Treatment of Soft Soil by Sand Columns

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ABSTRACT:

Stone or sand columns are most widely used to improve the engineering properties of soft saturated soils. In principles, sand columns technique is very close to the well-known stone columns technique and the only difference is the backfill materials.

The present work focuses on implementing sand columns in soft soil of different diameters, different relative densities considering both floating and end bearing types.

The model tests were performed inside a steel container (600mm x 600mm and 500mm in height). Sand columns of diameters ranging between 22mm to 50mm were constructed in beds of soil of undrained shear strength ranging between (15-20) kPa. Each individual sand column was loaded vertically through a rigid circular footing of diameters between 28.6mm to 64.7mm provided an area replacement ratio (a_s) of (0.6),the ratio of column depth to the column diameter (L/D) was (6).

The model test results revealed good improvements of the load carrying capacity of the columns ranging between (1.3 to 1.9) and significant reduction in the settlement over the untreated soil ranging between (0.18 to 0.47). End bearing columns exhibited better results than floating columns and the diameter of column has no effect on bearing capacity as the (a_s) and (L/D) are constants.

Keywords: Sand columns, soft soil, floating, end bearing.

معالجة التربة الطينية الضعيفة بواسطة الأعمدة الرملية

الخلاصة:

تقنية الأعمدة الحجرية أو الأعمدة الرملية تستخدم بصورة واسعة لتحسين الخواص الهندسية للترب الطينية المشبعة الضعيفة. تتشابه الأعمدة الرملية من حيث المبدأ مع الأعمدة الحجرية والفرق الوحيد هو المواد المستخدمة في ملئ الأعمدة.

يركز البحث الحالي على غرز الأعمدة الرملية في تربة طينية ضعيفة وبأقطار مختلفة, بكثافات نسبية مختلفة مع الأخذ بنظر الاعتبار نوعية الأعمدة الطافية وأعمدة التحمل الطرفي.

أُجريتالنماذج المختبرية بداخل صندوق حديدي بأبعاد (600 ملم*600 ملم وبارتفاع 500 ملم). نُفذت الأعمدة الرملية بأقطار تتراوح بين 22 ملم الى 50 ملم بداخل تربة طينية ذات مقاومة قص غير مبزول يتراوح بين (15-20) كيلو باسكال. كل الأعمدة الرملية مفردة وحملت بطريقة عمودية بواسطة

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أساسات دائرية صلبة تتراوح أقطارها بين 28.6 ملم الى 64.7 ملم مع الأخذ بنظر الأعتبار تثبيت نسبة المساحة الأستبدالية تساوي (0.6),نسبة طول العمود الى قطره تساوي (6).
أظهرت نتائج الفحوصات المختبرية تحسين جيد لقابلية التحمل يترواح بين (1.3 الى 1.9) وتقليل ملحوظ للهطول يتراوح بين (0.18 الى 0.47), أعمدة التحمل الطرفي افضل من الاعمدة الطافية, لايؤثر قطر العمود على قابلية التحمل في حال تثبيت نسبتي المساحة الأستبدالية وطول العمود الى قطره.

INTRODUCTION

Stone columns technique is widely used in different parts of the world to improve the engineering properties of soft saturated cohesive soils. Soft soils are identified by their low undrained shear strength (c_u< 40 kPa) and high compressibility (c_c ranging between 0.19- 0.44) ***(***Brand and Brenner, 1981). As an alternative, sand compacted columns were introduced initially by the Japanese as reported by (Aboshi et al., 1979).

The prime function of the granular columns (stone or sand) is to increase the stiffness of the composite soil and hence improving the bearing capacity and controlling the compressibility. Furthermore the stone columns act as drains to accelerate the consolidation process. On the other hand, sand columns are used as alternative technique to the stone columns.

Both techniques provide improvements in terms of bearing capacity and compressibility when implemented in soft saturated soil. The efficiency of the two techniques varies depending on many factors such as field condition, type of structure, availability of materials…etc.

The sand columns have been used increasingly during the past four decades as an alternative to the traditional stone columns ***(***Juran and Riccobono, 1991). The bearing capacity and settlement of soft soil reinforced with sand columns depend on several factors such as area replacement ratio, dimensions and pattern of installation of sand columns in the field, the amount and rate of load application and the placement conditions of the backfill materials as this plays the major role in providing the stiffness of the columns. The technique is most effective in clayey soils with undrained shear strength ranging from 15-50 kP a(Barksdale and Bachus, 1983; Juran and Guermazi, 1988). However, it becomes unfeasible in more compressible soils, which do not provide sufficient lateral confinement.

Aim of Study

The present article aims to evaluate the improvements in load carrying capacity and settlement reduction ratio of sand columns with different diameters, different relative densities and the investigation considered floating and end bearing types of columns.

Experimental Investigation:

Selection of soil

A brown clayey soil was brought from Al-Nahrawan city (35 km east of Baghdad city). Standard tests were performed to determine the physical and chemical properties of the soil and the details are given in Table (1). The soil consists of 16% sand, 34% silt and 50% clay. According to the Unified Soil Classification System, it is classified as (CL) soil.

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)	0.5
Specific Gravity (Gs)	2.69
Gravel (%) (G)	0
Sand (%) (S)	16
Silt (%) (M)	34
Clay (%) (C)	50
Classification (USCS)	CL
Calcium Oxide (CaO) (%)	0.36
Total Dissolved Salt (TDS) %	1.02
SO_3 Content (%)	0.52
Organic Material (O.M.) %	0.39
pH value	9.17

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

Sand

The sand was brought from Al-Akhedhar city (152 km south west of Baghdad city). Standard tests were performed to determine the physical and chemical properties of the sand, and the details are given in Table (2). The soil used as backfill materials consists of 10% gravel, 89.5% sand and 0.5% fines. According to the Unified Soil Classification System, it is classified as well-graded sand (SW).

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
Dry unit weight (kN/m^3) at D_r=15% and 70% respectively	17 and 19.1
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)	10
Sand (%) (S)	89.5
Fines (%)	0.5
Classification	SW
Specific Gravity (Gs)	2.65
Total Dissolved Salt (TDS) %	0.3
SO_3 Content %	0.15
Organic Material (O.M) %	0.09

Experimental Setup for load test
Steel Container

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

Model Footing

Circular steel model footings with diameters 28.6, 43.4, 54.6 and 64.7 mm and 10mm in thickness were 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).

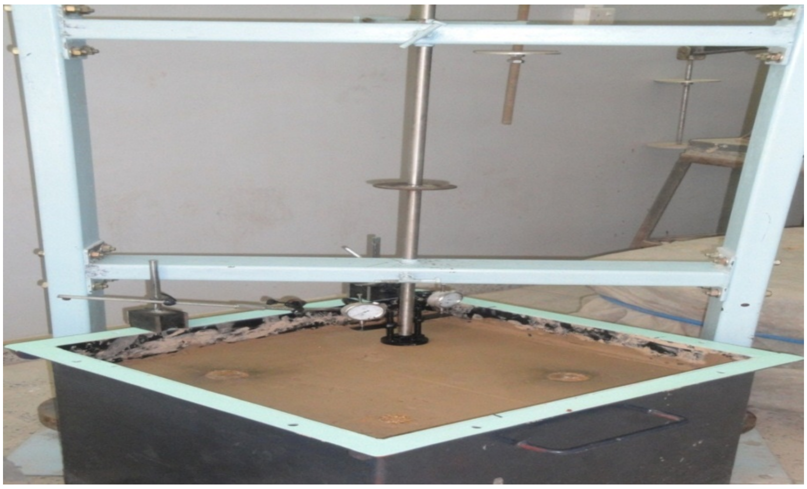

Figure (1):The frame of loading and the steel container

Preparation of soft clay bed

Beds of fully saturated soil were prepared at undrained shear strength between 15 to 20kPa. This value was achieved after several trials of drying and mixing the soil and water with continuous measurements of undrained shear strength. The undrained shear strength was measured after every test for all models by the vane shear device. 225 kg of natural soil was mixed with enough quantity of water to get the desired consistency; each 25 kg of dry soil was mixed separately till completing the whole quantity.

The soil was placed in layers with a thickness ranging between (50-75) mm for each layer, each layer was leveled gently using a wooden tamper, and then the leveled layer was tamped gently with a metal hammer of 9.87 kg and dimension of (150 x 150) mm in order to remove any entrapped air. This process continues for each layer till reaching a thickness of 400 mm of soil in the steel container for floating models and 300 mm for end bearing models.

After completing the final layer, the top surface was scraped and leveled to get as near as possible a flat surface, then covered with polythene sheet to prevent any loss of moisture. A wooden board of similar area to that of the surface area of bed soil (600 x 600) mm was placed on the bed of soil. The bed of soil was applied to setting pressure of 5 kP a for 24 hours to regain part of its strength.

Installation of Sand Columns

To install the sand columns correctly in their proper locations, the steel container was divided into four zones; each zone has area (300 x 300) mm. A hole was made at the center of each zone. The construction procedure of the sand columns starts directly after the preparation of the bed of soil. The depth of each column was predetermined (corresponding to L/D=6). A PVC pipe was pushed down into the bed to the specific depth and perpendicular on the bed surface; floating columns resting on the bed of soil while end bearing columns resting on the bottom of the steel container. To remove the soil inside the PVC pipe, a hand auger was used; after that the PVC pipe was removed gently. The sand was carefully put into the hole in three layers to achieve a unit weight of 17kN/m^3 (D_r=15%) just by adding by funnel for loose columns, while dense sand columns were put into the hole in five layers and compacted using 44 mm diameter rod to achieve a unit weight 19.1 kN/m^3 (D_r=70%) by a tamping rod. Following the completion of the construction of the columns, the loading system was placed and fixed in position and the footing was incrementally loaded with continuous measurements of the footing up to failure.

After completion of every test, the bulged shapes around the columns were observed and measured. Shelby tubes were inserted into the bed of soil and then the soil around the column was carefully scooped out and the columns cut to two halves using very thin wire and the bulged shapes at the end of the tests were inspected and measurements were recorded by the vernier along the columns.

Results and Discussion of Model Tests:

In all model tests, failure was defined as the stress required to generate settlement corresponding to 10% of model footing width depending on the proposal given by (Terzaghi, 1947) as cited by (Brand and Brenner, 1981).

The analysis of results of all model tests regarding the applied stress and the corresponding settlement is illustrated in terms of (q/c_u) vs. ($S/D_{footing}$). The (q/c_u) represents the ratio of applied stress to undrained shear strength of the bed of saturated soft clay, denoted as "bearing ratio" and ($S/D_{footing}$) represents the corresponding vertical settlement as a percent of the model footing diameter, denoted as "settlement ratio".

To obtain the degree of improvement achieved by each improvement technique, the results are plotted in the form of non-dimensional ratio $(q/c_u)_t/(q/c_u)_{unt}$which is the bearing ratio of treated soil to the bearing ratio of untreated soil denoted as "bearing improvement ratio", plotted against the settlement ratio ($S/D_{footing}$).

The reduction in settlement achieved by the model tests are presented in the form of (S_t/S_{unt}) which is the settlement of treated soil to the settlement of untreated soil at the same applied stress denoted as "settlement reduction ratio", plotted against the bearing ratio (q/c_u).

Bearing ratio and bearing improvement ratio

Untreated soil

In this series of tests, two footing diameters 64.7 mm and 28.6 mm were selected and loaded individually on a bed of soft saturated soil. Figure (2) illustrates the variation between the applied vertical stress q in (kPa) versus settlement S in (mm). The tested models demonstrate close results for bearing pressure at failure of 64.5 kPa and 66 kPa for footing diameters 64.7 mm and 28.6 mm respectively corresponding to the settlement ratio ($S/D_{footing}$) of 10%. The results comply well with theoretical bearing capacity theories where the failure stress is not a function of the footing size when the soil is fully saturated clay and tested under undrained condition.

This argument is better observed in Figure (3) where the bearing ratio q/c_u is plotted against settlement ratio ($S/D_{footing}$) and the curves are almost matching together with no significant difference. The bearing ratios q/c_u at failure are 4.08 and 4.18 for footing diameters 64.7 mm and 28.6 mm respectively which comply well with theoretical N_c value. N_c value ranging from 4 to 6.28 for saturated soil with Ø=0 at undrained condition.

Based on the above results, it was decided to select the model footing of 64.7 mm diameter as a reference to estimate the degree of improvement gained after introducing any type of reinforcement into the bed of soil.

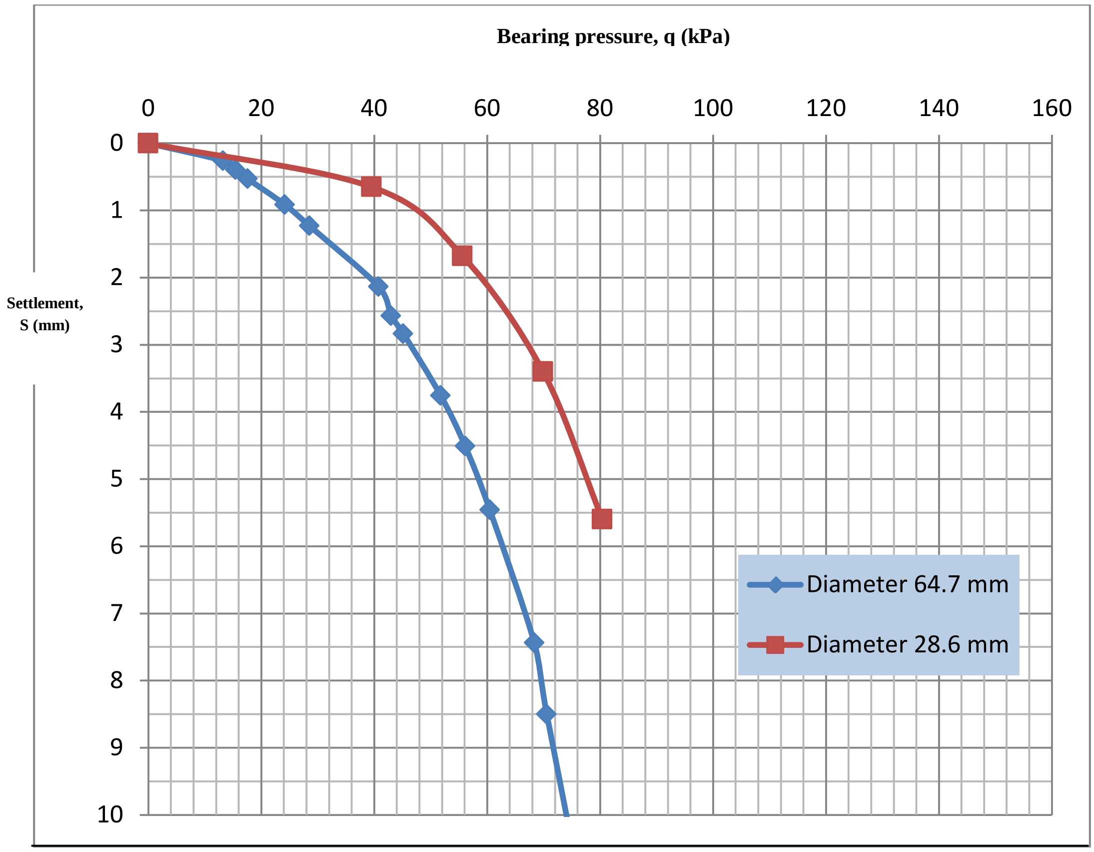

Figure (2): Bearing pressure versus settlement for untreated soil with different footing diameters.

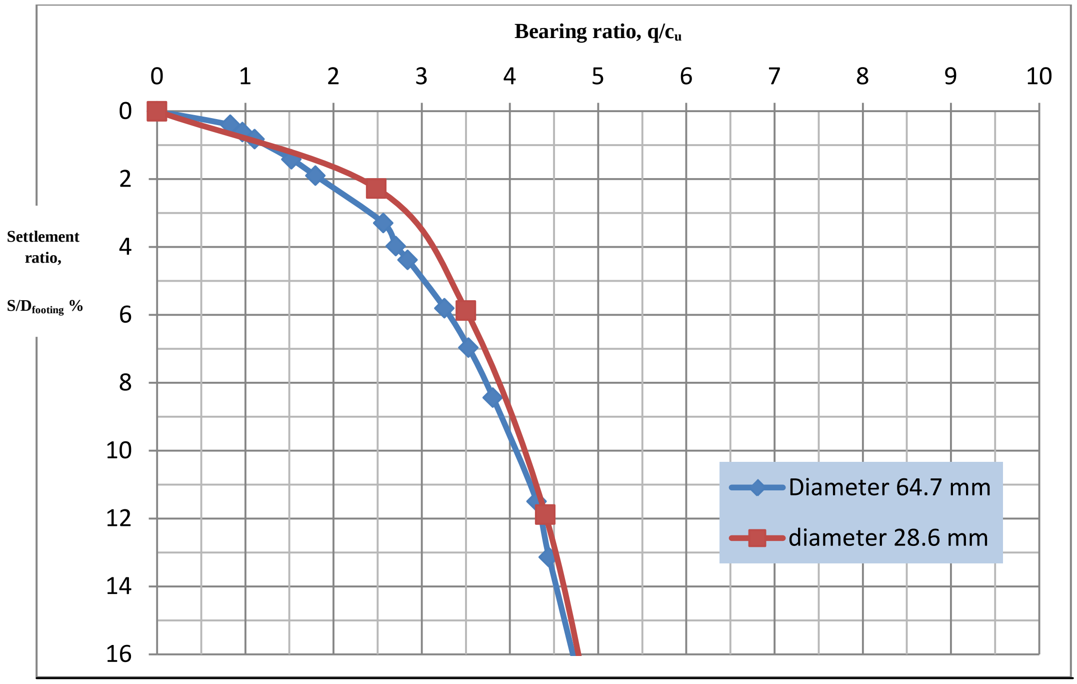

Figure (3): Bearing ratio versus settlement ratio for untreated soil with different footing diameters.

Soil treated with sand columns

Four floating type models were performed on bed of saturated soil. Model footing diameters 28.6 mm, 43.4 mm, 54.6 mm and 64.7 mm were used with corresponding column diameters of 22 mm, 33.6 mm, 42.3 mm and 50 mm respectively keeping the area replacement ratio=0.6 and L/D=6.

Figure (4) shows the relationship between the vertical stress plotted against the settlement for each sand column diameter. The bearing capacity at failure(which is the stress required to generate settlement corresponding to 10% of model footing diameter) for each sand column is (83, 79, 81 and 81) kPa for the sand columns with diameters (22, 33.6, 42.3 and 50) mm respectively. The test results indicate close results with no more 2.5% difference from average of the four tests.

The results are better observed in Figure (5) where the bearing ratio q/c_u is plotted against settlement ratio for each sand column diameter and the curves are almost matching with slight difference. The bearing ratio at failure for each sand column is (5.22, 4.97, 5.1 and 5.1) for the sand columns with diameters (22, 33.6, 42.3 and 50) mm respectively. The results indicate very close results with not more 2.6% difference from average of the four tests.

Based on the above results, the diameter of the column has no effect on bearing capacity of the cohesive soil with constant L/D and a_s, it was decided to select the 50 mm column diameter and 64.7 mm footing diameter for the rest of all models.

Four other model tests of 50 mm column diameter at different relative densities and different types of columns (floating and end bearing)were repeated to get more comprehensive picture about sand columns in soft soil.

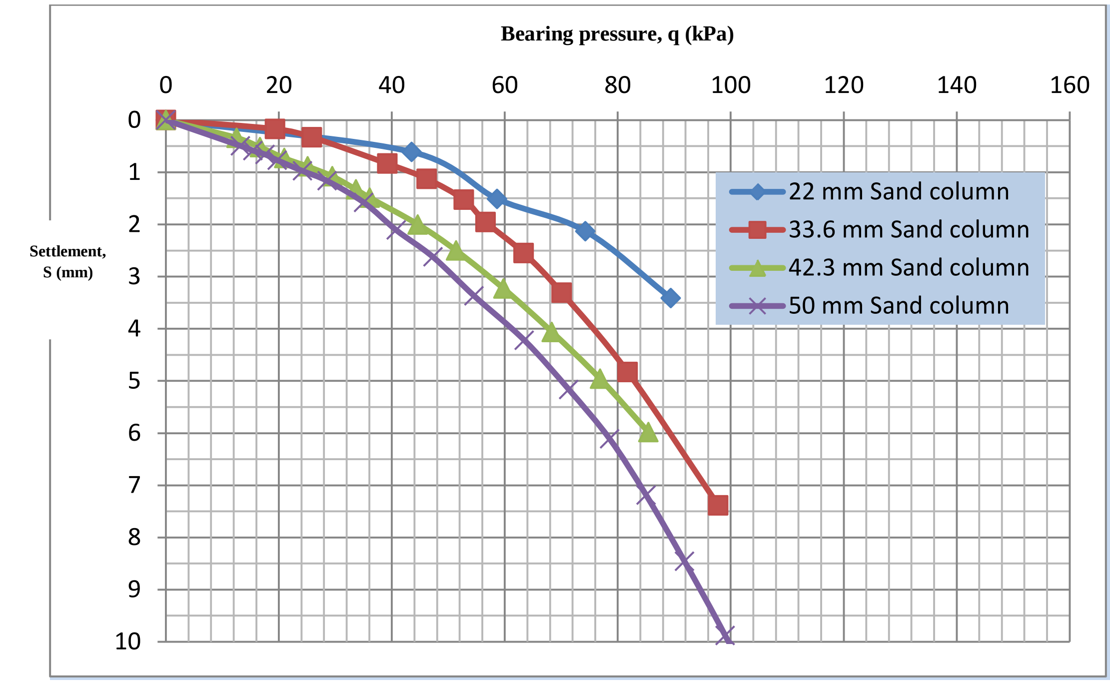

Figure (4): Bearing pressure versus settlement for soil treated with floating sand columns at loose relative density (γ=17 kN/m³) with different diameters.

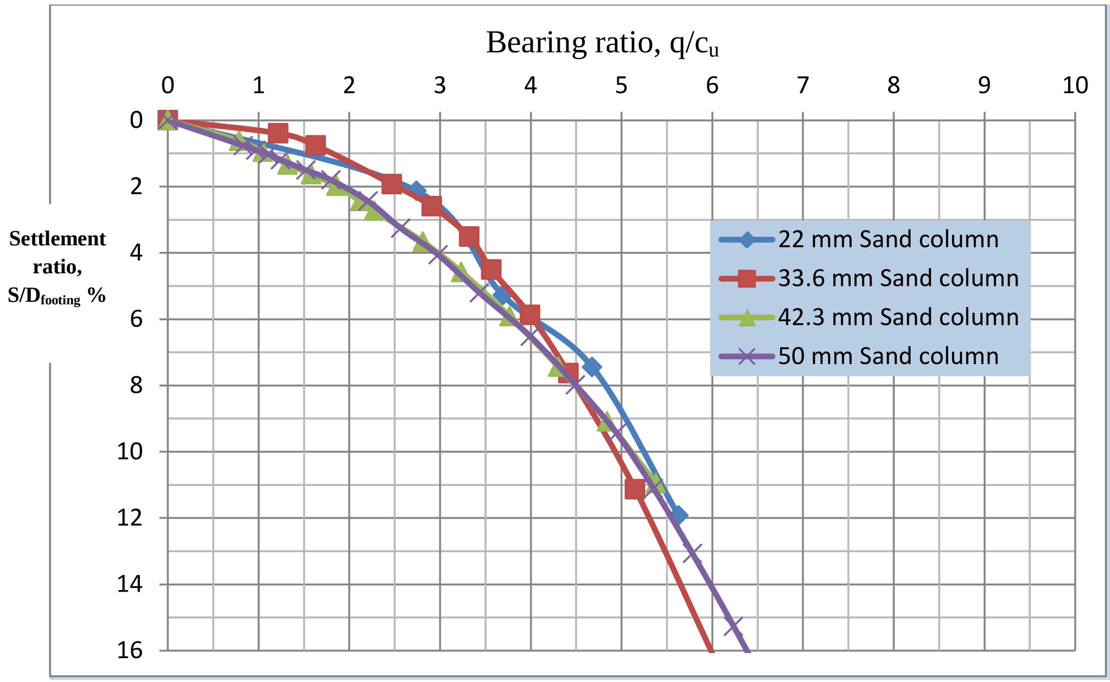

Figure (5): Bearing ratio versus settlement ratio for soil treated with floating sand columns at loose relative density (γ=17 kN/m³) with different diameters.

Figure (6) shows the relationship between the bearing ratio plotted against the settlement ratio for both floating and end bearing sand columns. The Figure illustrates that bearing ratio for end bearing columns generate less settlement ratio than floating columns; dense columns generate less settlement ratio than loose columns. The bearing ratios at failure for floating columns are 5.4 and 6.8 for loose and dense columns respectively, for end bearing columns are 6.1 and 7.7 for loose and dense columns respectively.

Figure (7) illustrates the deformations measured at the end of the test for floating sand columns. Great effort was made to get these cross sections of the sand columns. The measurements indicate the development of maximum bulge along the upper quarter, then gradually decrease with increasing depth and vanish at about two third the columns depth. Dense sand experienced large bulge size due to dilatancy as compared to the bulge size of the loose state sand column.

Figure (8) illustrates the deformations measured at the end of the test for end bearing sand columns. The measurements indicate the development of maximum bulge for loose column occurred close to the top of the sand column, then gradually decreases with increasing depth and vanishes at about 80% of the length of the column depth while the maximum bulge for dense column occurred at about third of the column depth, then gradually decreases with increasing depth and vanishes at about 60% of the length of the column depth. The magnitude and location of the failure angle were measured approximately and they are 31° at 175 mm from top surface for loose column, 30° at 130 mm from top surface for dense column.

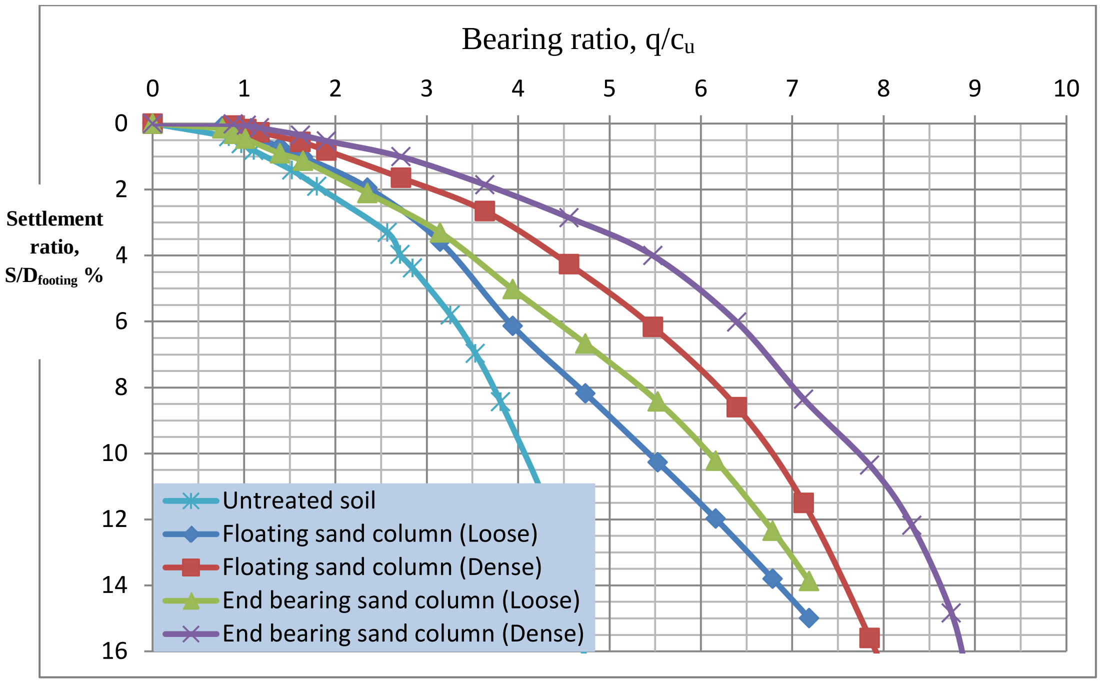

Figure (6): Bearing ratio versus settlement ratio for soil treated with floating sand columns and end bearing sand columns.

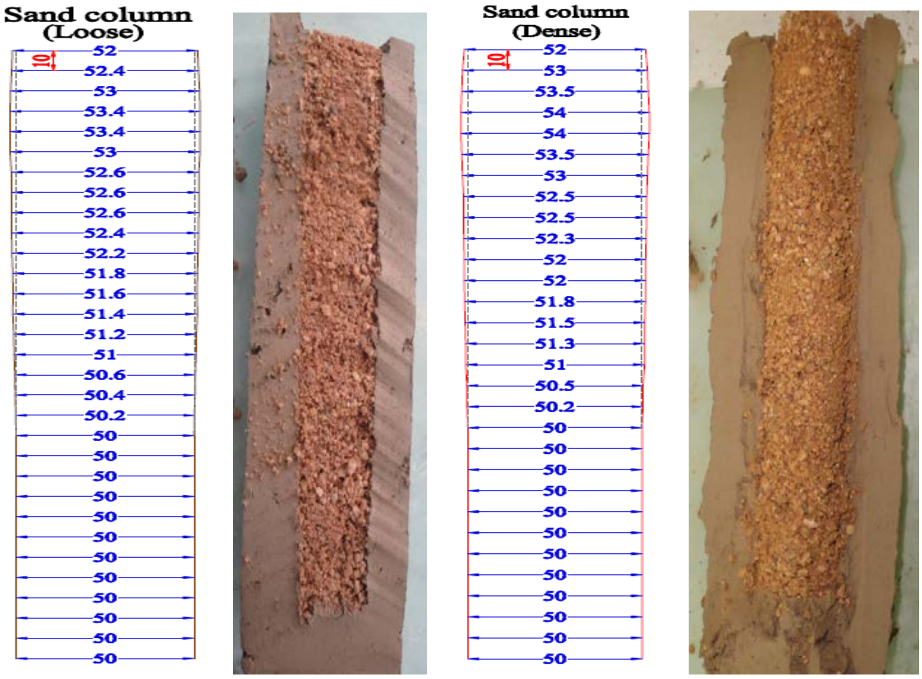

Figure (7): The deformation of floating sand columns at the end of test (all dimensions in mm).

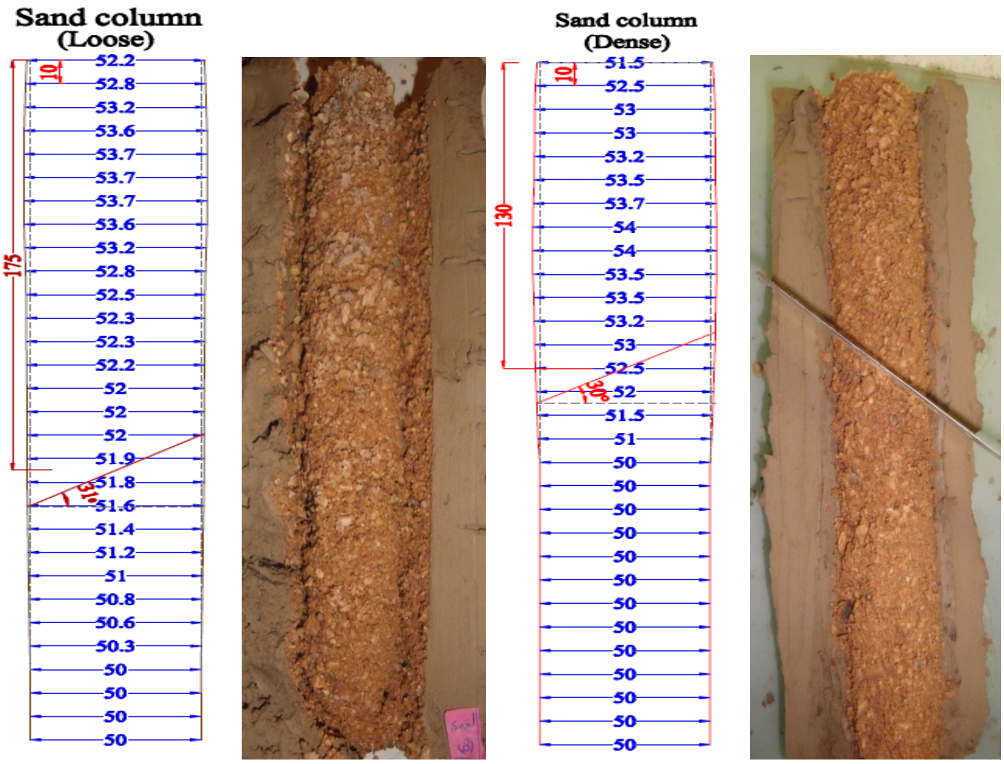

Figure (8): The deformation of end bearing sand columns at the end of test (all dimensions in mm).

To evaluate the amount of improvement achieved by the floating and end bearing sand columns configuration over untreated soil, the bearing improvement ratio $(q/c_u)_t$ / $(q/c_u)_{unt}$ versus settlement ratio $(S/D_{footing})$ is presented in Figure (9). Peak values of improvement ratio for both types of columns are observed at nearly $(S/D_{footing})$ =1%, followed by slight decrease and then remain nearly constant till the end of the test. The bearing improvement ratios at failure for floating columns are (1.3) and (1.7) for loose and dense columns respectively, for end bearing columns are (1.5) and (1.9) for loose and dense columns respectively.

Figure (10) shows the variation of settlement reduction ratio S_t/S_{unt} versus bearing ratio q/c_u for models tested with floating sand column and end bearing sand column. The results demonstrate a drop in settlement reduction ratio at bearing ratio 0.5 for both types followed by a gradual increase with increasing q/c_u. Maximum values of S_t/S_{unt} are achieved at nearly q/c_u=2.5. Then both types of tests exhibit a gradual decrease in settlement reduction ratio with increasing bearing ratio.

The settlement reduction ratios at failure for floating columns are (0.47) and (0.27) for loose and dense columns respectively, for end bearing columns are (0.38) and (0.18) for loose and dense columns respectively.

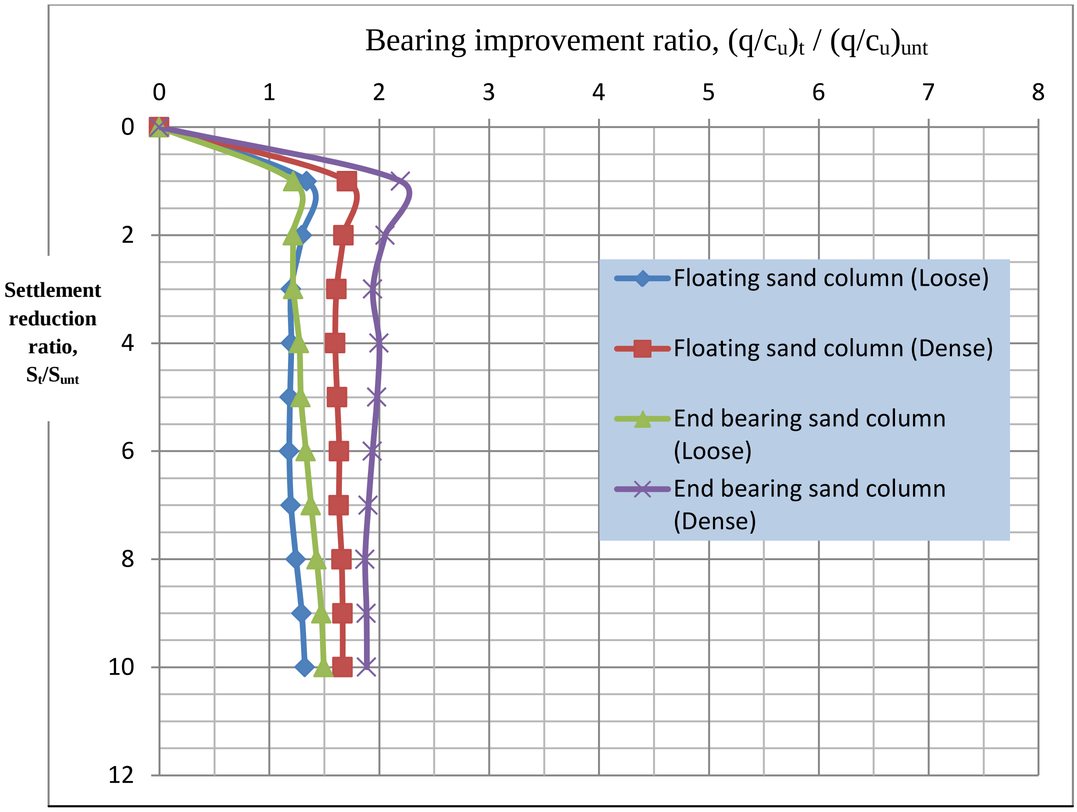

Figure (9):Bearing improvement ratio versus settlement ratio for soil treated with floating sand columns and end bearing sand columns.

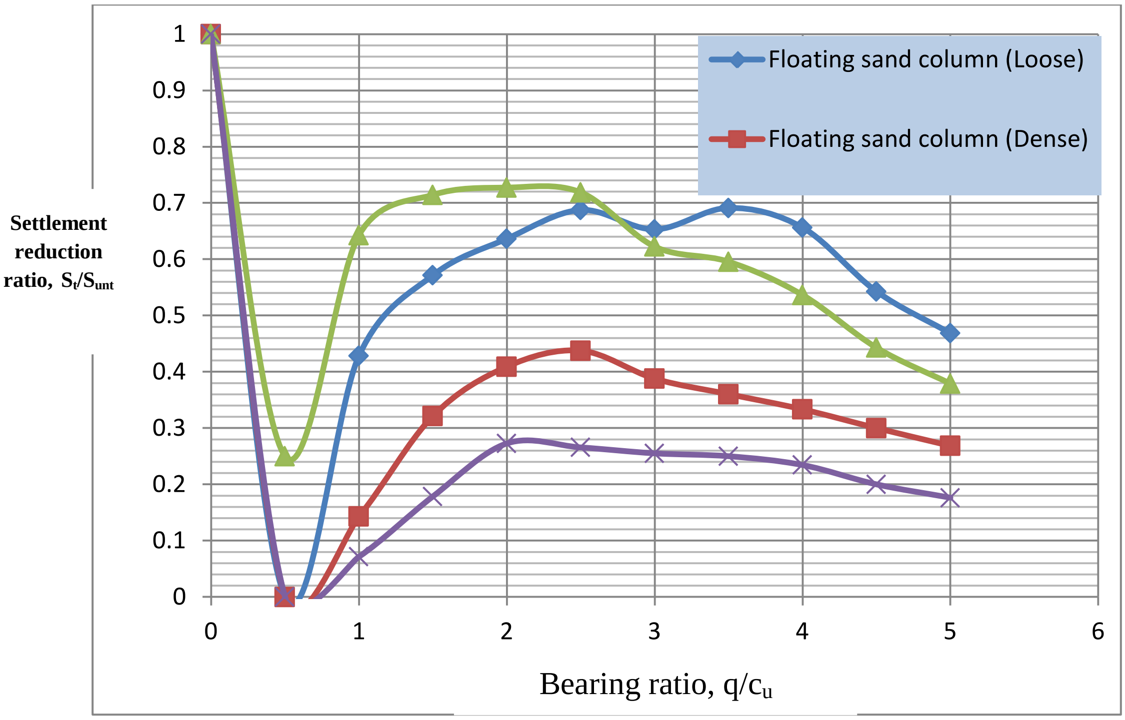

Figure (10):Settlement reduction ratio versus bearing ratio for soil treated with floating sand columns and end bearing sand columns.

CONCLUSION:

Based on analysis of 10 model tests performed on untreated soil and soil treated with sand columns performed at L/D=6 and a_s=0.6. The main outcomes are outlined below.

- Floating sand columns of different columns diameters (22, 33.6, 42.3 and 50) mm and corresponding footings diameters (28.6, 43.4, 54.6 and 64.7) mm exhibited close results in term of bearing ratio versus settlement ratio.
- Floating sand columns at loose state (Dr =15%) provided bearing improvement ratio 1.3 and settlement reduction ratio 0.47, and at dense state (Dr =70%) provided bearing improvement ratio 1.7 and settlement reduction ratio 0.27.
- End bearing sand columns at loose state (Dr =15%) provided bearing improvement ratio 1.5 and settlement reduction ratio 0.38, and at dense state (Dr =70%) provided bearing improvement ratio 1.9 and settlement reduction ratio 0.18.

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