement gained by each improvement pattern. The term “settlement reduction ration” is defined as the ratio of the settlement of the treated soil to the settlement of the untreated soil and given the notation S_t/S_u.

BEARING RATIO AND BEARING IMPROVEMENT RATIO

Untreated soil

The first set of model tests was performed on untreated soil to determent the relationship between the applied stresses versus settlement. This relationship is considered as benchmark for comparison purposes of different patterns of improvement. Typical results are shown in Figure (2) relating the bearing ratio versus settlement ratio. The bearing ratio at failure is 4 at corresponding to 10 % settlement ratio.

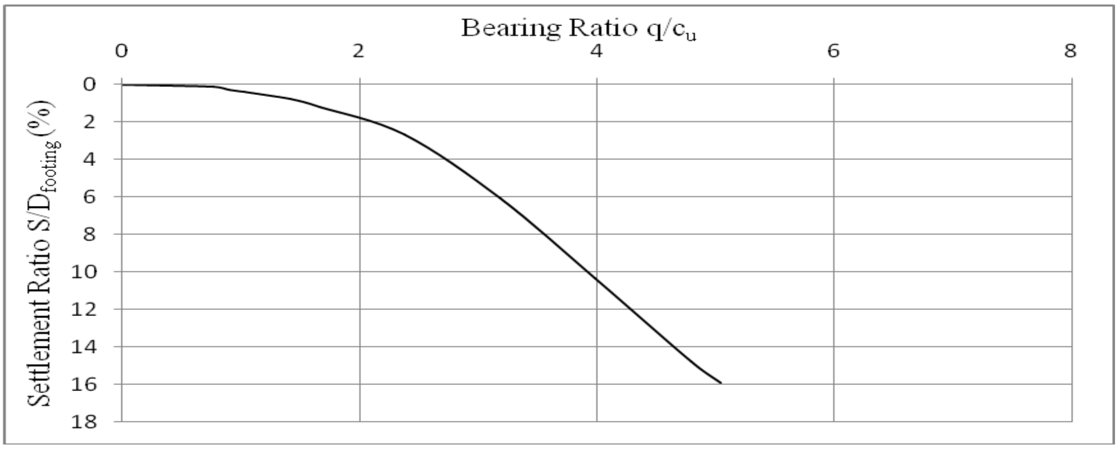

Figure (2) Bearing Ratio versus Settlement Ratio of Untreated Soil.

Soil treated with sand columns

Figure (3) demonstrates the relationship between q/c_u and $S/D_{footing}$ for soil reinforced with sand column at relative density 15 % corresponding to a loose state, the $D_{footing}$ is the diameter of footing, the center of the footing coincided with the center of the column. At initial stress increments up to $q/c_u \approx 2$, the untreated and treated models exhibited approximately the same settlement ratio indicating no significant influence of the presence sand columns. At this stage, the applied stress was evenly distributed over the contact area of the composite soil and no sign of stress concentration was noticed. The influence of the sand column becomes noticeable when the bearing ratio exceeds 2 and reached its maximum value at stress levels close to failure revealing bearing ratio (q/c_u) at failure equal to 5.4.

The bearing improvement ratio $(q/c_u)_t /(q/c_u)_u$ versus settlement ratio $S/D_{footing}$ is presented in Figure (4). The bearing improvement ratio $(q/c_u)_t /(q/c_u)_u$ at failure is 1.38.

Variation of settlement reduction ratio S_t/S_u versus bearing ratio q/c_u is shown in Figure (5). The settlement ratio exhibits a decreasing trend then increasing bearing ratio revealing a settlement reduction ratio of (S_t /S_u) equal to 0.58 at failure.

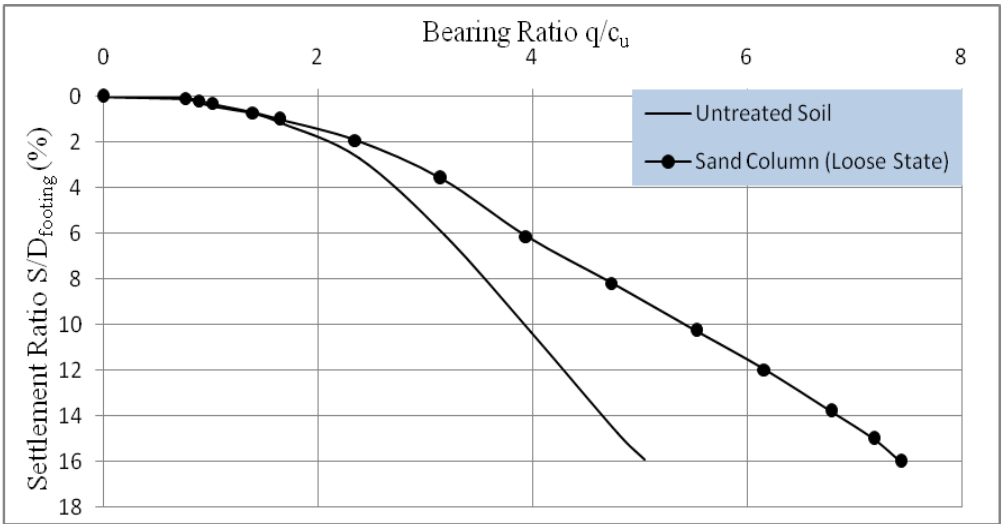

Figure (3) Bearing Ratio versus Settlement Ratio of Sand Columns.

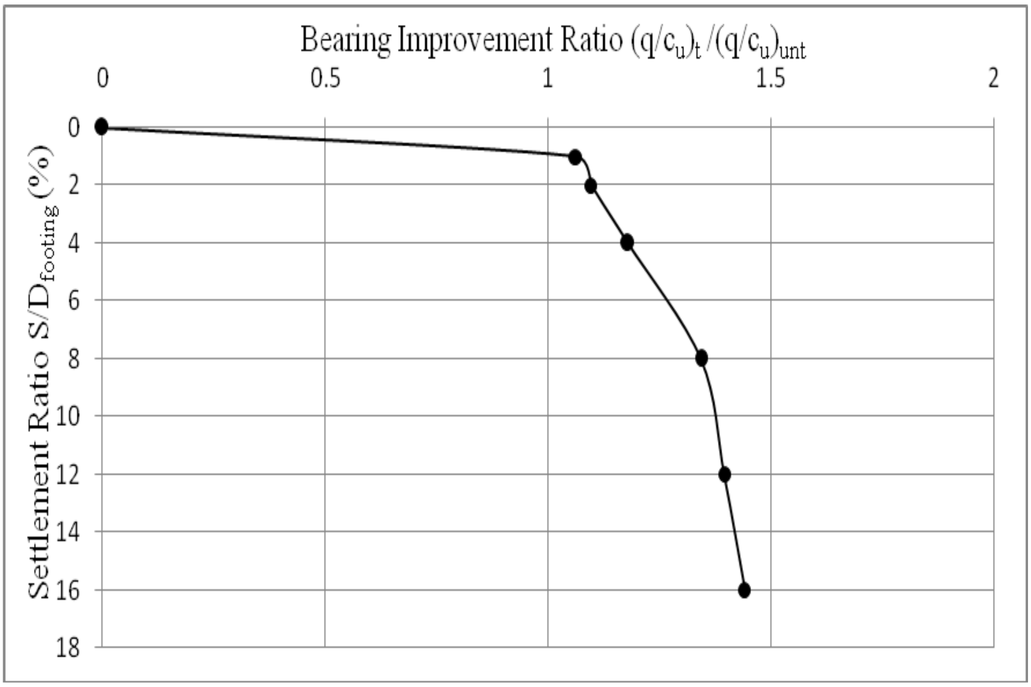

Figure (4) Bearing Improvement Ratio versus Settlement Ratio of Soft Soil Treated with Sand Columns.

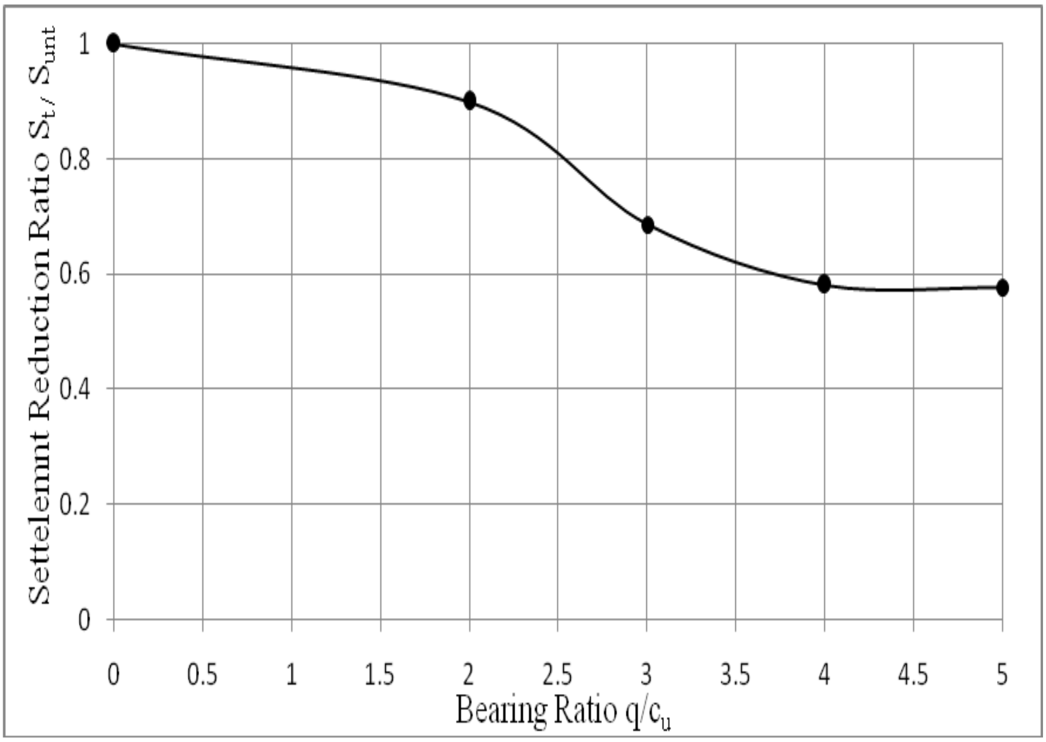

Figure (5) Settlement Reduction Ratio versus Bearing Ratio of Sand Columns.

Soil treated with sand –lime columns

Six model tests were performed on sand - lime column tested after seven days curing. Figure (6) shows q/c_u versus $S/D_{footing}$ for all percentages of lime used. Results of the untreated soil and soil treated with sand columns are also presented for comparison purposes. At stress increments $q/c_u \approx 2$, all models, untreated and treated models, exhibit approximately the same deformation indicating no significant influence of sand column or sand – lime columns. The bearing ratio q/c_u at failure ($S/D_{footing}$ =10%) are 5.4, 5.8, 6, 5, 4.5 and 4.8 for 1, 3, 5, 7, 9 and 11% lime respectively as shown in Table (4). It is clear that lime used does not provide satisfactory improvements, 5 % lime provided the maximum improvements in bearing ratio and any extra lime percent over this percentage generate a reverse action.

This discussion is also supported by bearing improvement ratio $(q/c_u)_t$ /$(q/c_u)_u$ versus settlement ratio $S/D_{footing}$ in Figure (7). The results illustrate peak values in $(q/c_u)_t$ /$(q/c_u)_u$ at $S/D_{footing}$ =1% then gradually decreases followed by a second increase close to failure. The bearing improvement $(q/c_u)_t$ /$(q/c_u)_u$ =1.4, 1.5, 1.55, 1.29, 1.17 and 1.25 for 1, 3, 5, 7, 9 and 11% lime respectively at failure ($S/D_{footing}$ =10%).

Variation of settlement reduction ratio S_t /S_u versus bearing ratio q/c_u is shown in Figure (8). The figure indicates that, there is a general decreasing trend in settlement reduction ratio with increasing bearing ratio. The 5% lime content is found to be most efficient content in providing a minimum value of settlement reduction ratio of 0.49. The settlement reduction ratio S_t /S_u =0.57, 0.49, 0.49, 0.64, 0.73 and 0.69 for 1, 3, 5, 7, 9 and 11% respectively at q/c_u =5 as summarized in Table (4).

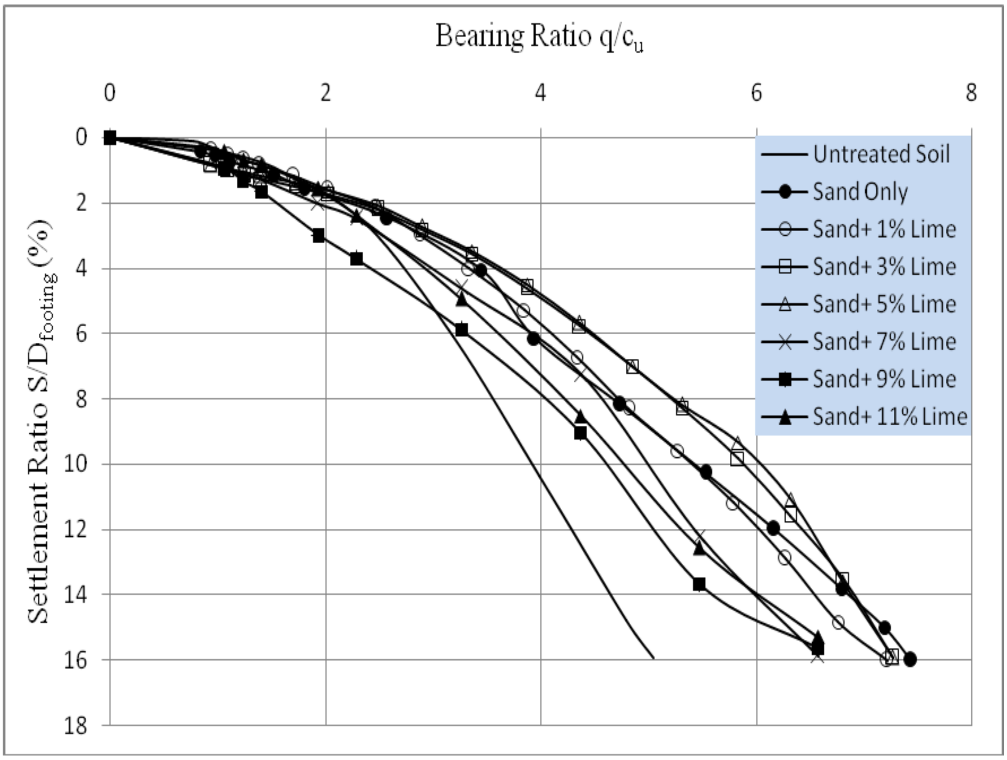

Figure (6) Bearing Ratio versus Settlement Ratio of Sand Columns Treated with Lime.

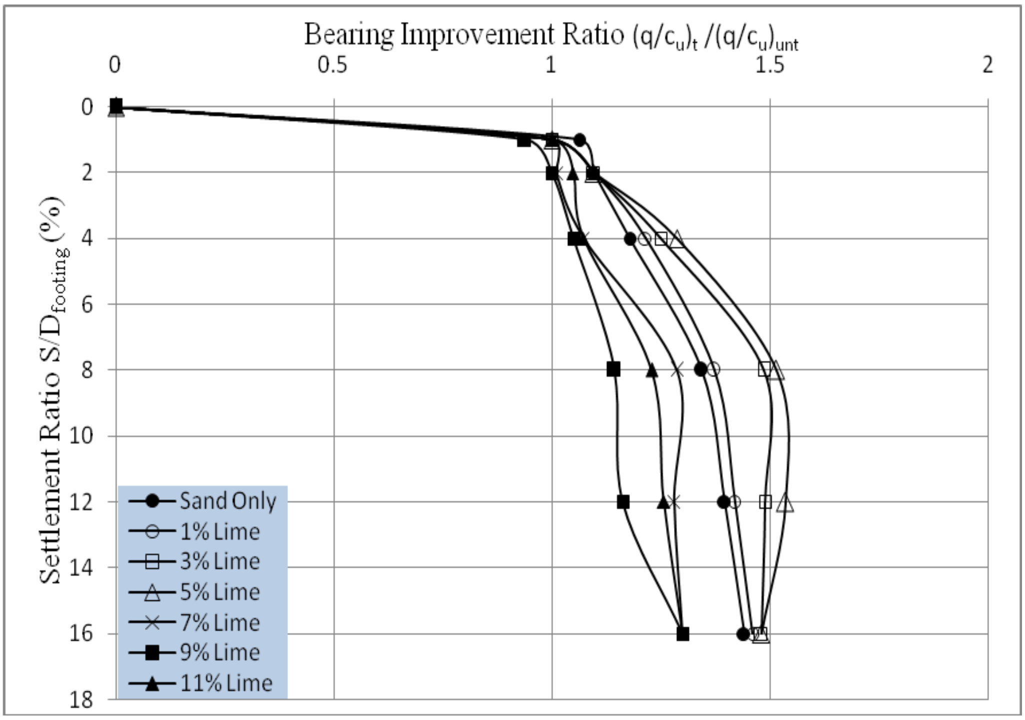

Figure (7) Bearing Improvement Ratio versus Settlement Ratio of Sand Column Treated with Lime.

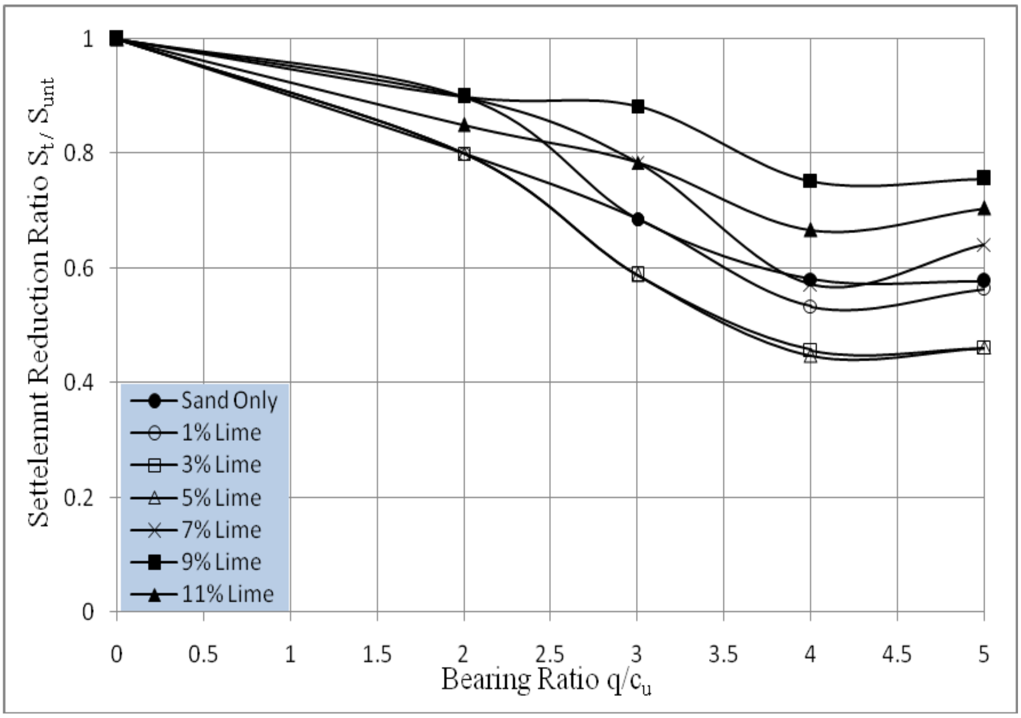

Figure (8) Settlement Reduction Ratio versus Bearing Ratio of Sand Column Treated with Lime.

Table (4) Summary of Test Results at Failure.

	q/c_u	$(q/c_u)_t /(q/c_u)_u$	S_t /S_u
Untreated Soil	4	---	---
Sand Only	5.4	1.38	0.58
Sand +1% Lime	5.4	1.4	0.57
Sand +3% Lime	5.8	1.5	0.49
Sand +5% Lime	6	1.55	0.49
Sand +7% Lime	5	1.29	0.64
Sand +9% Lime	4.5	1.17	0.73
Sand+11% Lime	4.8	1.25	0.69

CONCLUSIONS

The following points are drawn from the models tests. It is worth to mention that the values obtained for bearing improvement ratio and settlement reduction ratio are limited to the type of lime used in the tests.

- The bearing improvement ratio and settlement reduction ratio achieved by the sand columns are 1.42 and 0.58 respectively.
- Optimum lime content in sand – lime columns is 5 %, providing bearing improvement ratio and settlement reduction ratio of 1.55 and 0.49 respectively.

REFERENCES

[1]. Bergado, D.T., Anderson, L.R., Miura, N. and Balasubramaniam, A.S., "Soft Ground Improvement in Low Land and Other Environments.", ASCE press, (1996), New York, USA. 427 pp.

[2]. Federal Highway Administration, FHWA, "Design and Construction of Stone Columns.", Vol. 2, Report No. FHWA/RD-83/26, Washington, (1983).

[3]. Mitchell, J.K., "Soil improvement, state of the art report.", general report 12, proceedings, 10th International Conference on Soil Mechanics and Foundation Engineering, Vol.4, (1981), Stockholm, Sweden pp. 509-565.

[4]. Aboshi, H., Ichimoto, E., Enoki, M. and Harada, K., "The Composer, A Method to Improve Characteristics of Soft Clays by Inclusion of Large Diameter Sand Columns.", Proceedings International Conference on Soil-Reinforcement, Proc. Int. Conf. soil reinforcement ENPC paris , (1979), 1 pp 211-216.

[5]. Al-Zuhairi, A.H.A., "The Use of Sand Columns to Improve Soft Soil", M.Sc. thesis, University of Baghdad, (2000).

[6]. Al-Gharbawi, A.S.A., "Lime Stabilization of Sand Columns in Soft Soils.", M.Sc. Thesis, Building and Construction Engineering Department, University of Technology, Baghdad, (2013).

[7]. ASTM, "Soil and Rock (I). ", Vol. 04.08, (2003).