©2022 International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

ISSN 2228-9860 eISSN 1906-9642 CODEN: ITJEA8

TuEngr Group

International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

http://TuEngr.com

Large-Scale Laboratory Modeling of the Performance of the Stone Column Group in Improving the Behavior of Sandy Soils

Reza Naderi[1] , **Ali Yousefi Samangani**[2*]

[1]*Faculty of Civil & Architectural Engineering, Shahrood University of Technology, Shahrood, IRAN.*
[2]*Civil-Geotechnics Group, Shahrud Industrial University, IRAN.*
**Corresponding Author (Email: r_naderi@shahroodut.ac.ir).*

Paper ID: 13A5S

Volume 13 Issue 5

Received 24 December 2021
Received in revised form 15 April 2022
Accepted 25 April 2022
Available online 02 May 2022

Keywords:
Stone column group; Sandy soil; Load-carrying capacity; Soil load settlement behavior; Geometric arrangement; Single stone column.

Abstract

One of the efficient methods to improve soil behavior is the use of stone columns. Due to the high volume of studies on the performance of single Stone columns, in this study, we will seek to investigate the performance of group Stone columns in improving the behavior of sandy soils. Sandy soils, especially in coastal areas, due to the lean mechanical properties of the soil, have always been considered an unsuitable soil sample in the design and the need for improvement in this type of soil is urgently needed. Therefore, in this article, by using stone columns as a group, we will seek to improve the behavior of sandy soil. How to arrange the stone columns (square, triangular arrangement) and the diameter of the stone columns (60, 80 and 120 mm) are the main variables in this article. In all models, the length-to-diameter ratio is considered equal to 5. The load-carrying capacity and soil settlement have been investigated for different modes of stone column arrangement in the laboratory environment as superimposed load. The results obtained from the article show that the arrangement of the stone column in a triangular and square shape can increase the soil load carrying capacity by 31.8 and 37.5%, respectively. This incremental trend is more noticeable in the square arrangement. Also, based on other results of this article, it was observed that by increasing the diameter column parameter and increasing the diameter equivalent of the stone column group, we will see an improvement in the performance of the stone column group in increasing the sandy soil load-carrying capacity.

Disciplinary: Civil Engineering (Geotechnical Engineering).

Cite This Article:

Naderi, R., Samangani, A.Y. (2022). Large-Scale Laboratory Modeling of the Performance of the Stone Column Group in Improving the Behavior of Sandy Soils. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 13*(5), 13A5S, 1-13. http://TUENGR.COM/V13/13A5S.pdf DOI: 10.14456/ITJEMAST.2022.103

1 Introduction

Soil improvement is a process in which an increase in soil quality is observed. In other words, in the process of soil improvement, mechanical and resistance parameters, the soil increases. In different conditions, according to the characteristics of the earth for the construction of the structure and also according to the time and economic factors, the optimal method for improving feeble soil can be selected. Currently, the stone column method is implemented in a wide range of soil types, especially feeble soils. As a simple and complete definition of a stone column, it can be said that the replacement of a part of feeble soil by compacted vertical columns consisting of aggregate in a regular and completely permeable set in the soil layers is called stone or sand columns. Stone columns, as one of the suitable options, to improve the load-carrying capacity of loose, cohesive and aggregate soils, which in addition to reducing soil settlement, is an effective, economical and environment-friendly method in structures built on Soil is also considered. Due to the actual damage and casualty caused by the construction of various buildings on feeble soils, the importance of developing improved methods in feeble and unsuitable soils is essential. Moreover, sandy soils are always considered as an example of unsuitable soil in design. The use of stone columns as an environmentally friendly method is one of the most common methods of soil improvement in cohesive and non-cohesive soils. In this method, the stone column replaces part of the feeble soil. This method is based on replacing 15 to 35% of feeble soil volume, which is done by shaft sinkings with a certain diameter, depth and distance from each other and filling the wells with sand or gravel. Accordingly, group stone columns are mainly Square arrangements or Triangle arrangements (Figure 1).

Figure 1: Display the square and Triangle arrangement of stone columns in the present article

In a triangular arrangement, the number of stone columns in a fixed surface area is more than in the square arrangement. In triangular and square arrangements, the loading surface of each column (A) will be regular and square hexagons, respectively [1]. From the point of view of seismic geophysical engineering, stone columns are mainly used for reduction and lateral expansion effects in granular soils [2]. It is necessary to pay attention to the fact that the main application of stone columns is in fine-grained soils with a high fine-grained percentage. In non-cohesive soils, the presence of stone columns increases the soil loading capacity. Also, in conditions where the soil mass is considered, the presence of a stone column, due to the reduction of soil porosity, will reduce the soil liquefaction. In general, stone columns can increase load carrying capacity, reduce settlement, increase effective soil stress and create drainage conditions. Laboratory studies and numerical loadings have shown that the main reason for improving the soil behavior reinforced with stone columns is the higher stiffness of the stone column compared to the stiffness of the surrounding soil [3]. In saturated and non-cohesive soils, the pore water pressure increases rapidly and may be such that the particles are suspended separately from each other and for a moment the strength and stiffness of the soil are completely lost. The most effective way to deal with displacement and settlement in saturated sands is to use stone columns.

2 Review

The stone column was first proposed by Wei Hu [4] in 1995. In this study, the behavior of a reinforced soft clay soil sample with a set of stone columns is studied and tested and the collapse real mechanism and collapse of stone columns with a rigid circular base and by performing a series of controlled experiments, vertical loading has been investigated in vitro. Based on the results of this article, the length-to-diameter ratio of about 6 is introduced as the critical length of the stone column in the design [4]. Bae et al. [5] reviewed a laboratory model of a group of stone columns and while comparing the results with the results of the numerical finite element model, reported the coordination and agreement between the results.

Andrew and Papadopoulos [6] studied the effect of load-carrying capacity, area ratio, internal friction angle and undrained shearing strength on the horizontal displacement of a stone column in cohesive soil. The column was subjected to extensive loading through a rigid foundation and was modeled using the single-cell concept. They use an axial symmetric finite element analysis while using the Mohr-Coulomb criterion for columns and soil, they examined the effect of the variables on the improved ground. Jahromi et al. [7] evaluated the loading indicators of soft grounds improved with the stone column group. In this study, various factors such as stone column area ratio, material strength and resistance and mechanical specification of the stone column and soil at the group scale have been studied and evaluated to determine the impact of these factors on the design and improvement of soft grounds. The results of this study clearly show that factors such as modulus of elasticity and internal friction angle of the stone column material as well as the Poisson’s ratio of soil around the stone column, have a significant impact on increasing the load-carrying capacity of soil improved by the method presented in this study. Castro [8] studied a series of two-dimensional and three-dimensional finite element analyses to evaluate the performance of a group of stone columns under a rigid foundation.The results of this research showed that the number and arrangement of stone columns have the least effect on changes in the load-settlement curve.He also showed that in order to estimate the reduction of settlement and the critical length of stone columns, the group of stone columns located under the foundation can be replaced with a stone column with an equivalent surface in the center of the foundation. Meshkin Ghalam et al. [9] studied a numerical investigation of the impact of stone columns. The results of this study showed that by increasing the distance from the center to the center of the columns, the effect of the group in reducing the overpressure of the pore water pressure. At a certain number, as the distance between the columns decreases, the soil swelling increases. For the distance from the center to the center of the columns 2.5 to 3.5 times the column diameter, the column group performs better in reducing settlement. By applying a superimposed load, in the model with the column group in a circular range with an approximate radius equal to the distance from the center to the center of the columns, the settlement is significantly reduced compared to the column less mode. Haji Azizi and Nasiri [10] conducted a laboratory study on the effect of bond area on the earthen sustaining slopes with stone columns. Laboratory results and numerical analysis obtained from this study showed that 5% of cohesive fine-grained soil has a great effect on increasing the slope stabilization of reinforced stone columns. The results obtained from numerical analyzes show good coordination with laboratory modeling. Lajevardi et al. [11] conducted a laboratory study of singular and group stone columns confined in geotextiles. In this study, single and group stone columns in two normal modes with geotextile coating were studied in the laboratory. Singular stone columns with a diameter of 63 and 80 mm with a length-to-diameter ratio of 5 have been loaded. The results show that the load-carrying capacity of the column is increased by placing a geotextile coating around it. In the following, the stone columns with a diameter of 63 mm were tested in groups in different arrangements and their load carrying capacity was compared with each other.The results of this study show, that with increasing the diameter of a singular stone column, its load-carrying capacity has decreased and in loading on singular and group stone columns, the placement of adjacent columns has increased the load-carrying capacity of the samples by 6.3% and 8%, respectively. Also, based on the results of this study, it was found that the load-carrying capacity of group columns with two triangular and square arrangements has a difference of 5% from each other. Dinarvand and Ardakani 2018 [12] in a study to investigate the behavior of granular columns enclosed with geosynthetics in silty sand soil under a direct shear test. In this study, the effect of factors such as fine-grained soils, normal stress, the effect of the granular column group and the granular of the column material on the passive resistance of the soil and granular column set has been investigated. In the present study, large-scale laboratory studies have been performed to evaluate the performance of stone column groups in improving sandy soil behavior. In this regard, the effect of the presence of stone columns, the effect of the type of triangular or square arrangement of stone columns and the effect of the diameter of the stone column on the load-carrying capacity of sandy soil have been investigated. Therefore, after making the test box, the various modes studied were performed in the laboratory environment and the samples were exposed to lateral loading.

3 Laboratory Studies

3.1 Testing (Box) Machine

Due to the fact that in this research, large-scale laboratory modeling is considered, it is necessary to make the dimensions of the experiment clear. Therefore, in order to perform experiments on group stone columns with the desired arrangement, it is necessary to make the necessary equipment to perform the experiment. For this purpose, equipment including a large metal box was made as a simulated earthen bed with dimensions of 111 * 111 * 95. It should be noted that after making the device with the desired dimensions and considering that the wedge created under the foundation is spread to a distance of about 2 to 2.5 times the width of the foundation from the center of the foundation to the surrounding area, the border conditions on The results of large-scale experiments will not be effective. Figure 2 shows the built-in test box. Other equipment required for laboratory studies including a loading plate, displacement sensors, dynamometer and the hydraulic jack can be seen in Figure (3). In this study, in order to apply load on group stone columns, a circular steel loading plate has been used. A hydraulic jack with a maximum capacity of 3 tons is applied to the center of the loading plate and two displacement sensors record the amount of displacement recorded on the steel plate. Also, by installing a dynamometer sensor, at the point of contact of the jack with the steel plate, the amount of force applied to the steel plate can be controlled and measured.

Figure 2: built test device in this study

Figure 3: required laboratory device in this study

3.2 Construction of Stone Columns

There are different methods for making stone columns. In this study, a plastic sheath (thin-walled pipe) with diameters of 60, 80 and 120 mm was used to make stone columns. During the construction of the model, at each stage, according to the specific gravity of the column, the required sand was poured into the pod and compacted. At this stage, the sand was granulated. Figures 3 and 4 show the sand granulation curve and the details of the stone column construction, respectively. Specific gravity, internal friction angle, modulus of elasticity and specific gravity of sand used to make stone columns are 16 kN / m^2, 41°, 100 MPa and 2.6 kg/m^3, respectively. It should be noted that after the installation of each of the stone column pipes, the soil inside the stone columns is removed by Oger and the space inside the pipes is filled with sand.

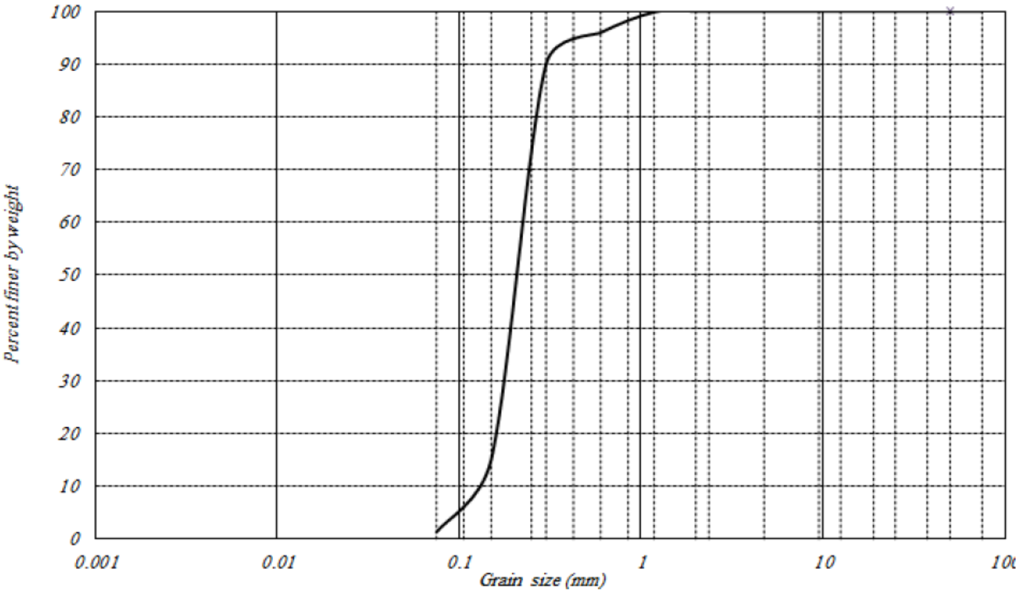

Figure 4: Granulate curve of sand as the main materials forming the stone pillar

Figure 5: construction processes of stone column

3.3 Material

The soil studied in this study is sandy. Therefore, the stone columns surrounded by sand have been installed and tested. The characteristics of the studied sand can be seen in Table (1).

Table 1: introduce properties of sandy soil used in this study

Parameters	Value
Dry specific weight	16 kN/m^2
Saturated specific weight	18 kN/m^2
Dry internal friction angle	40 degree
Saturated internal friction angle	36 degree
Adhesion	0
Elasticity module	40 Mpa
Specific density	2.65
Poisson’s ratio	0.3
Max porosity ratio	0.6
Min porosity ratio	0.3

3.4 Introduction of Studied Laboratory Models

The models studied in this study are classified and named based on the studied variables. Therefore, the models are introduced based on the arrangement and diameter of the stone columns, according to Table (3). The main variables in this study are:

- Diameter of stone columns (d): The diameter of stone columns has been used as one of the variables in three values of 60,80 and 120 mm.

- Length to diameter ratio of stone column (L / d): This parameter is considered 5. According to the proposed diameters, the length of the stone columns will be in the form of a table (2).

- Layout of stone columns: Stone columns have been studied and evaluated as a group in two categories of 3 (with triangular arrangement) and 4 (with square arrangement).

Table 2: stone column length

D (mm)	L/d=5
60	300
80	400
120	600

According to the introduced variables, 6 different modeling modes (1* 2 * 3modes) have been studied, which are introduced in Table (3). It should be noted that the loading on the samples continued until the soil settles to the extent of 50 mm. All tests were performed under controlled displacement and at a constant rate of 2 mm/min. To ensure the accuracy of the results, all experiments were performed twice and the results were compared with each other.

Table 3: Introducing the studied modes

Row	Abbreviation	Stone column diameter (mm)	Stone column length (mm)	Geometric of arrangement
1	SC60-300-3	60	300	Triple
2	SC60-300-4	60	300	Square
3	SC80-400-3	80	400	Triple
4	SC80-400-4	80	400	Square
5	SC120-600-3	120	600	Triple
6	SC120-600-4	120	600	square

4 Experimental Results

The effect of stone columns in single and group mode with two triangular and square layouts on soil loading capacity has been evaluated and analyzed. Therefore, the settling load curve for sandy soil without stone columns, sandy soil improved using a single stone column, sandy soil improved by using three stone columns in a triangular arrangement, and sandy soil improved by using four columns A stone is obtained in a square arrangement. Also, in order to investigate the effect of the diameter of stone columns on soil loading capacity, the results for stone columns with three diameters of 60, ,80 and 120mm in both triangular and square layouts have been analyzed. In the following, we will examine the effect of the presence of the stone column, the diameter of the stone column and the geometric arrangement of the stone column on the loading capacity of sandy soil.

4.1 The Effect of Stone Columns on the Loading Capacity of Sandy Soil

According to Figure 5, the presence of stone columns in sandy soils has increased the loading capacity of the soil. In a way, the use of a single stone column has increased the loading capacity of sandy soil by 29.7% compared to the case of not using a stone column. Also, the comparison of the performance of the group of three stone pillars in comparison with the single stone pillar shows that the use of three stone pillars with a diameter of 60 mm has increased the loading capacity of the soil by 318%. Figure (6) shows the effect of the arrangement of a group of 4 stone columns on the settlement load curve of sandy soil. In this figure, it is observed that the use of the arrangement of 4 stone columns with a diameter of 60 mm, has increased the loading capacity of sandy soil by 37.5% compared to the case of using a single stone column. It can be seen that the presence of stone columns in the sandy soil bed has increased the loading capacity of the soil. This upward trend is more noticeable with the increase in the number of stone columns participating in the group of stone columns.

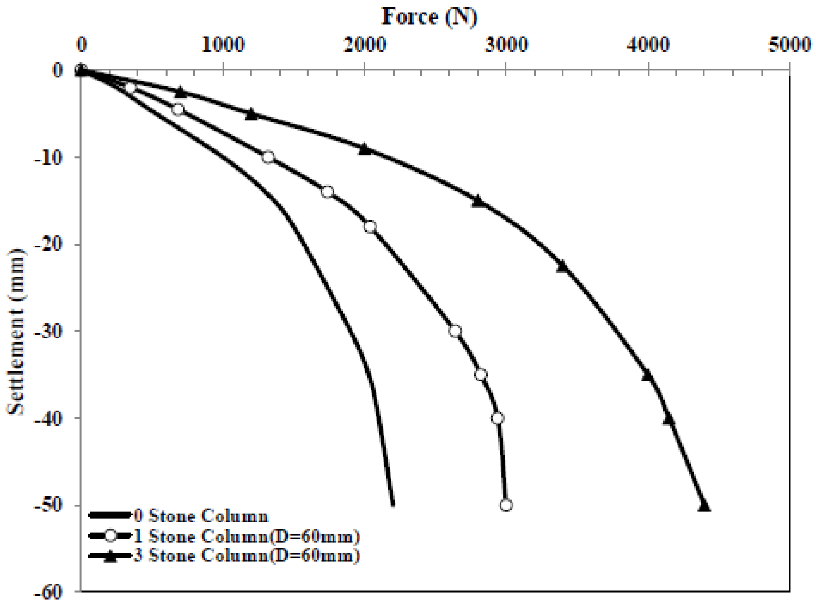

Figure 6: Comparison of load settlement behavior of sandy soil with various stone column arrangements.

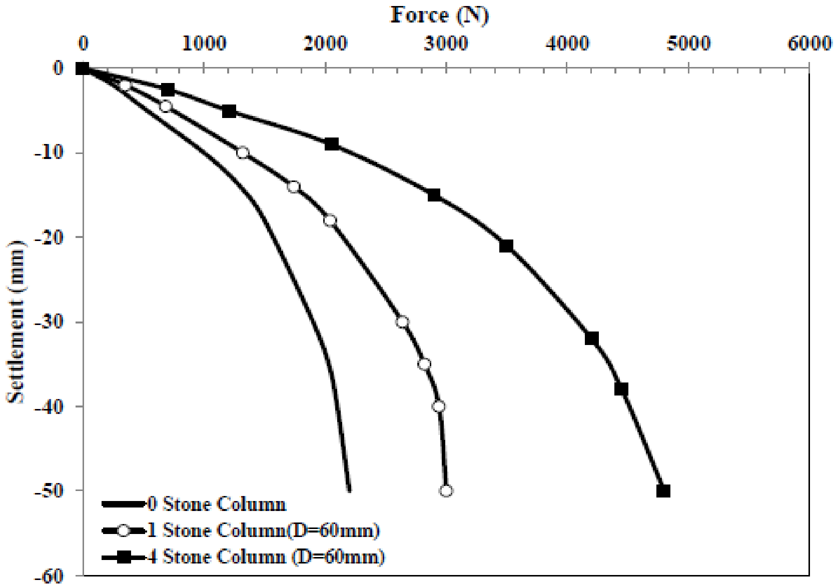

Figure 7: Comparison of load settlement behavior of stone column with single and square arrangements.

4.2 Effect of Stone Column Diameter on Sandy Soil Loading Capacity

To investigate the effect of the diameter of stone columns on the loading capacity of sandy soil, a group of stone columns consisting of single stone columns with diameters of 60,80 and 120 mm with two triangular (triple) and square (quadruple) arrangements was tested. Figure (7) shows the load-settlement curve of the group of stone columns with a triangular arrangement with three different diameters. It can be seen that increasing the diameter of the stone column has increased the final loading capacity of the sandy soil. So that the use of stone columns with a diameter of 80 and 120 mm, compared to a diameter of 60 mm in a triangular arrangement has increased the soil loading capacity by 15.4 % and 24.1%, respectively. Also, in Figure (8) the effect of changes in the diameter of stone columns on the loading capacity of sandy soil with a square arrangement is investigated. The results show that the use of the square arrangement of stone columns with a diameter of 80 and 120 mm compared to stone columns with a diameter of 60 mm, respectively, increased the loading capacity of sandy soil by 22.5% and 30%, respectively.

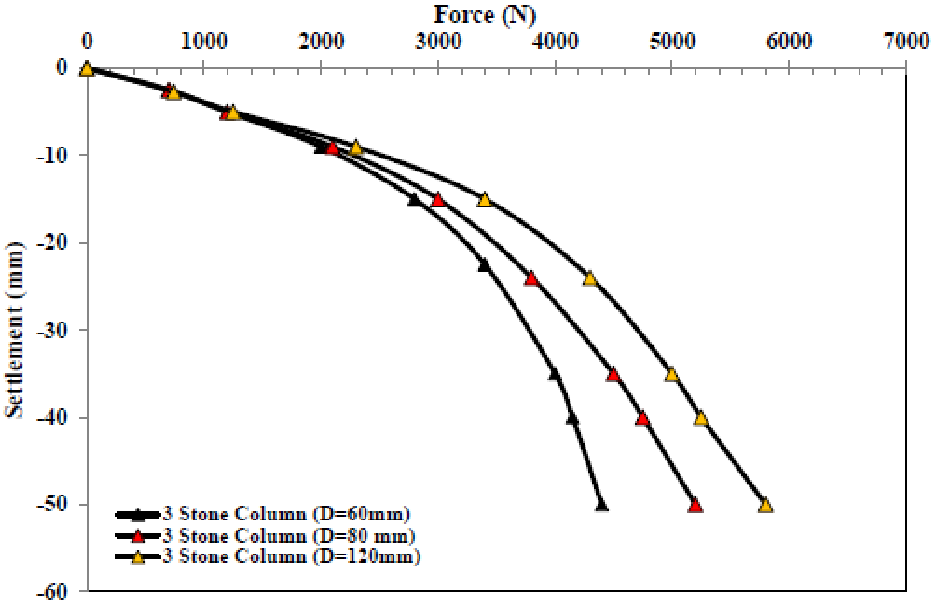

Figure 8: Effect of stone column diameter on the loading capacity of sandy soil with triangle arrangement

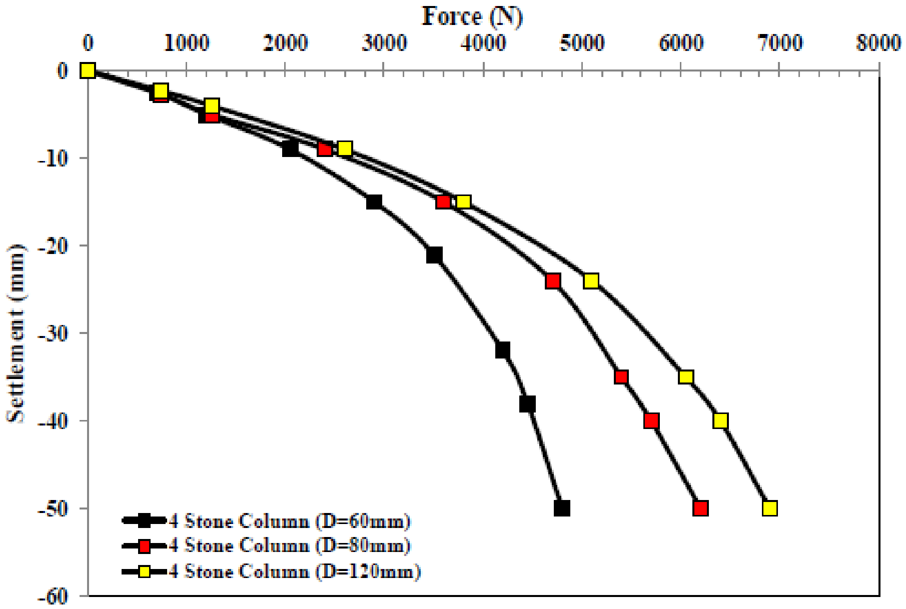

Figure 9: Effect of stone column diameter on the loading capacity of sandy soil with the square arrangement

4.3 The Effect of Geometric Arrangement of Group of Stone Columns on the Loading Capacity of Sandy Soil

To investigate the effect of the geometric arrangement of the group of stone columns (with fixed column diameters), the settlement load diagram for three diameters in two triangular and square layouts was examined. According to Figures 9 to 11, the effect of the geometric arrangement of the stone column group on the loading capacity of sandy soil can be evaluated. It can be seen that in the case of stone columns with a diameter of 60mm, changing the geometric arrangement of the stone column groups from triangular to square shape has increased the loading capacity of sandy soil by 8.3%. Also, if the diameter of the stone column is equal to 80 and 120 mm, this increasing trend has increased the loading capacity of the soil by 19% and 15.09% respectively, by changing the arrangement from triangular to square. Therefore, it can be concluded that with increasing the diameter of stone columns and increasing the equivalent diameter in the group of stone columns, the loading capacity of sandy soil has an upward trend.

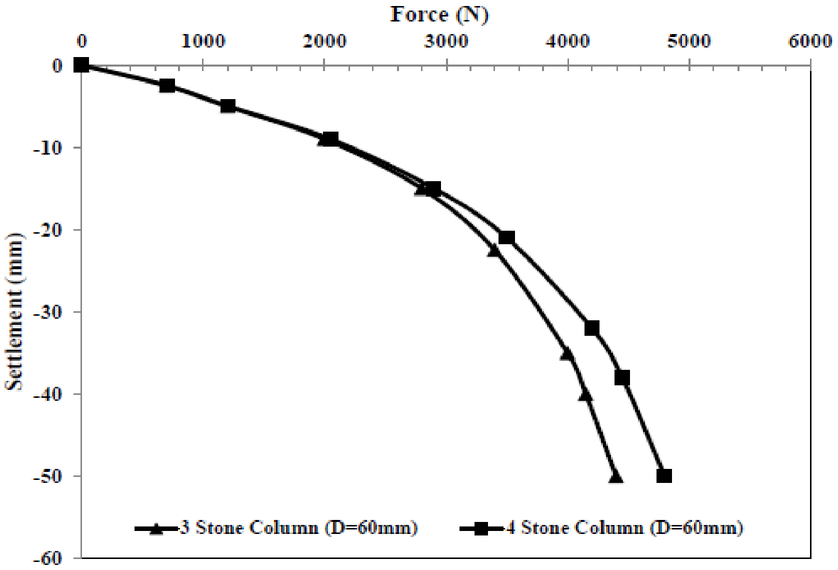

Figure 10: effect of stone column arrangement on the loading capacity of sandy soil with 60 mm diameters.

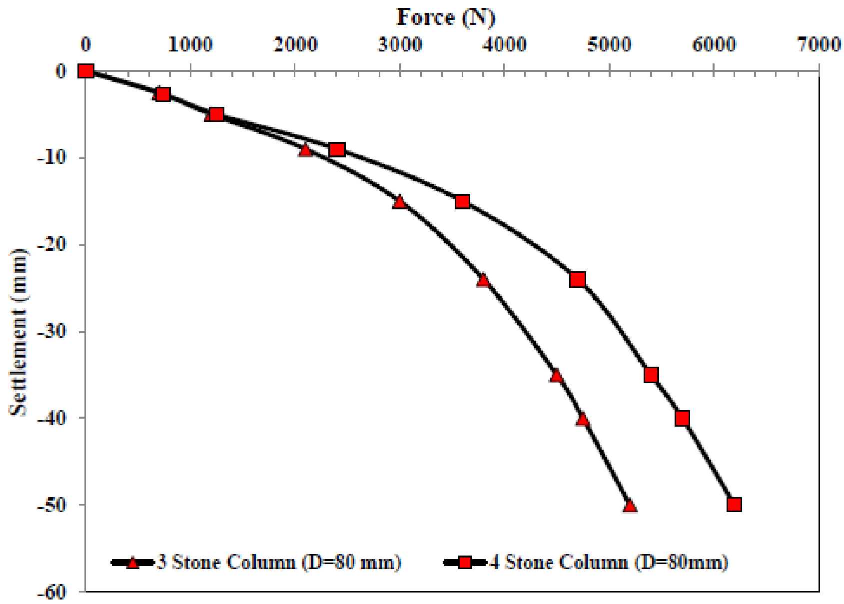

Figure 11: effect of stone column arrangement on the loading capacity of sandy soil with 80 mm diameters.

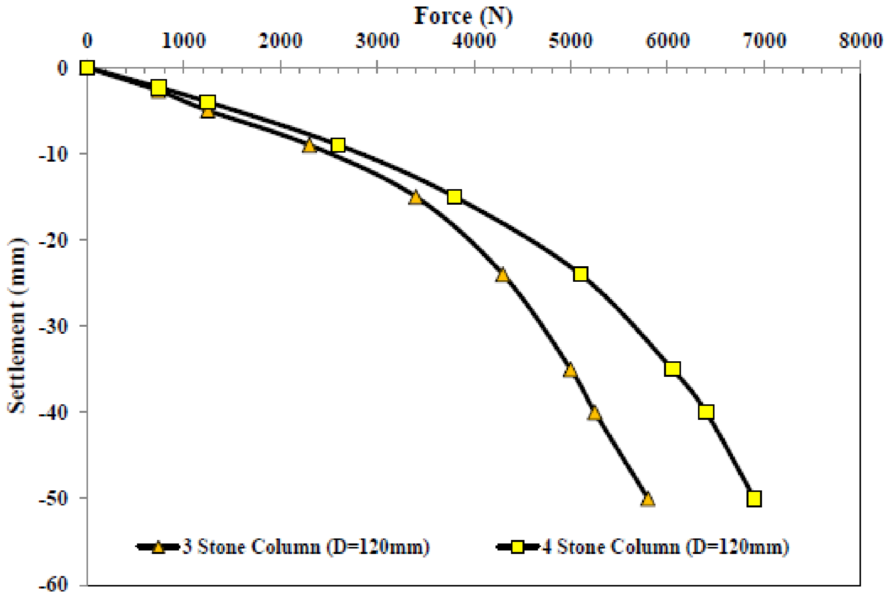

Figure 12: effect of stone column arrangement on the loading capacity of sandy soil with 120 mm diameters.

5 Conclusion

In this study, a number of experiments were performed on stone columns in both single and group modes with two different arrangements to evaluate the effect of some parameters affecting the loading capacity of sandy soil. Therefore, stone columns with three diameters of 60, 80 and 120 mm singularly and in groups in two modes of triangular arrangement (with three single columns) and square arrangement (with four single columns) with a length to diameter ratio of 5 in the experiment box was evaluated and tested on a large scale. According to the experiments, the results obtained are as follows:

The presence of stone columns in sandy soils has increased the loading capacity of the soil. The use of a single stone column has increased the loading capacity of sandy soil by 26.7% Also, the comparison of the performance of the group of stone columns with the triangular arrangement in comparison with the single stone column shows that the use of the triangular arrangement of stone columns with a diameter of 60 mm increases 31.8% and the use of the arrangement of 4 stone columns with a diameter of 60 mm with arrangement Square, 37.5% have increased the loading capacity of sandy soil compared to the use of a single stone column.

Increasing the diameter of the stone column has increased the final loading capacity of the sandy soil. So that the use of stone columns with a diameter of 80 and 120 mm, compared to the diameter of 60 mm, in a triangular arrangement has increased 15.4% and 24.1% soil load capacity, respectively. Also, the use of the square arrangement of stone columns with a diameter of 80 and 120 mm in comparison with stone columns with a diameter of 60 mm, has increased the loading capacity of sandy soil by 22.5 % and 30.4%, respectively.

Changing the geometric arrangement of the stone column groups from triangular to square has increased the loading capacity of sandy soil by 8.3%. If the diameter of the stone column is 80 and 120 mm, this increasing trend increases the loading capacity of the soil by 19% and 15,9%, respectively, by changing the arrangement from triangular to square. It can be concluded that by increasing the diameter of stone columns and increasing the equivalent diameter in the group of stone columns, soil loading capacity can be increased.

6 Availability of Data and Material

Data can be available by contacting the corresponding author.

7 References

Pulko, B. and Majes, B. (2006). Analytical method for the analysis of stone columns according to the Rowe Dilatancy theory. *Acta Geotechnica Slovenica, 3*(1), 37-45.

Krishna, M. and Madhav, M.R. (2009). Engineering of ground for liquefaction mitigation using granular columnar inclusions: recent developments. *American Journal of Engineering and Applied Sciences, 2*(3), 526-536.

Ambily, A. P. and Gandhi. S. R.. (2007). Behavior of Stone Columns Based on Experimental and FEM Analysis. *Geotechnical and Geoenvironmental Engineering*, 133.

Hu, W.. (1995). *Physical Modeling of Group Behavior of Stone Column Foundations*. Ph.D. dissertation, Univ. of Glasgow, U.K.

Bae, W., Bang, W. and Byung, C.. (2002). Behavior of Foundation System Improved with Stone Columns, *Proc. 12th Int. Offshore and Polar Engineering Conf.*, Int. Society of Offshore and Polar Engineers, Cupertino, CA.

Andreou, P. and Papadopoulos, V.. (2006). Modelling Stone Columns in Soft Clay. *Proc. 6th European Conf. on Numerical Methods in Geotechnical Engineering*, Graz, 777–780.

Castro J. (2014). Numerical modelling of stone columns beneath a rigid footing. *Computers and Geotechnics*, 60, 77-87.

Ghalam, M., et al. (2020). Numerical study of the effect of stone columns. *Journal of Civil & Environmental Engineering*, 49(2).

Azizi, M.H. and, Massoud, N. (2017). Laboratory study of the effect of adhesion on the stability of earthen slopes reinforced with stone columns. *Journal of Modares Civil Engineering*, 17(1).

Lajevardi, S.H., Enami, Shamsi, S.H.R., Hamidi, M. (2019). Experimental study of single and groups of stone columns encased by geotextiles. *Amirkabir J. Civil Eng*, 50(6).

Dinarvand, R. and Ardakani, A. (2019). Behavior of geosynthetically enclosed grain columns in sandy loam soil under direct shear testing. *Journal of Civil Engineering Amirkabir*, 50(5).

Dr.Reza Naderi is an Associate Professor at the Shahrood University of Technology in IRAN. He is Assistant Professor Faculty of Civil & Architectural Engineering. He holds a PhD in Geotechnical Engineering. His research encompasses Numerical Methods in Geotechnical Engineering Soil Mechanics Rock Mechanic

Ali Yousefi Samangani is a Ph.D. student in the Civil-Geotechnics Group at Shahrud Industrial University in IRAN.