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The Use of Stone Columns to Reduce the Settlement of Swelling Soil Using Numerical Modeling

Mehdi Mokhberi, Hossein Khademi*

Department of Civil Engineering, Islamic Azad University, Estahban Branch, Estahban, Iran

*Correspondence should be addressed to Hossein Khademi, Department of Civil Engineering, Islamic Azad University, Estahban Branch, Estahban, Iran; Tell: +989177679910; Fax: +987136321044; Email: khademi_hosein57@yahoo.com.

ABSTRACT

The existing soils in the nature that is used for construction cannot necessarily bear the loadings on the structure. For example, in granular soils, the natural soil may be very loose and show a lot of elastic settlement. Sometimes, there are soft layers, saturated clay and swelling soils at the lower depths, which may cause significant settlement in the structure in terms of foundation load and clay layer thickness. To avoid such settlements, it is necessary to use certain techniques to improve the soil condition. One of the methods that have recently been widely used to reduce the settlement of soft soils and swelling soils is stone columns or single piles. In this research, first of all, the parameters in need for the analysis will be gained by using the experimental data, and then, the static and dynamic behavior of the confined stone columns is examined with geotextile and without geotextile by a group and single manner as in two-dimensional form using Plaxis numerical method of the finite element and the impact of the following parameters will be investigated in both static and dynamic modes: Column length, column diameter, single and group behavior of columns, and soil cohesion effect on the behavior of the confined stone column in geotextile and reduction of soil settlement during use of stone columns. The results of this research indicate correct understanding of the use of geotextile (Woven Geotextile with a specific elastic normal strength) to prevent the camber and the settlement of the column and increase of the strength and bearing capacity of the column.

Key words: Stone column, Geotextile, Static and dynamic analysis, Single and group behavior, Settlement.

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1. INTRODUCTION

From the perspective of Geotechnical engineering, methods of soil reinforcement can be divided into two general categories: 1. Physical methods including all the things that increase soil density; 2. Chemical methods including soil stabilization by adding materials such as lime, cement, bitumen and other materials. One of the methods that recently have been widely used for the repair of soft sediments and loose fine aggregate soils is stone columns or granular piles. Stone columns or granular piles are often used for reinforcing the soft clay, silts and loose silty sands with fine aggregate and are one of the most popular methods for the soil improvement that have relatively low costs to perform and their installation is easy. These stone columns increase the strength of the loose soils and also reduce the settlement that has been created by loading. The technique of using stone columns is one of the methods for the restoration of poor soils such as clay, silt and sand, which its efficiency and compatibility with the environment has been proven. The construction of a stone column involves the replacement of inappropriate soils with a vertical and a compact column of aggregates, which usually penetrates completely into the weak layer and its stiffness is provided by the confining created by the lateral stresses in the surrounding soil. This column creates a composite material with a lower compressibility and more shear strength than the original soil. The same settlement of the column and its surrounding soil causes the stress concentration in it and as a result, it reduces the settlement and increases the bearing capacity of the total land and the stone column due to the vertical stress on the surface and more stiffness of the stone column than the soil. The use of stone columns is not possible in very soft soils or soil of the plants that have less than 15 kpa of the drainage's strength due to the lack of efficient confining in these soils, the confining tensions created during the installation process of the stone columns in very soft soils is not noticeable and on the other hand, the activation of additional confining stresses during loading on the stone columns requires a very large settlement of the column as a result, its large lateral deformation, which means disrupting the stone column (1). The stone columns are used to improve the load bearing capacity of clay layers, but if the clay is very loose, it will disrupt the column, therefore, to avoid the collapse of the column and improve it, the use of geosynthetic coating is recommended due to its high tensile strength to cover the stone column. The use of stone columns to improve the fine aggregate soils returns to the 1950s, which the stone column was used for the first time in Canada. The theory of force transition as well as the estimation of their bearing capacity and the prediction of the final settlement in stone columns was proposed first time by Greenwood in 1970 (2). Hughes and Withers (1974), based on laboratory tests showed that a single stone column is disrupted by the camber at the upper section (3). Subsequently, following studies of the Priebe (1976) (4), Vekli et al., (2012) (5), Balaam NP, (1981) (6) it was proved that the stone column can reduce the settlement dramatically. In 1977, Balaam et al., Based on the results of laboratory tests on a single stone column, concluded that each stone column in the stone column group could also be deformed and disrupted independent of its adjacent columns. In other words, the effect of the columns on each other is not considered in this method. This method was later introduced as a unit cell method by a number of investigators such as Balaam (1977) (7), and it was the basis for the analysis and designing of the stone column for many years. After years of using stone columns with the spread of geosynthetic, Katti et al initially, could achieve the stone column application that is covered by geosynthetic material (8). Subsequently, via the experiments on the small scale, Kousik et al. showed that the use of geosynthetic effectively reduces the differential settlement and total settlement (9). Murgan and Rajagopal examined a confined single stone column in geotextile in the laboratory and considered the effect of stone material type in contact with the geotextile layer (10). Their results indicated an increase in bearing capacity with increasing the granule size. Deb et al. conducted a series of laboratory tests to investigate the effect of strengthening sand bed on stone columns (11). Ghazavi and Afshar have conducted studies on the bearing capacity of stone columns with geosynthetic coating in single and group mode (12). So far, little researches have been done on the group behavior of columns that most of these researches have been conducted about the uncovered columns (13-18), and in the case of coated column's group, no detailed studies have been reported about its behavior and earthquake effects. In this research, we have tried to study the behavior of single and group columns and their settlement during applying the static and dynamic loads and then we compared them with each other. In addition, the strength of this research is to achieve a suitable pattern for designing the stone columns based on the unit cell method and the new interaction method, considering both static and dynamic situations.

2. REQUIRED PARAMETERS

2.1. Geotextile (History of using geotextile)

The history of the construction and application of geotextile materials backs to the 1950s, at which time, single-strand woven geotextile sheets were used as a filter for erosion control in the state of Florida. In 1975, Geotextile was used to protect the coasts of a river in the Netherlands. In the US, since the late 1970s the use of woven geotextile increased. Geotextiles are thin structures with a vertical strength, but without the flexural strength and they only bear the tensile strength and cannot withstand compressive forces. These Geotextiles are commonly used to model reinforced soils. The only characteristic of these materials is the normal elastic axial strength as its specifications are specified in the main material data. Table 1 shows the used physical properties of the geotextile in this study based on the factory guideline (19).

Table 1. Specifications of consumable geotextile (CE121) (19)

Maximum tensile strength (kN / m)	7.68
Tensile strain at maximum loading (%)	20.2
Load at 10% stretching (kN / m)	6.8
Tensioning at half the maximum strength (%)	3.2
Normal stiffness of Elastic Axial (EA) (kN / m)	120
Axial Stiffness (kN / m)	35

2.2. Soil and Stone Column

The data extracted and required in this study by using the carried out Geotechnical tests in one of the projects in Bandar Abbas are as follows (Table 2).

Table 2. Geotechnical tests results

Soil Specification	Clay	Column
Specific gravity (kN / m3)	1600	2000
Saturation Specific gravity (kN / m3)	1750	2150
Ø (degree)	0	42
V	0.45	0.3
E (kN / m2)	2000	40000
C (kN / m2)	20	10
ψ (Degree)	0	12

3. MODELING AND ANALYSIS RESULTS

In this section, the static and dynamic behavior of stone columns is investigated as two-dimensional state using Plaxis finite element numerical method. Plaxis 2D is a two dimensional finite element software package which is developed especially for analysis of deformation and sustainability analysis in Geotechnical engineering projects (Figure 1). It simulates the actual position using either the plane strain condition or the axial symmetry model. In this study, two plastic and dynamic analyses have been used.

3.1. Verification

At the beginning of the modeling, the software is verified by laboratory work that is presented by Murugesan and Rajagopal (20). Geometry and results of soil parameters and other data of the main article were completely presented in the mentioned references.

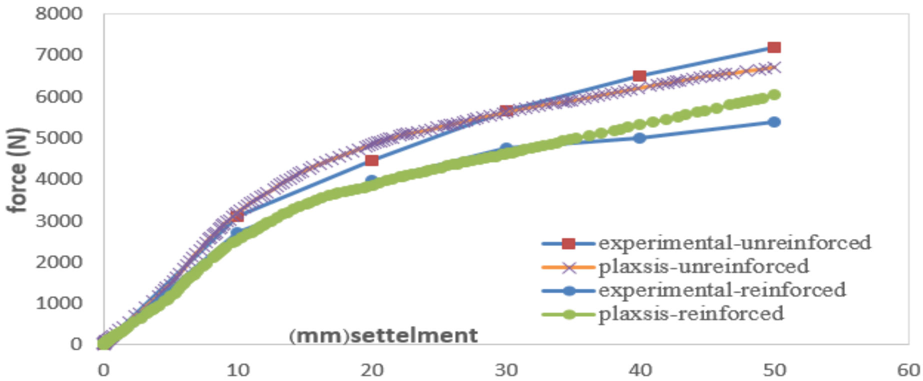

Figure 1. Verification based on the article of Murugesan and Rajagopal (20)

Based on performed verification, it is observed that the simulations of this research have a good accuracy and the amount of minor differences is due to the lack of calibration of measuring devices and error arising from the readings' devices.

3.2. Checking in the static mode

3.2.1. Single stone column (Effect of column diameter)

In this section, a circular surface with a diameter of 5 meters (which is the standard diameter of the reservoirs) is considered and modeled by axial symmetry method. The dimensions of the environment are considered 15 meters in horizontal direction and 20 meters in vertical direction, so that the boundaries of the model do not affect the results. Figure 2 shows the settlement-force curves for the stone column with different diameters (50, 70, 90, 110 and 130 cm) in unreinforced conditions. The choice of diameters is based on the conventional diameter of the execution of stone columns, which is about 90 cm, and is chosen to cover a diameter of more than and less than 90 cm.

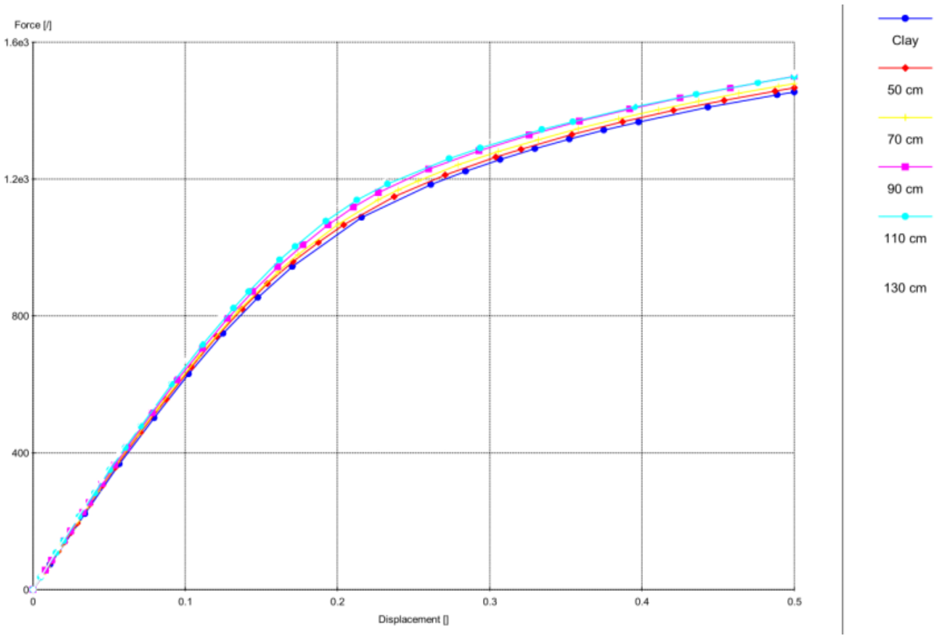

Figure 2. Settlement-Force curve for different diameters of the stone column

According to Figure 2, the diameter of the column parameter does not have a significant effect on the bearing capacity. Accordingly, in another analysis, the Pi (π) diameter is 90 cm, which is the conventional diameter of the stone pillars. It is noteworthy that with increasing the diameter from 50 to 90, there was a small increase in the bearing capacity, but when the diameter of the column exceeds 90 cm, the bearing capacity did not increase significantly.

3.3. Effect of column length

In this section, for the Pi (π) with 10 meters diameter, the stone columns have been used with different lengths of 4, 7, 10, 13, 15 and 18 meters and with 90 cm diameter in reinforced and unreinforced conditions. The reason for using these lengths is that the length of more than 20 meters reduces the effectiveness of the stone column, in which case it is necessary to use a pile instead of a stone column. By looking at the modeling meters, it is observed that with increasing the length of the column, more areas of the soil beneath foundation are deformed and simultaneously it is under stress that this behavior is more visible when the soil is reinforced. According to Figure 3, which is for bearing capacity diagrams in loading conditions of foundation with a diameter of 10 meters, the presence of a stone column has not had a significant effect on bearing capacity. In this section, the diameter of the foundation reduces from 5 m to 3 m in the axial symmetry and the above calculation is done again. In Figure 3 and Figure 4, the force-settlement diagram is given to the mentioned conditions. It is clear that when the diameter of the foundation decreases, the effect of the length of the column is more noticeable. It should be noted that loading is based on the control strain (VESIC method) and in each case in all modeling; we consider the same settlement for the columns.

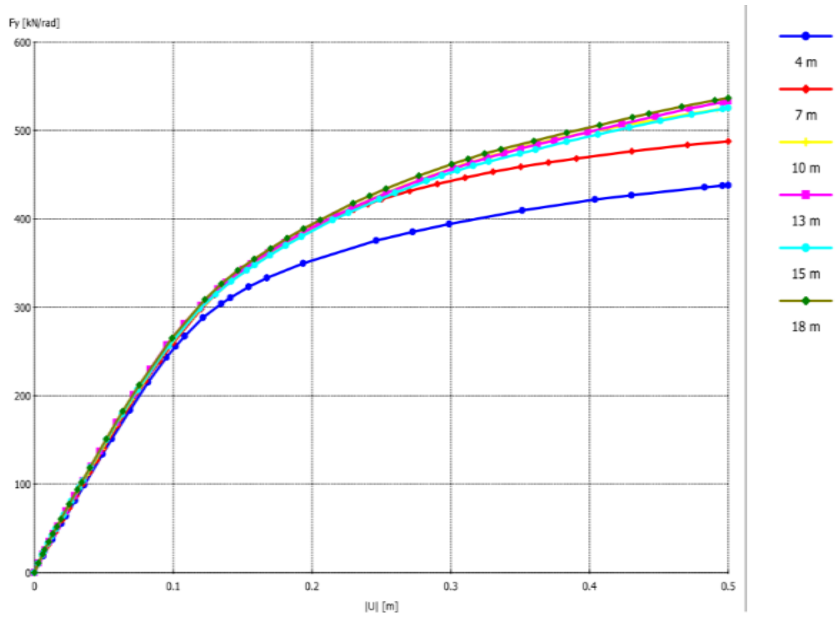

Figure 3. Effect of column length in unreinforced state for the foundation with 4m diameter

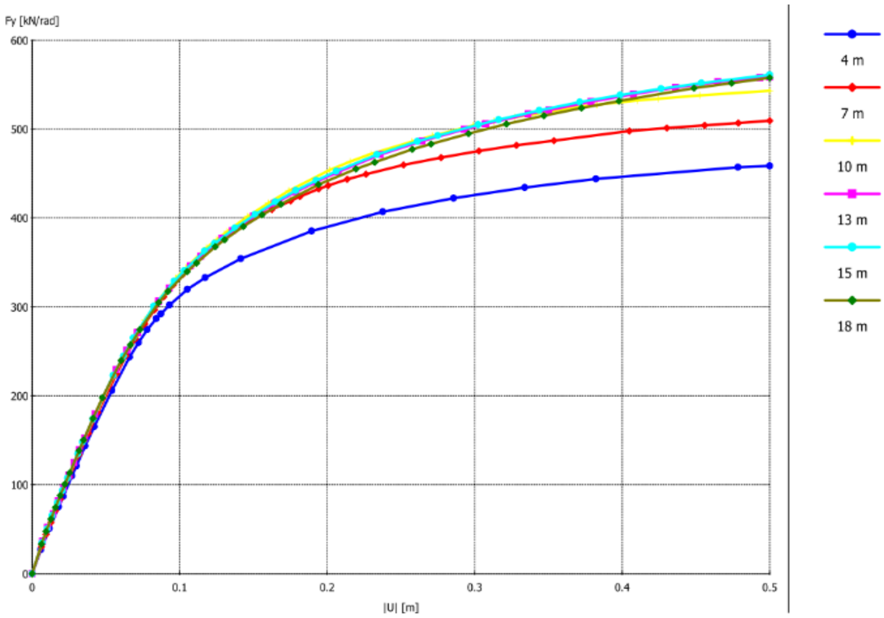

Figure 4. Effects of column length in reinforced state for the foundation with 5m diameter

As shown in Figure 5, increasing the length of the column for the foundation with a diameter of 5 to 10 meters, leads to increase the bearing capacity. Amount of bearing capacity is 500 kN at its maximum and then the bearing capacity is almost constant and increasing the length of the column has not had a significant effect on the bearing capacity (about 7%). In these charts, the bearing capacity is calculated based on a 30cm settlement. In the next stage analysis, the diameter of the foundation reduces to 3m. The size of 30 cm has been chosen because the curves obtained at this point (the number 30 in the graph of settlement) are flat and almost as a horizontal curve.

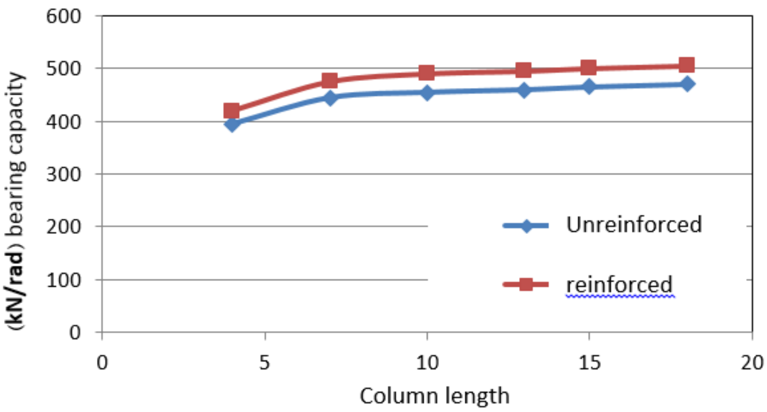

Figure 5. Comparison of the effect of column length in reinforced and unreinforced states with 5m

The Figure 6 and Figure 7 show the effect of increasing the length of the column in a reinforced state and unreinforced states for a foundation with 3m diameter.

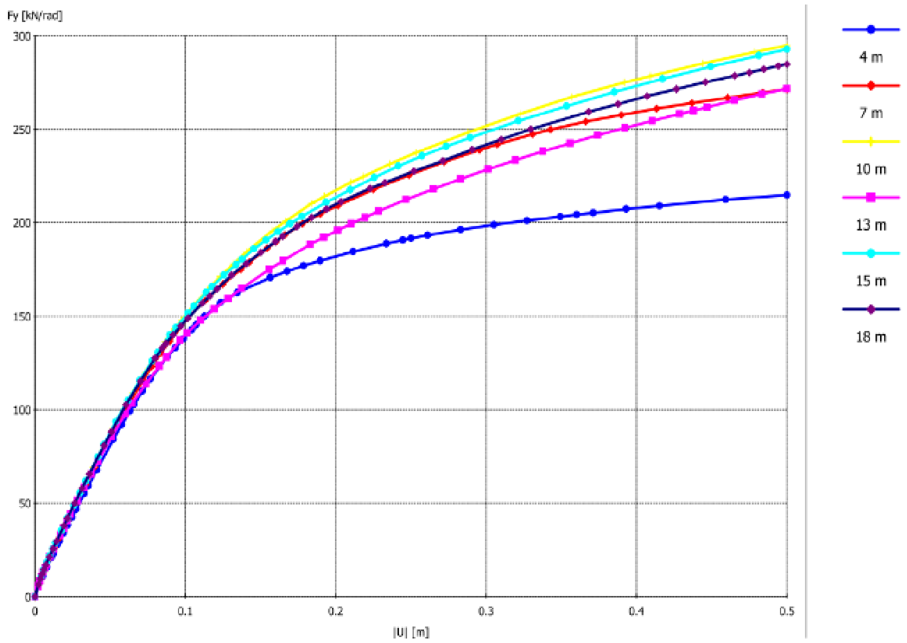

Figure 6. Effect of column length in unreinforced state for a foundation with 3m diameter

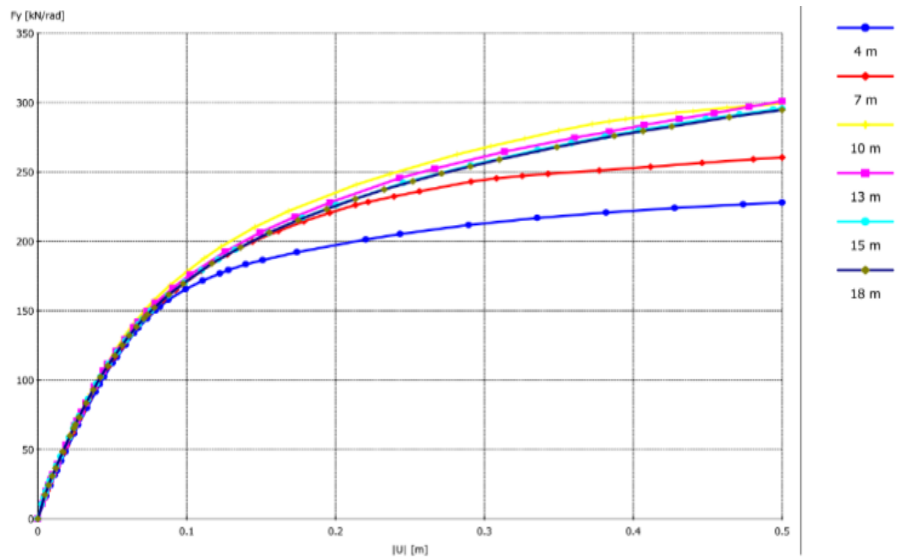

Figure 7. Effect of column length in unreinforced state for a foundation with 3m diameter

As shown in Figure 8, the increase in the length of the column for a foundation with 3m diameter and a length of about 10m for reinforced and unreinforced conditions leads to increase the bearing capacity. The maximum of the amount of the bearing capacity is 275 KN, and the bearing capacity decreases with more length. Therefore, increasing the length of the column for a foundation with 3m diameter did not have a significant effect on the bearing capacity (about 5.5%). In order to find the reason for reducing the bearing capacity, changing conditions in the geotextile layer shape must be examined.

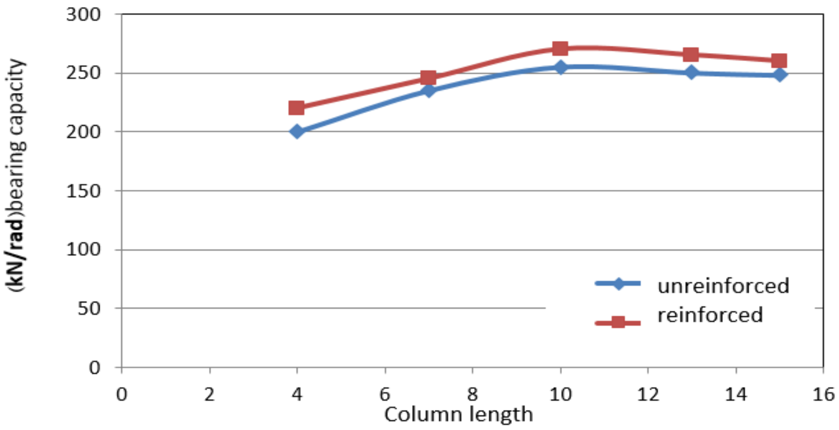

Figure 8. Comparison of the effect of column length in reinforced and unreinforced conditions with 3m diameter

3.4. Effect of clay cohesion around the column

In this section of the study, the effect of the clay cohesion around the column on the bearing capacity, as well as the stone column application has been examined. For this purpose, we use a stone column with a length of 10 m and a diameter of 90 cm in both reinforced and unreinforced conditions. The amount of cohesion is considered with 15, 20, 25, 30, 35, 40, 45 and 60 kN/m2 variables. The reason for the use of these sizes is that these are for common cohesion in ordinary soils, and the soil cohesion rate in Bandar Abbas is in these rates more than other rates. In Figure 9 and Figure 10, Settlement-Force curves are presented for two reinforced and unreinforced conditions.

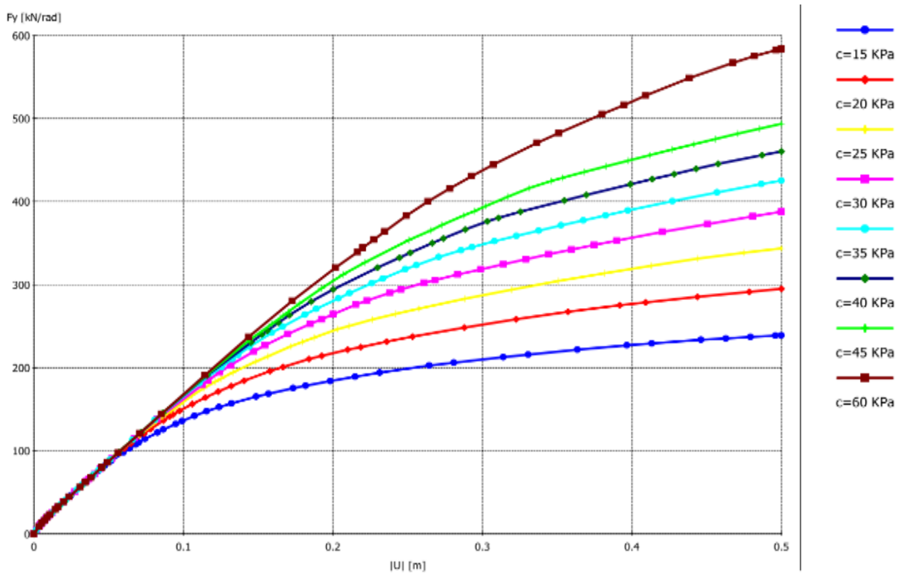

Figure 9. Effect of Cohesion of the swelling Soil on Settlement-Force Curves for unreinforced condition

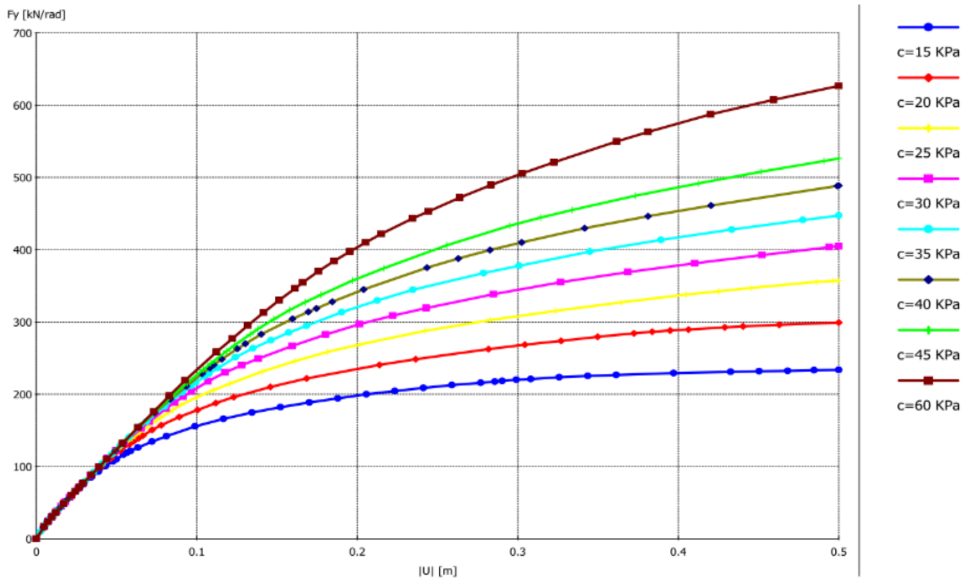

Figure 10. Effect of Cohesion of the swelling Soil on Settlement-Force Curves for unreinforced condition

Figure 11 shows the comparison between the bearing capacity of the foundation for reinforced and unreinforced conditions with different cohesions at a 20 cm settlement. The reason for choosing this size is to reduce the slope of the curve and its horizontal mode. As seen, the bearing capacity has increased with increasing cohesion. Initially, the slop of the curve is steeper (in other words, more bearing capacity) and with increasing the cohesion, the slop of the curve become low (in other words, lesser bearing capacity). Another point is that with increasing the soil cohesion, the difference between the bearing capacity increases in the reinforced and unreinforced conditions and the geotextile layer in the soil with more cohesion can create more bearing capacity of the soil. In other words, the difference between two curves (reinforced state with the geotextile and unreinforced condition) has increased with cohesion.

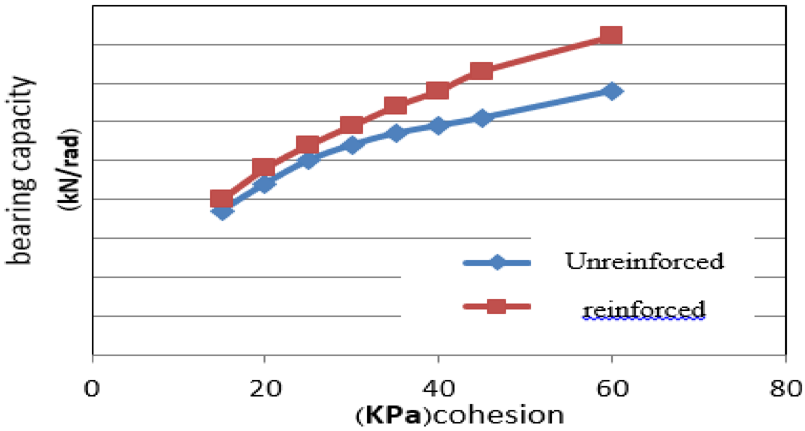

Figure 11. Graph of the cohesion Effect of the bearing capacity of the foundation with the stone column in the reinforced and unreinforced conditions

3.5. Stone column group

In this section, the effect of the stone column group of a circular foundation with 10 m diameter (5 m radius) is examined. It should be noted that according to the results obtained from the previous section, the diameter of the stone column in the reinforced and unreinforced conditions is considered to be 90 cm. In addition, the length of the column is considered equivalent with two different sizes of 10 and 18 meters. For modeling of the pile group, according to the suggestion given by various researchers such as Ghazavi and Afshar (12), Mitchell and Huber (13), the group of stone columns that are at the same distance from the center are used with a ring according to Figure 12, with a thickness that is equal to the area of the all columns and the area of the ring. Also, because in the reinforced conditions, the used geotextile area is less than the area of separated columns, the axial stiffness of the geotextile layer should be increased in proportion to their environments, which this issue has been also stated by the mentioned researchers. In Table 3, the modeling specifications are presented by 6 stone columns, 12 stone columns and 18 stone columns conditions around the central column. In Table 3, the numbers were based on the form and mentioned references. The distance between the columns is 2m, which has been chosen selectively. The numbers of the column have been obtained by dividing the geotextile area into the geotextile circumference and it is equivalent to the ring thickness. The geotextile stiffness are also derived from the division of the area into the geotextile circumference and multiplies the obtained result by the initial stiffness. Other numbers and no mentioned items have been also extracted from the mentioned references in this section.

Table 3. Profile Modeling Group stone column

Environment ring (m)	Ring distance of central column (m)	Geotextile hardly equal to kN / m	The thickness equivalent Ring (m)	Environment columns (m)	Columns' area (m2)	The number of columns around central column
12.56	2	42.25	0.6075	16.956	3.8151	6
25.12	4	42.25	0.6075	33.912	7.6302	12
37.68	6	42.25	0.6075	50.868	11.4453	18

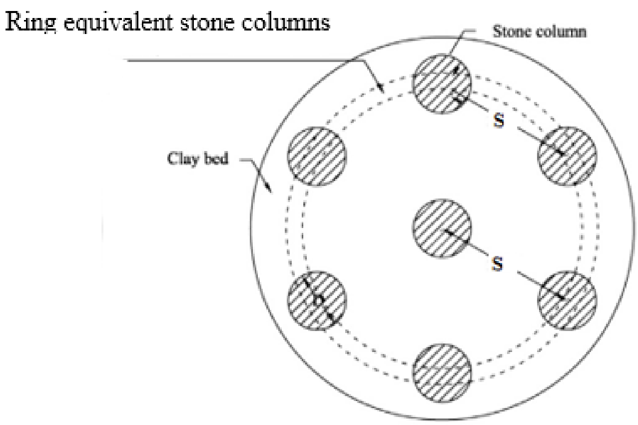

Figure 12. Modeling groups of stone column (six stone column and central column) (12)

3.6. Results of the stone column group effect under the static load (10 meter stone column examination)

In this section of the study, the results related to the effect of increasing the number of reinforced and unreinforced stone columns in the static loading conditions have been examined. It should be noted that for a modeled foundation with 10m diameter (5m radius), the use of a single stone column did not have a significant effect on the bearing capacity, so the number of columns was increased step by step. At the first step, 6 stone columns are created around the column, in the second step, 12 columns and at the last step, 18 columns are created around the initial single column and eventually, the group effects of the stone columns are examined. Figure 13, Figure 14 and Figure 15 show the impact of increasing the number of stone columns over the increase of the bearing capacity for the group of stone columns with a length of 10m with reinforced and unreinforced geotextile. As can be seen, with the increase in the number of columns in the area of the beneath foundation, the bearing capacity has increased, and when the number of columns exceeds the area of the beneath foundation, it will not have much impact on the bearing capacity, but will reduce the horizontal displacement of the soil. Of course, when a stone column is covered with geotextile on the outside of the area of foundation (18 columns), it has a more significant effect than the uncovered state in the bearing capacity of the foundation. In these diagrams, the bearing capacity of the settlement is calculated 15-mm.

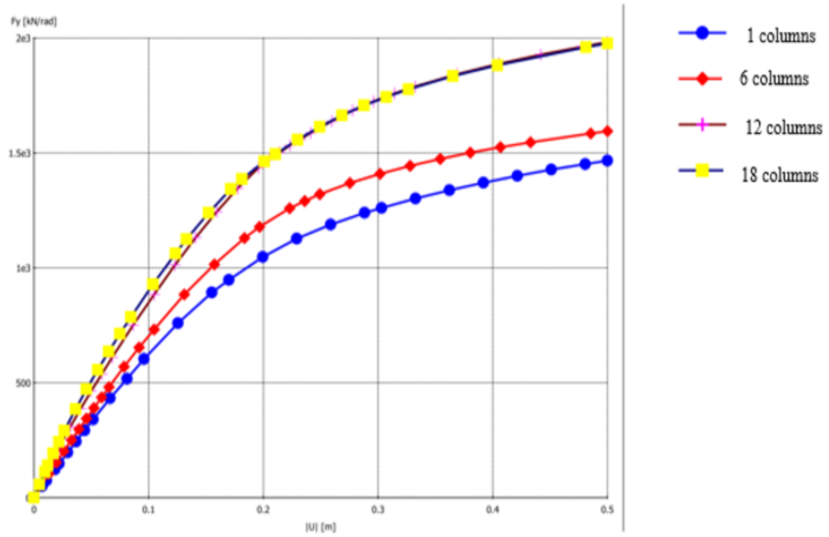

Figure 13. Total settlement-force curve for unreinforced group of stone columns with a length of 10m

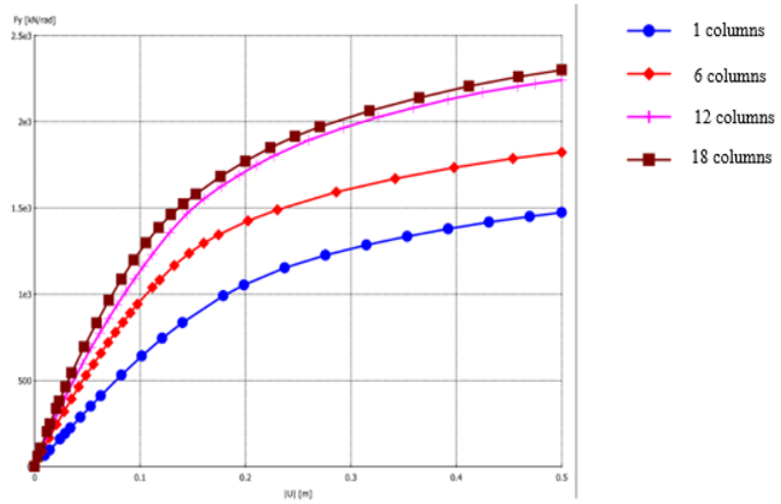

Figure 14. Total settlement-force curve for reinforced group of stone columns with geotextile

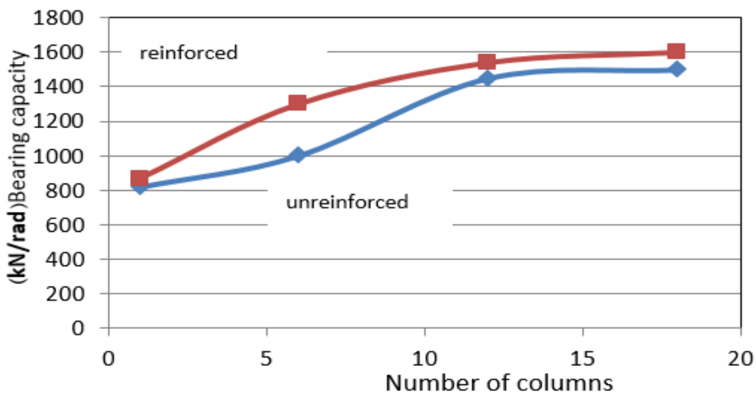

Figure 15. The effect of increasing the number of stone columns over increasing the bearing capacity (10m length)

3.7. 18 meter stone column examination

In this section of the study, the length of the stone column increases to 18 meters, and we examine it with both reinforced and unreinforced states. As shown in Figure 16, Figure 17 and Figure 18, the use of geotextile has led to a reduction in horizontal displacement. In the 10-meter column, most of the horizontal displacement was observed at the end of the columns, but in the 18m column, more horizontal displacement was observed on the surface near the loading, indicating that the used length of the stone column should be selected correctly. In Figure 18, the comparison between the geostationary-armed and unarmed state is shown to increase the length of the stone pillar to 18 m. It can be seen that increasing the length of the column has no significant effect on the load capacity.

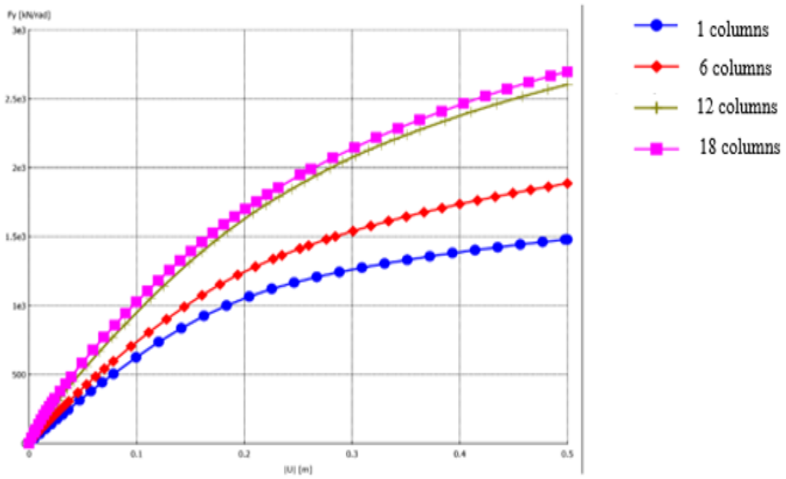

Figure 16. Total settlement-force curve for unreinforced group of stone columns with length of 18m

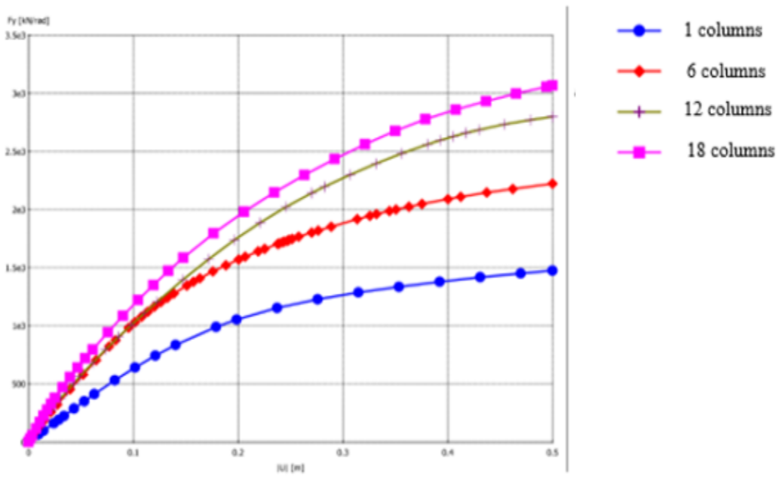

Figure 17. Total settlement-force curve for reinforced group of stone columns with length of 18m

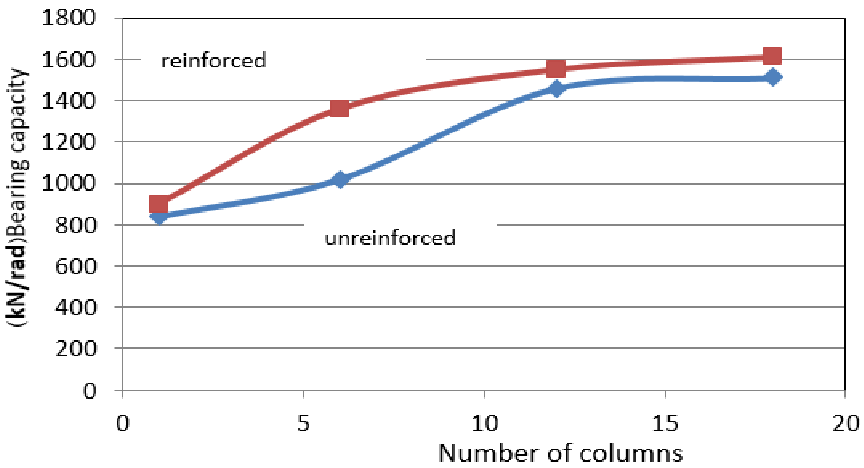

Figure 18. The impact of increasing the number of stone columns with increasing the bearing capacity (length of 18 meters)

In the following, a general comparison is carried out between the lengths of 10 and 18 meters. As shown in Figure 19, considering the amount of bearing capacity as well as the economic aspect and cost of execution, the choice of stone column with a length of 10m is a suitable option for foundations.

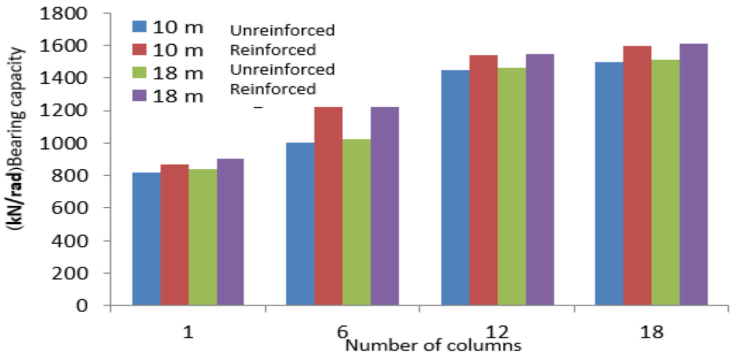

Figure 19. Comparing the effect of the length in the stone column group in reinforced and unreinforced conditions

3.8. Dynamic State Examination

As we know, the behavior of the stone columns changes in the exertion of the dynamic load behavior and shows a different behavior from the static state. So far, few studies have been studied to investigate the behavior of stone columns. Therefore, in this section of the study, the results of the increase in the number of reinforced and unreinforced stone columns have been investigated under the dynamic loading conditions. Since a single 10m (5m radius) modeled foundation had no significant effect on the bearing capacity, in this section, the number of columns has been expanded and studied step-by-step. In the first step, 6 stone columns are created around the column. In the next step, 12 columns and at the last step, 18 columns are created around the initial single column and the group effects of the stone columns are examined in this way. To create a dynamic load, firstly, it is necessary to define the absorbing boundaries. These boundaries have special conditions to define the soil as a semi-infinite environment. Without these special boundary conditions, waves will reflect on the boundaries of the model due to the turbulence. To avoid these false reflections, the absorbent boundaries are determined on the bottom and right sides of the boundaries. In Figure 20, only the boundaries on the bottom and right sides of absorbent boundaries and the boundaries of the left side are the symmetry axis and upper boundary of the free surface.

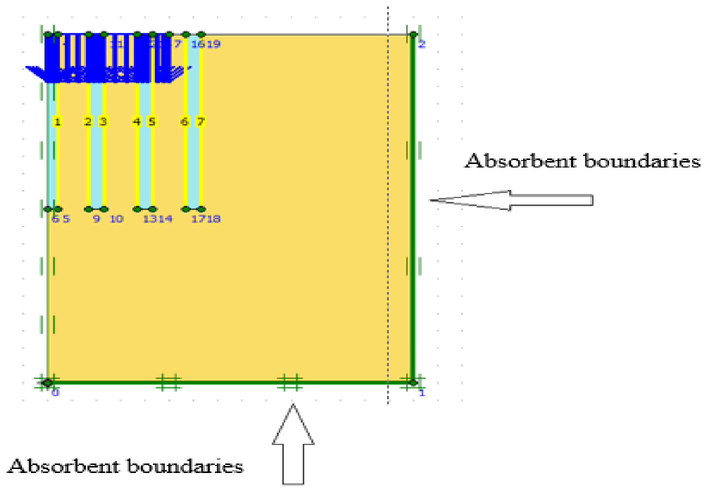

Figure 20. Absorbent boundaries in dynamic analysis

A computational phase is used to exert the dynamic load with the dynamic analysis type, and dynamic loading is a type of displacement with an amplitude of 50cm and a frequency of 10Hz. The loading is harmonic (for example, fluid vibration inside the reservoir) and the impact of the above vibration is at the foundation. The reason for choosing this type of earthquake record is the proximity of the earthquake record of the highest earthquake in Bandar Abbas. Figure 21 shows the time of the settlement for exerting the dynamic loading. In this research, the dynamic loading time has been considered 0.5 seconds.

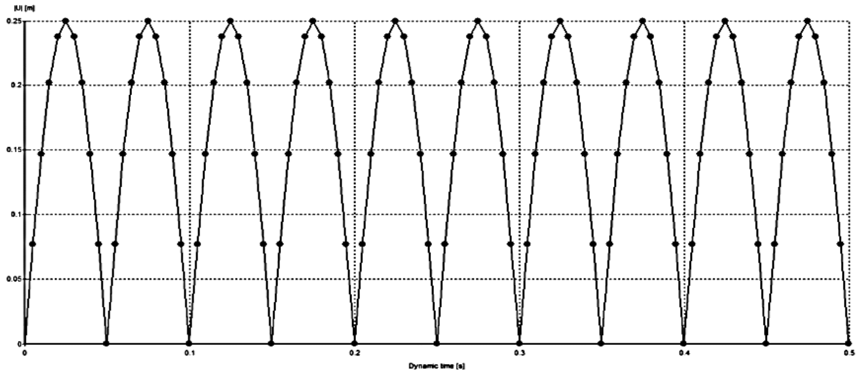

Figure 21. Settlement Time Graph for Dynamic Loading

Figure 22 and Figure 23, the force-time curves show the exerted dynamic loading for unreinforced state. It is clear that with increasing the number of columns, the bearing capacity of the foundation has also increased. When the number of columns increases to 18 columns (in other words, when the diameter of the foundation increases), the bearing capacity has not changed significantly. It is clear that with the increase in the number of stone columns, the bearing capacity of the foundation has had a more significant increase than the next cycles of dynamic loading in the initial loading cycles. It can also be concluded that in an unreinforced state, with increase in the number of stone columns up to 18 columns, the bearing capacity did not increase in comparison with 12 columns, but when the geotextile coating is used, the bearing capacity in the case of 18 stone columns has a significant increase in comparison with 12 stone columns. Figure 24 shows a comparison between the two reinforced and unreinforced states that its difference is about 75%.

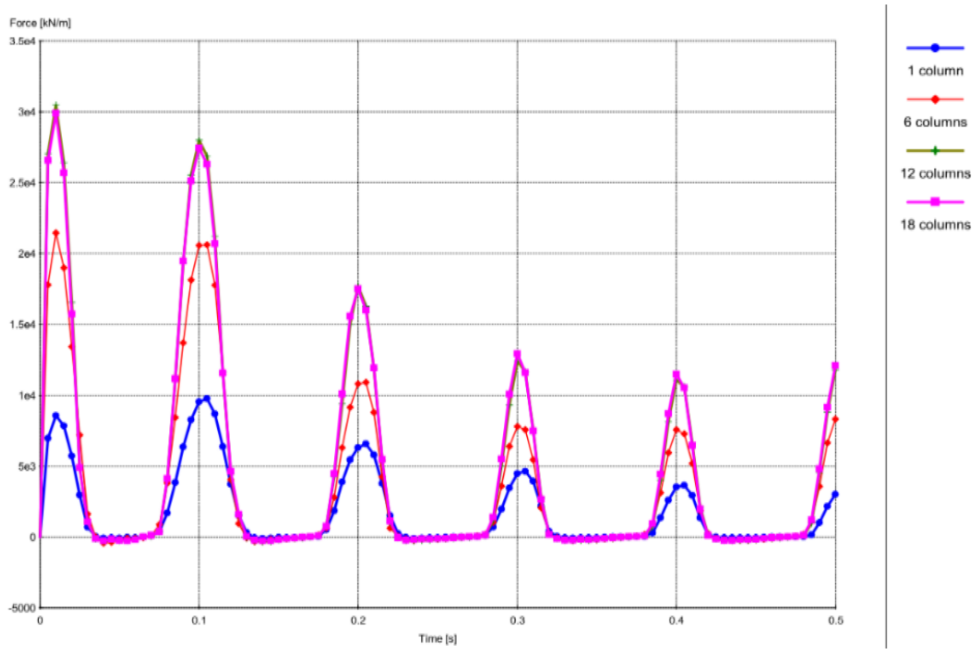

Figure 22. Force-time curves for dynamic loading in unreinforced state

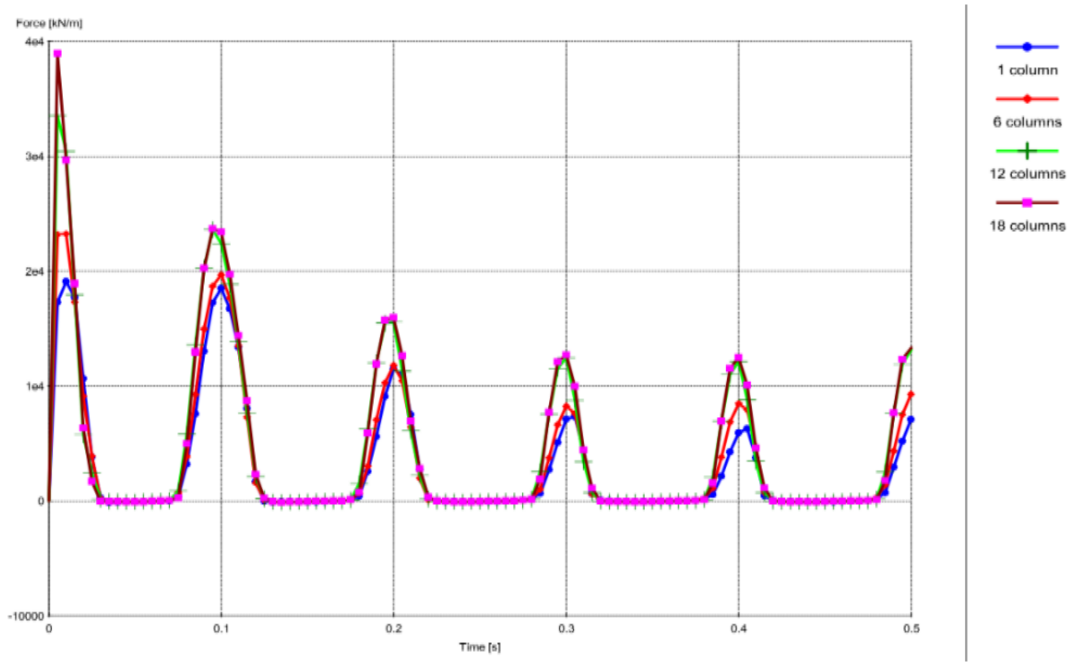

Figure 23. Force-time curves for dynamic loading in reinforced state

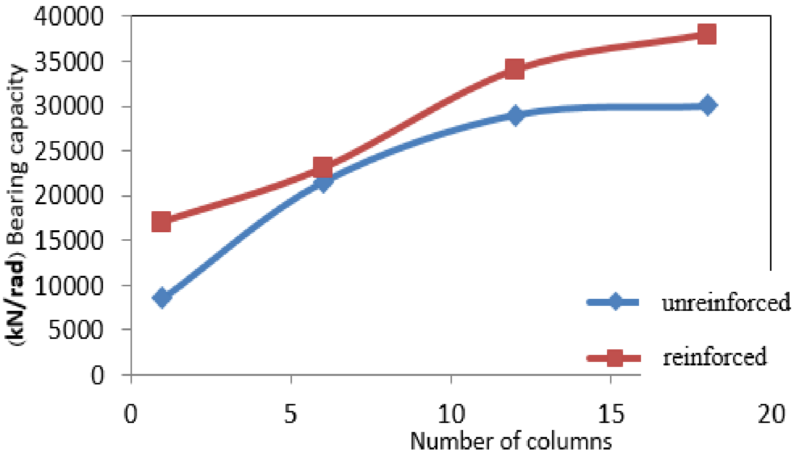

Figure 24. Bearing Capacity in Dynamic Loading in reinforced and unreinforced states

4. CONCLUSION

In this research, the numerical analysis of the confined stone columns by geotextile was studied and the static and dynamic behavior of confined stone columns in Geotextiles were examined as the signal and group states in two-dimensional mode with axial symmetry conditions. The various parameters considered in this research include the length of the stone column, the stone column thickness, the number of the stone columns, clay soil cohesion and loading width. After verifying with three laboratory tests, the following results can be confidently extracted from this research:

1. Increasing the diameter of the stone column up to 90cm leads to reduce the settlement of the foundation, however, increasing the diameter more than 90cm, does not effect on the reduction of the settlement. In addition, the diameter of the column does not significantly affect the load capacity. Choosing the 90cm diameter of a column which is the common diameter of the stone columns is a good choice. As the diameter ranged from 50 to 90, the bearing capacity was low, but when the diameter of the column exceeded from 90cm, the bearing capacity did not increase dramatically.

2. Bearing capacity graphs in loading conditions with a diameter of 10 meters indicate that the existence of the stone column has no significant effect on the bearing capacity and when the diameter of the foundation reduces to 5 meters, the increase in the length of the column to about 10 meters in length of the column increases the bearing capacity. Moreover, the bearing capacity is almost constant and the length of the column length has not had a significant effect on the bearing capacity.

3. Increasing the length of the stone column up to 10 meters reduces the foundation settlement, and increasing the length of the column does not affect the reduction of the settlement as well as increasing the length of the column for a 3m diameter in foundation about a length of 10 meters for a reinforced and unreinforced column leads

to increase of the bearing capacity. After that, the bearing capacity decreases, and the length of the column has not had a significant effect on the bearing capacity.

4. The use of geotextile in increasing the length of the stone column up to 10m leads to 30% settlement reduction and by increasing the length of the column and the geotextile layer, the most horizontal displacement occurs about 4m below the loading surface. In addition, with increasing the length of the column more than 10m, the end of the column will not be displaced horizontally and subsequently the horizontal stress and it cannot increase the bearing capacity.

5. The best selection of the stone column to reduce the settlement is a column with a diameter of 90cm and a length of 10m and the geotextile coating.

6. The best selection of the soil to reduce the settlement is the soil with 30kpa cohesion and increasing the cohesion leads to enhance the bearing capacity. Initially, the slope of the curve was steeper and it will reduce with increasing the cohesion. By increasing soil cohesion, the difference of the bearing capacity increases in the reinforced and unreinforced states and the geotextile layer can create more bearing capacity in the soil with more cohesion.

7. The presence of the geotextile layer leads to less displacement of the soil around the column, and when this displacement occurs at the top of the column, it creates more deformation inside the liner (the stone column material) which this deformation can increase the bearing capacity.

8. Selection of 12 stone columns reduces the settlement significantly and increasing the number of them does not impact on the settlement reduction and by increasing the number of columns, the horizontal displacement of the columns decreases and this reduction increases when the column is covered with geotextile. Increasing the number of columns in the area below of the foundation leads to increase the bearing capacity. Moreover, when the number of columns gets more than the area of the foundation, they have no much significant impact on the bearing capacity, but leads to reduce the horizontal displacement of the soil and when the stone column is covered with geotextile, the use of stone columns in the out of the foundation area has a more significant impact than the uncovered mode in the bearing capacity of the foundation.

9. The best selection of the stone column group to reduce the settlement is the choice of 12 columns with a length of 10 meters in reinforced conditions, which can reduce the settlement 50 percent in comparison with the single state.

10. When the length of the column exceeds a certain limit, the wedge of breaking occurs along the columns and increasing the length of the column to a certain extent does not have a significant effect on the bearing capacity of the foundation (to the point where the stress bubbles decrease very much). In the 10-meter column case, the most horizontal displacement is observed at the end of the columns. But in the 18m column case, a more horizontal displacement is observed in the near surface of loading.

11. With increase in the number of stone columns, the bearing capacity of the foundation in the first cycles of dynamic loading has a significant increase than the next loading cycles. In addition, in the unreinforced state, with increasing the number of stone columns up to 18 columns, the bearing capacity did not increase than the 12 columns state. However, when the geotextile coating is used, the capacity of bearing in the case of 18 stone columns also had a significant increase compared to the 12 stone columns.

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REFERENCES

1. Madhav M, Iyengar N, Vitkar R, Nandia A, editors. Increased bearing capacity and reduced settlements due to inclusions in soil. Proceedings of International Conference on Soil Reinforcement, Reinforced and other Techniques; 1979.
2. Greenwood D, editor Mechanical improvement of soils below ground surface. Inst Civil Engineers Proc, London/UK/; 1900.
3. Hughes J, Withers N. Reinforcing of soft cohesive soils with stone columns. Ground engineering. 1974;7(3).
4. Priebe H. Abschätzung des Setzungsverhaltens eines durch Stopfverdichtung verbesserten Baugrundes. Die Bautechnik. 1976;53(5):160-2.
5. Vekli M, Aytekin M, Ikizler SB, Çalik Ü. Experimental and numerical investigation of slope stabilization by stone columns. Natural hazards. 2012;64(1):797-820.
6. Balaam N, Booker JR. Analysis of rigid rafts supported by granular piles. International Journal for Numerical and Analytical Methods in Geomechanics. 1981;5(4):379-403.
7. Donner H. Balaam pseudopropheta: Vandenhoeck & Ruprecht; 1977.
8. Katti R, Katti A, Naik S. Monograph to analysis of stone columns with and without geosynthetic encasement. CBIP Publication, New Delhi. 1993.
9. Deb K. A mathematical model to study the soil arching effect in stone column-supported embankment resting on soft foundation soil. Applied Mathematical Modelling. 2010;34(12):3871-83.
10. Murugesan S, Rajagopal K. Studies on the behavior of single and group of geosynthetic encased stone columns. Journal of Geotechnical and Geoenvironmental Engineering. 2009;136(1):129-39.
11. Deb K, Samadhiya NK, Namdeo JB. Laboratory model studies on unreinforced and geogrid-reinforced sand bed over stone column-improved soft clay. Geotextiles and Geomembranes. 2011;29(2):190-6.
12. Ghazavi M, Afshar JN. Bearing capacity of geosynthetic encased stone columns. Geotextiles and Geomembranes. 2013;38:26-36.
13. Castro J, Sagaseta C. Consolidation and deformation around stone columns: Numerical evaluation of analytical solutions. Computers and Geotechnics. 2011;38(3):354-62.
14. Gniel J, Bouazza A. Construction of geogrid encased stone columns: A new proposal based on laboratory testing. Geotextiles and Geomembranes. 2010;28(1):108-18.
15. Muir Wood D, Hu W, Nash D. Group effects in stone column foundations: model tests. Geotechnique. 2000;50(6):689-98.

16. McKenna J, Eyre W, Wolstenholme D. Performance of an embankment supported by stone columns in soft ground. Geotechnique. 1975;25(1):51-9.
17. Malarvizhi S. Comparative study on the behavior of encased stone column and conventional stone column. Soils and Foundations. 2007;47(5):873-85.
18. Wu C-S, Hong Y-S. Laboratory tests on geosynthetic-encapsulated sand columns. Geotextiles and Geomembranes. 2009;27(2):107-20.
19. Jahandari S, Saberian M, Zivari F, Li J, Ghasemi M, Vali R. Experimental study of the effects of curing time on geotechnical properties of stabilized clay with lime and geogrid. International Journal of Geotechnical Engineering. 2017:1-12.
20. Murugesan S, Rajagopal K. Geosynthetic-encased stone columns: numerical evaluation. Geotextiles and Geomembranes. 2006;24(6):349-58.