Effect of Area Replacement Ratio on Bearing Capacity of Soil Treated With Stone Column

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تأثير نسبة المساحة المستبدلة على قابلية تحمل التربة المعالجة بالأعمدة الحجرية

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Abstract

This experimental study was conducted to demonstrate the relationship between the bearing improvement ratio (which is defined as the ratio between the bearing capacity of the soil treated with stone column to the bearing capacity of untreated soil at the same settlement level) or ($q_{treated}/q_{untreated}$) and the area replacement ratio (which is defined as the ratio between the area of cross-section of stone column and the area of soil surrounding it).

The investigation was carried out using model tests of stone column with different diameters (20, 30, 50 and 60 mm) or area replacement ratio (Ar) (0.042, 0.099, 0.333 and 0.563) performed inside the container with dimensions of 240 mm x 240 mm and in height of 260 mm. The undrained shear strength of the soil prepared in the containers ranged from 11 kPa to 22 kpa The study showed that the bearing improvement ratio were 1.16, 1.29, 1.64 and 2.29 for the soil having (cu = 16 kPa) treated with stone columns of (Ar = 0.042, 0.099, 0.333 and 0.563) respectively.

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الخلاصة

أجريت هذه الدراسة المختبرية لبيان العلاقة بين نسبة تحسين التحمل (والتي تعرف بأنها النسبة بين تحمل التربة المعالجة بالأعمدة الحجرية إلى تحمل التربة غير المعالجة بها عند نفس منسوب الهطول) وبين نسبة المساحة المستبدلة (والتي تعرف بأنها النسبة بين مساحة مقطع العمود الحجري إلى مساحة التربة المحيطة به).

تم هذا العمل الحالي باستخدام نماذج فحص لأعمدة حجرية بأقطار مختلفة هي (20 ، 30، 50 و 60 ملم) والتي تكافئ نسبة مساحة مستبدلة (Ar) (0.042 , 0.099 , 0.333 و 0.563) داخل حاوية بإبعاد 240 ملم * 240 ملم وبارتفاع 260 ملم. حضرت التربة المعالجة داخل الحاوية بمقاومة قص غير مبزولة (cu) تراوحت بين (11 kPa– 22 kPa).

لقد بينت هذه الدراسة بان نسب تحسين التحمل تساوي 1.16 و 1.29 و 1.64 و 2.29 في التربة ذات مقاومة القص (cu= 11 kPa) والمعالجة بالأعمدة الحجرية عند نسبة مساحة مستبدلة (Ar) مساوية إلى (0.042 و 0.099 و 0.333 و 0.563) على التوالي.

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Introduction

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 vibroreplacement method, the vibro-compaction method, the vibro-composer method and ramming by dropping hammer (15 to 20 kN). The effectiveness of the load redistribution to the columns mainly depends on the lateral support from the surrounding soft soil. The lateral support is expressed by means of the undrained shear strength. According to German regulations, the application of stone columns is generally limited to soils with undrained shear strength cu = 15 - 25 kN/m² (FGSV 1979). Stone columns are also occasionally used in very

soft soils with an undrained shear strength cu < 10 kN/m² (Raju 1997). Generally, however, there is a risk in installing stone columns in sensitive or organic soils [1].

For low-rise buildings and structures such as liquid storage tanks, abutments, embankments, and factories that can tolerate some settlement, stone columns (also known as granular piles or granular columns) provide an economical method of support in compressible and fine-grained soils. Stone columns are either constructed as fully penetrating through a clayey soil layer overlying a firm stratum or as floating (or partially penetrating) with their tips embedded within the clayey soil layer[2].

Ref. [3], performed seven field tests in Baghdad city to investigate the bearing improvement ratio and the settlement reduction ratio in case of ordinary stone column and when reinforcement of steel discs is used in the upper part of the column. The tests were carried out with area ratio of (0.042) to (0.18). The results showed that addition of reinforcement in the upper half revealed an improvement of bearing ratio of (0.16) and (1.78) for two and three discs of reinforcement with corresponding sttlement reduction ratios of (0.25) and (0.2), respectively .

Ref. [4]developed a numerical model, based on a two dimensional finite element technique. The model is capable to identify the different mode of failures of single and group of stone columns for a given columns/soil/loading condition. In these cases, group interactions were examined and evaluated. Parametric study was conducted on the parameters believed to govern this behavior. The results produced in this study showed that ground reinforced by group of stone columns may fail by general, local or punching shear failure, depending on geometry of the group and properties of the surrounding soils.

Ref. [5] found from finite element study that the bearing improvement ratio (q treated / q untreated) increases with increase in the area replacement ratio (Ar) for both ordinary and encased stone columns, the increase in (Ar) is more efficient for encased stone column than ordinary stone column especially when (Ar) is more than 0.25 .

Ref. [6] carried out a series of numerical analysis to evaluate bearing capacity and settlement of a strip footing resting on soil reinforced by a group of stone columns. It is found that the bearing improvement ratio or (BCR) values depend mainly on footing width. In certain replacement ratios, with increase in footing width, a decrease in BCR taken place. With increasing replacement ratio, a decrease taken place in the effect of footing width on BCR .

Experimental Work

The model tests were carried out in a test tank of size, 240 mm * 240 mm * 265 mm. Granite stone chips were used for the formation of stone columns. The load tests were carried out using Multispeed frame of Unconfined test machine with electronic load cell (50 kN), displacement transducer (50 mm) and 5 channels digital unit as shown in figure (1). Load test were carried out on single stone columns with various diameters (20 mm, 30 mm, 50mm, and 60 mm). The test were conducted in soft clay soil with different shear strength 11 kPa, 16 kPa and 22 kPa.

Mild steel footing plate of 100 mm in diameter , were placed over column and this column supported plate were loaded during the load test. Granite stone chips of sizes varying from 1 to 12 mm were used in constructing the column.

Soil Used

Clay soil samples were collected from depths of 0.50 m to 2.00 m of the ground surface in a site north of Babylon in Iraq. 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 specifications[7].

2- Atterberg limits (liquid and plastic limits) according to ASTM D423 and D424 specifications[7].
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.

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

Property	Value
Liquid limit (LL)	44%
Plastic limit (PL)	22%
Plasticity index (PI)	22%
Specific gravity (G_S)	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

Preparation of The Soil bed

The soil used in test was mixed with specified quality of water to get the preferred shear strength that varied from 11 to 22 kPa . The soil was packed carefully in layers of thickness of about 40 mm or in six layers to reach the final height of 260 mm and after the placement of each layer, it was pushed lightly to remove the entrapped air. As the soil bed was formed conforming to very soft to soft undrained shear strength, there was no difficulty in forming a homogeneous soil bed. The uniformity in the soil bed was checked by measuring the density at various stages of the soil bed formation, typical formation and a typical density of 18.50 kN/m^3 were obtained.
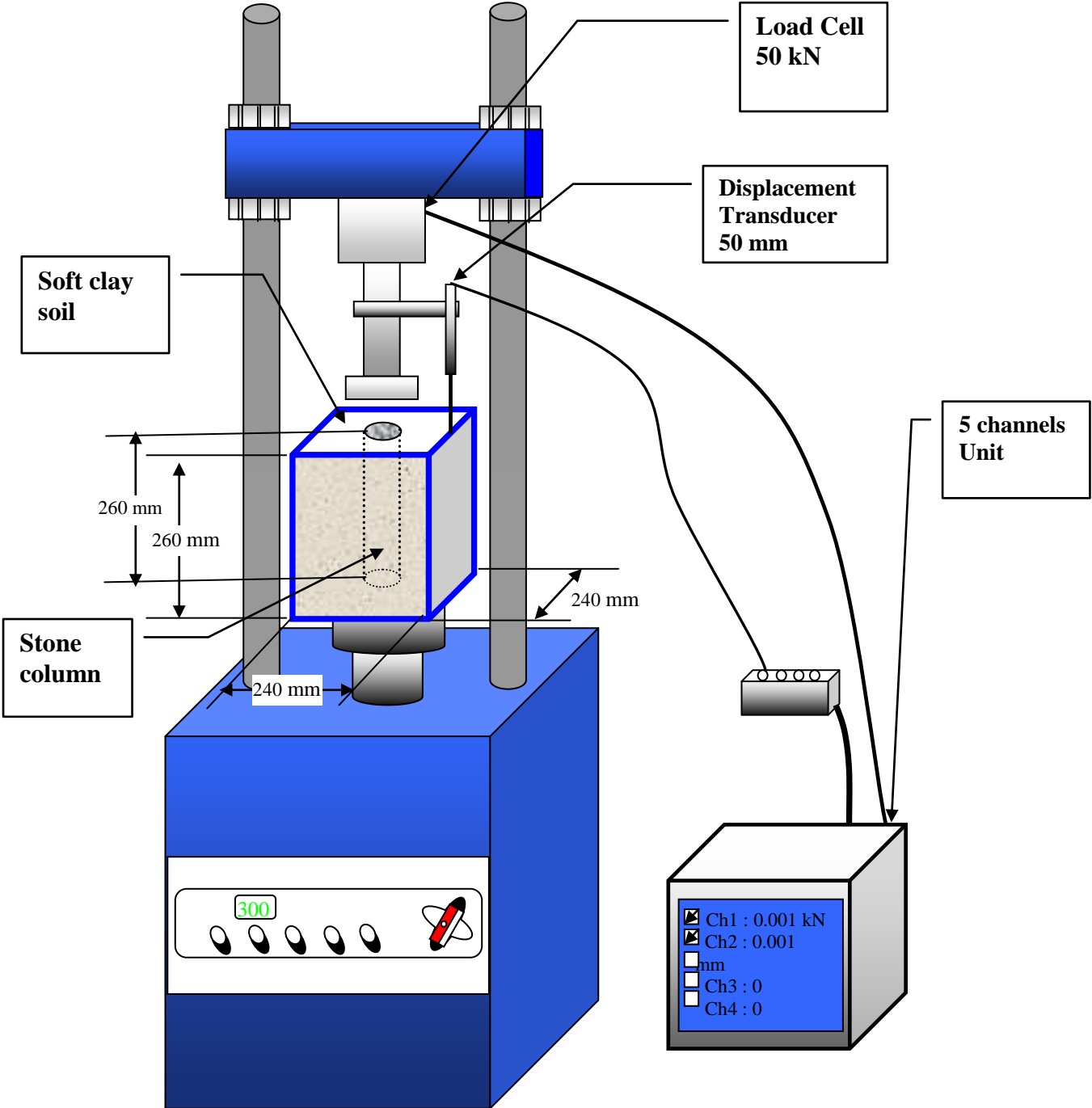
Figure (1): The Loading frame and the accessories

Installation of the stone column

1. The position of the stone column to be constructed was properly marked on the center of the mould(container) of the tests.
2. A hollow PVC tube, with various diameters (20 mm, 30 mm, 50mm, and 60 mm), coated with petroleum jelly was inserted vertically to the required fully penetrated depth (260 mm)
3. The soil inside the PVC tube was removed by the auger for each diameters of stone column excepted 20 mm.
4. The tube was slowly withdrawn and twisted during the lifting process.
5. The crushed stone was poured into the hole and compacted to gain the density about of   kN/m^3 (figure 2).

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a   b

Figure (2) : **Installation of the stone column**

Testing Program

Fifteen experimental tests were conducted as follows

1-Five model tests for soil having shear strength, cu= 11 kPa, including the following cases.
a- Single model test for untreated soil
b- Four model tests for soil treated with a stone column of various diameters 20,30,50 and60 mm.
2- Five model tests for soil having shear strength, cu= 16 kPa, including the same model test in item 1.
3- Five model tests for soil having shear strength, cu= 22 kPa, including the same model tests in items 1 and 2.

Model Testing Procedure

1. The footing plate attached with electronic load cell was located on the center of soil bed.
2. The displacement transducer were placed on the outer edge of the mould of test to measure the settlements of plate (figure 1)..
3. In purpose of measuring the applied load on footing and its settlement, the electronic load cell and the displacement transducer were connected to five channels unit(figure 1).
4. The loads were applied , through multispeed loading frame in increment of   20 N i.e. the loading test was carried out according to stress controlled style.
5. The displacement transducer readings were recorded for each load increments by electronic load cell unit.
6. The incremental loads were stopped when the final settlement reached 40 mm millimeters.
7. The loading test were performed for untreated soil only for comparison purposes .
   Figures (3) presented the stone column model through and after the test.

a. Through the test

b. After the test

Figures (3) : Stone column model through and after the completion of the test

Calculation of Area Replacement Ratio

For calculating the area replacement ratio (Ar), it should be followed the next steps (for example the stone column model of 50 mm in diameter)

1- Calculate the area of surrounding clay soil

Area of surrounding clay soil $(A_s) = [(D_f^2-D_c^2)/4]* PI = [(100^2-50^2)/4] * 3.1416$
$$= 5890.486 \text{ mm}^2$$

2- Calculate the area of stone column

Area of stone column $(A_c) = (D_c^2/4)* PI = (50^2/4) * 3.1416$
$$= 1963.495 \text{ mm}^2$$

3- Calculate the area replacement ratio according to Ref.[8]

Area replacement ratio $(Ar) = A_c/ A_s$
$$= 1963.495 / 5890.486 = 0.333$$

Where :

D_f = Diameter of footing.

D_c = Diameter of stone column.

D_s = Diameter of surrounding soil.

285

Presentation of Results and Discussion

There are many approaches proposed to define the ultimate bearing capacity and failure of stone column. In present work, Terzaghi (1947) proposal is adopted, , where failure was defined as the load corresponding to 10% of the model footing width (or pile diameter). Also the proposal is adopted by Ref.[9].

Figures (4, 6, and 8) relate the applied load with the settlement for untreated soil and soil treated with stone column at area ratios 0.042, 0.099, 0.333 and 0.563, respectively. The surrounding soil was prepared at undrained shear strength of (c_u=11 kPa, 16 kPa and 22 kPa), respectively. These models were tested 24 hours after preparation. The figures demonstrate that the stone column in all bearing ratios shows significant difference in the behavior corresponding to the settlement.

The figures also indicate that the improvement of the soil having shear strength, c_u=16 kPa by using a stone column technique was more efficient than the soils having (c_u= 11 and 22 kPa) and a clear increasing in applied load is noticed. This behavior is attributed to that the validity of use the stone column as soil improvement technique were in the specific range of shear strength of soft soils [5]. Thus the effect of improvement seemed clearly in the soft soil of untrained shear strength (c_u= 16 kPa).

The bearing improvement ratio achieved by stone columns is presented by the relationship between the ratio ($q_{treated}$ / $q_{untreated}$) and the   deformation ratio (S/D). It can be noticed from ($q_{treated}$ / $q_{untreated}$) in figures (5, 7 , and 9) that the bearing improvement ratios were 1.11, 1.18, 1.55 and 2.18 for the soil having (c_u = 11 kPa) treated with stone columns of (A_r = 0.042, 0.099, 0.333 and 0.563) respectively at S/D=10% [Figure (5) and table (2)]. The ratio ($q_{treated}$ / $q_{untreated}$) ranges from 1.16 to 2.29 for soil having (c_u = 16 kPa) treated with stone columns of (A_r = 0.042 and 0.563) respectively at S/D=10% [Figure (7) and table (2)].

The ratio ($q_{treated}$ / $q_{untreated}$) ranges from 1.09 to 2.05 for soil having   (c_u=22 kPa) treated with stone columns of (A_r = 0.042 and 0.563) respectively at S/D=10%   [Figure (9) and table (2)]. It can be concluded from the previous values that the bearing improvement ratio is increased with increasing the area ratio by a percentage ranges between (6%) and (97%). The results obtained from Figures (5, 7, and 9) are presented briefly in figure (10).

The results obtained from figure (10) are close that with of Etezad, (2006). Also it is found that the values of bearing improvement ratio are in a good agreement with results of finite element study of Fattah and Majeed (2009) in low range of area ratio (0.1 to .25), but when the area ratio increases , the values of bearing improvement ratio of finite element study are higher than the present values.

Table (2) : Bearing improvement ratio for the soil treated with stone column at (S/D = 10%).

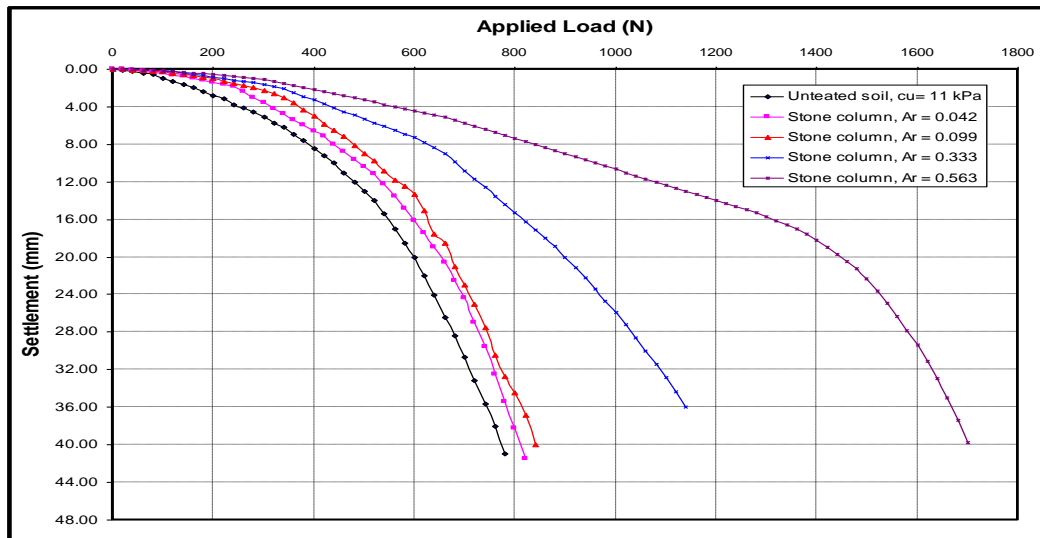| Shear strength	Area ratio (A_r)			
	0.042	0.099	0.333	0.563
c_u= 11 kPa	1.11	1.15	1.51	2.32
c_u= 16 kPa	1.16	1.22	1.69	2.64
c_u= 22 kPa	1.09	1.13	1.52	2.18

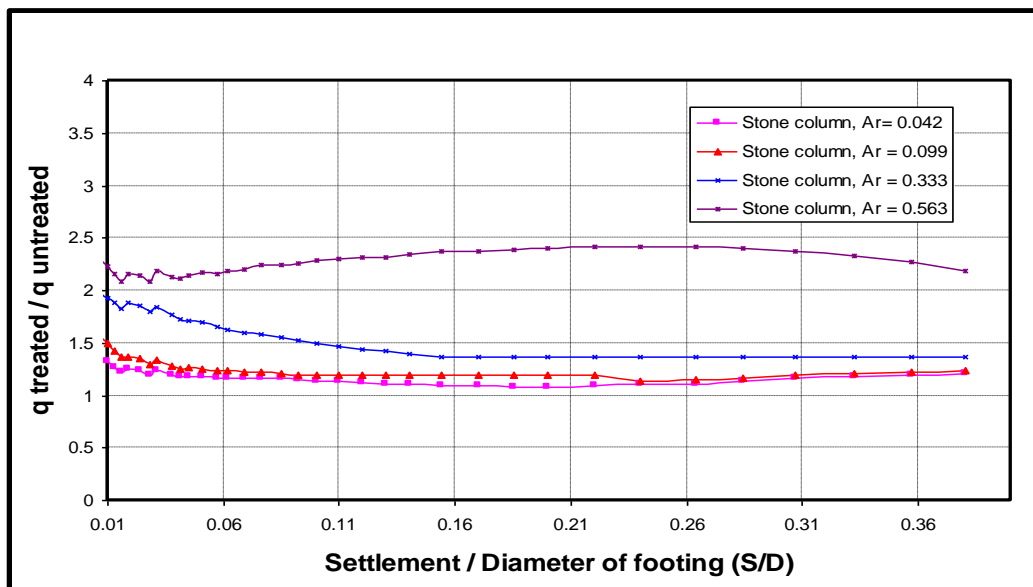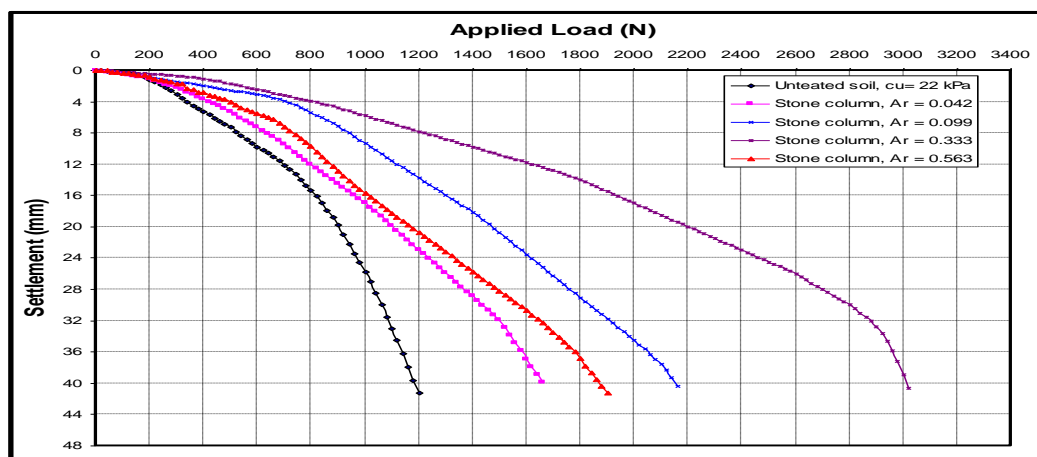Figure (4): Applied load versus settlement for soil treated with stone column, cu= 11 kPa.

Figure (5): ($q_{treated}$ / $q_{untreated}$) ratio versus (S/D) for the soil treated   with stone columns,cu= 11 kPa.

Figure (6): Applied load versus settlement for soil treated with stone   column, cu= 16 kPa.

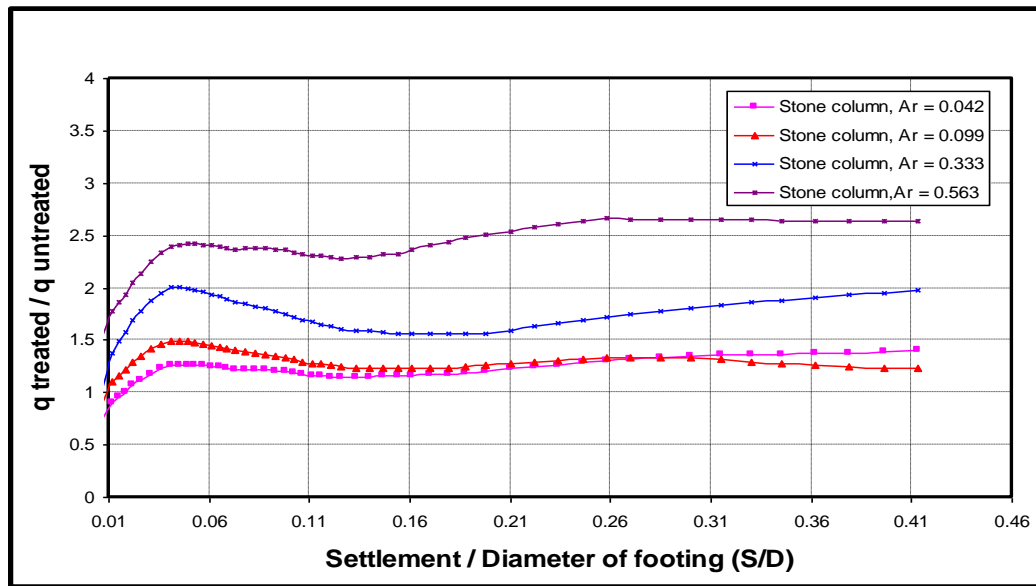Figure (7): ($q_{treated}$ /$q_{untreated}$) ratio versus (S/D) for the soil treated with stone columns, cu = 16 kPa.

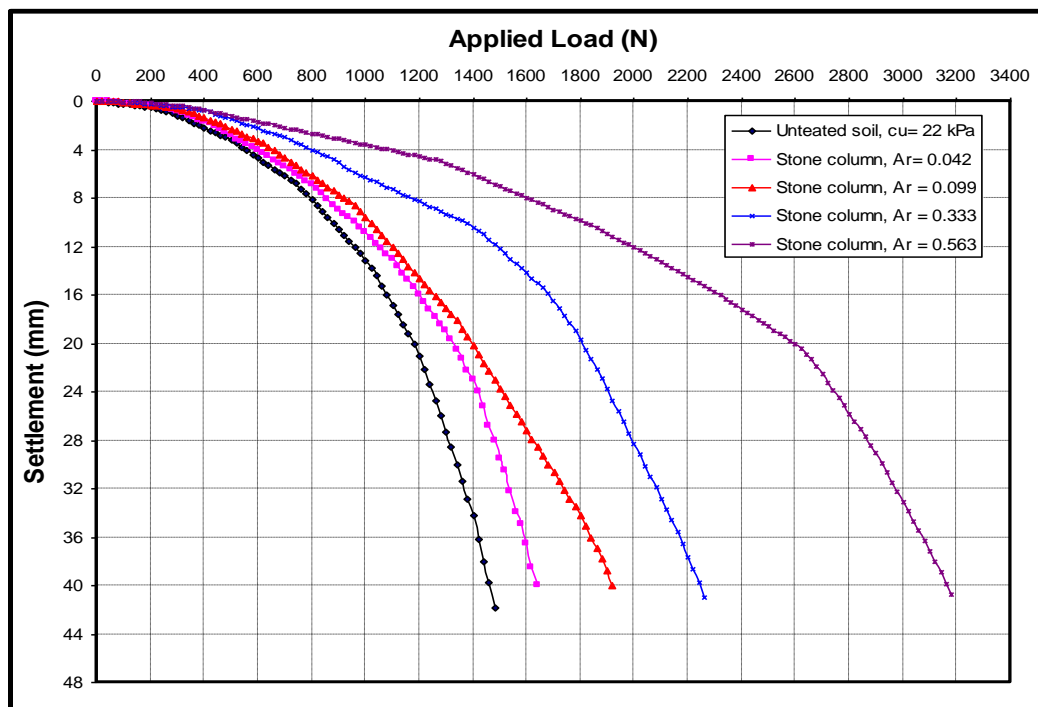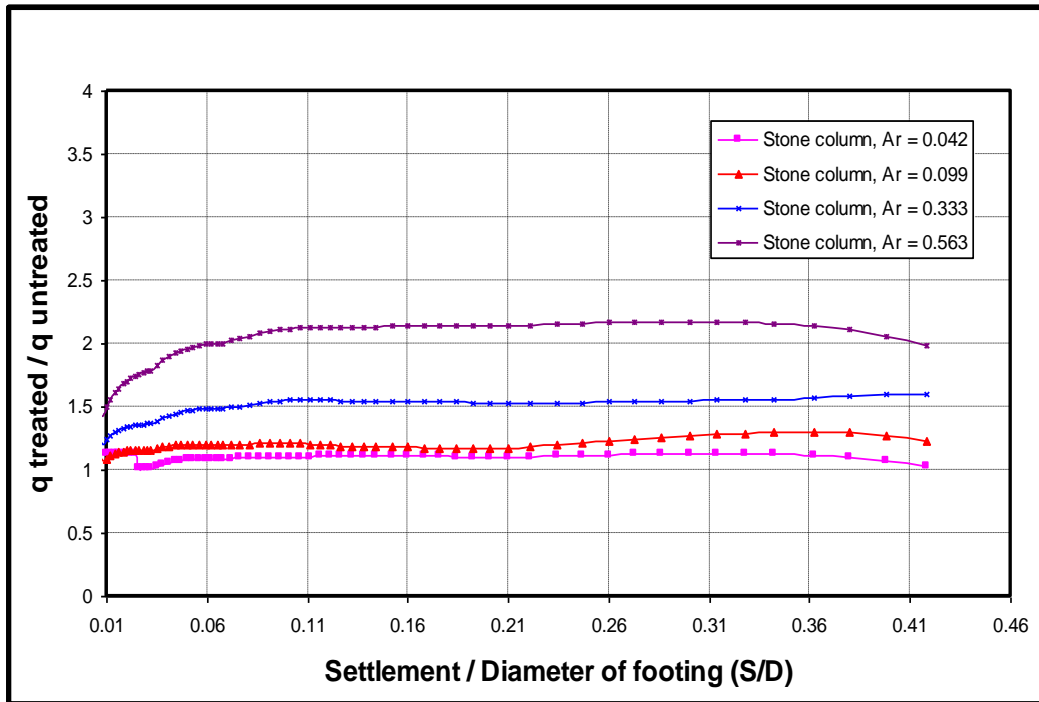Figure (8): Applied load versus settlement for soil treated with stone column, cu= 22 kPa.

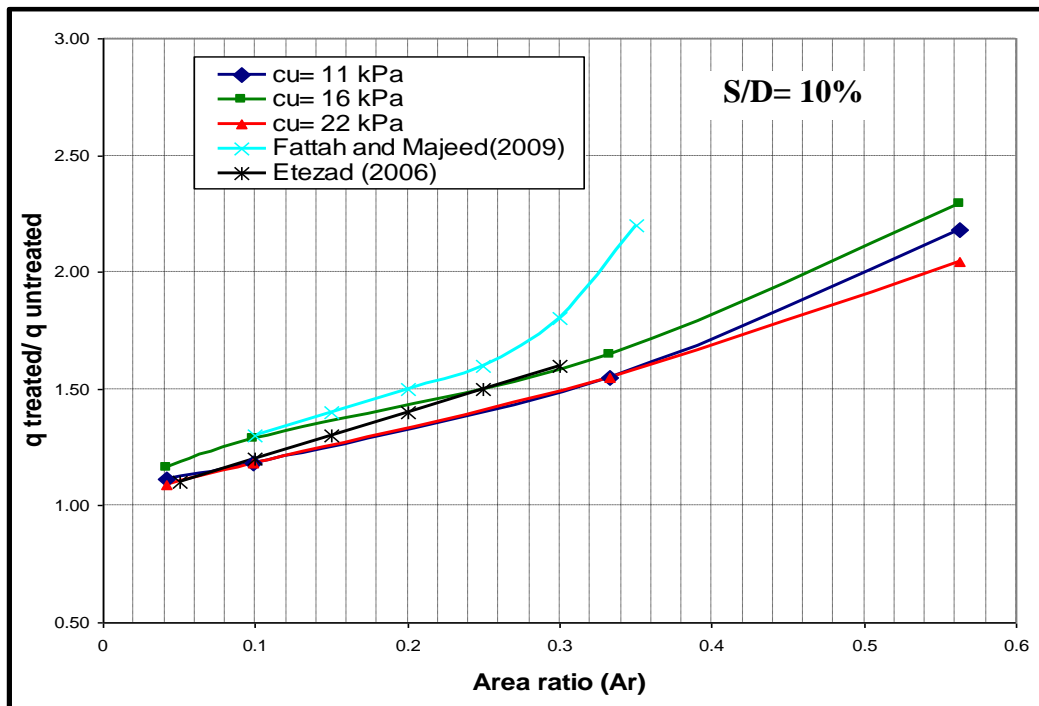Figure (9): (q$_{treated}$ / q$_{untreated}$) ratio versus (S/D) for the soil treated   with stone column, cu= 22 kPa.

Figure (10): (q$_{treated}$ / q$_{untreated}$) ratio at (S/D = 10%) versus area ratio for the soils treated   with stone column, cu= 11, 16 and 22 kPa.

Conclusions

1. the bearing improvement ratios were 1.11, 1.18, 1.55 and 2.18 for the soil having (cu = 11 kPa) treated with stone columns of (Ar = 0.042, 0.099, 0.333 and 0.563) respectively at S/D=10%

2. The highest values for bearing improvement ratio is in the soil with shear strength (cu=16 kpa) which are (1.16, 1.29, 1.64 and 2.29) at area ratio values (0.042, 0.099, 0.333 and 0.563) respectively. The results of the soil of cu= 11 kPa is approximately closed to results of the soil of cu= 22 kPa.

3. The bearing improvement ratio increases slightly with increasing the load and it reaches the plateau at the end of the test.

4. The results obtained from a past numerical studies are close to the results of present work at low range of area replacement ratio.

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