Experimental investigation on bearing capacity of geosynthetic encapsulated stone columns

Étude expérimentale sur la capacité portante des colonnes de pierre géosynthétiques encapsulées

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ABSTRACT: Civil engineers have developed different soil improvement techniques in recent decades to improve the bearing capacity of soft soils loaded by foundations and reduce soil settlement. A method for increasing the bearing capacity of foundation soil is the use of stone columns. However, one of the major weaknesses in use of stone columns in loose soils is lack of confinement. Using geosynthetic reinforcement to compensate low confinement pressure in these soils, is a solution to this problem. This paper presents the results of an experimental study on the improvement of the bearing capacity of stone columns reinforced by geosynthetics. In this study the influences of three variables have been investigated, including: surrounding soil types (i.e. clay and sand), stone column aggregate size and length of reinforcement. Having mentioned these variables, the results showed that encapsulating stone column with geosynthetic is more effective in cohesive soil compared to granular soil. The results of the experiments revealed that the coarser the aggregate the better behavior is expected for the stone column. The results also showed that, reinforcing half height of stone columns is the optimal encapsulating length.

RÉSUMÉ: Ces dernières décennies, les ingénieurs civils ont développé différentes techniques pour l'amélioration de la capacité portante du sol mou ainsi que celles des fondations. Une des techniques couramment utilisée permettant l'augmentation de la capacité portante des sols et des fondations est l'utilisation des colonnes de pierre. Cependant, l'une des grandes faiblesses de l'utilisation de colonnes de pierre dans les sols mous est le manque de confinement. L'utilisation de renforts géosynthétiques permet de compenser pour la faible pression de confinement. Cet article présente les résultats d'une étude expérimentale sur l'amélioration de la capacité portante des colonnes de pierre renforcées par des méthodes géosynthétiques. Dans cette étude, l'influence de trois variables ont été étudiées, notamment: le type de sol environnant (i.e. argile et sable) ainsi que la longueur de l'armature de renforcement. Les résultats démontrent que l'emploi de la colonne en pierre avec encapsulation géosynthétique est plus efficace dans un sol consistant comparé aux sols granulaires. De plus, les résultats de ces expériences ont révélé que plus la rugosité de l'agrégat augmente, plus le comportement des colonnes de pierres est amélioré. Finalement, les résultats indiquent que la longueur d'encapsulation optimale est atteinte en renforçant la hauteur médiane des colonnes de pierre.

KEYWORDS: stone column, bearing capacity, geosynthetic, reinforcement.

1 INTRODUCTION.

In recent years with increasing in population density in specific locations,the value of land has increased signifacntly. This has made the use of areas with soft soils inevitable.

Due to the lack of bearing resistance in these soils, different methods of soil improvement techniques, including stone columns as a method of strengthening the loose soil are used.

Stone columns behavior has been studied experimentally, theoretically and numerically by many researchers (Bergado and Teerawattanasuk2008, Guetif et al. 2007, Castro and Sagaseta2011)

However, one of the major weaknesses in use of stonecolumns in loose soils is lack of confinement. This lead researchers and practioners to use geosentitics to increase confinement of column, compansating the scarcity of studding around reinforced stone columns (Malarvizhi and Ilamparuthi2007, Gniel and Bouazza2009, Gniel and Bouazza2010). In this study the parameters affecting the behavior of reinforced stone columns have been investigated. These parameters are reinforced length, column material and surrounding soil type.

2 LABORATORY SETTINGS

Since the focus of this research was on the laboratory results, the phyical model, is described, firstly.

2.1 *Test apparatus*

A cylindrical tank (height=1.0 m and dia.=1.0m) filled with soil was used as the soilenvironment. Stone column run in the middle of the tank.The static loading system consists of a loading arm and weights were used(Razavi and Hataf, 2003) to determine the bearing capacity of a circular foundations resting on stone column, Figure 1.

2.2 *Soil tested*

To test and evaluate the behavior of reinforced stone columns in loose soil, two soil types were used, a clay soil as cohesive soil and a sandy soil as granular soil.

Physical properties of the soils are listed in Table 1.

2.3 *Specimens preparation*

To prepare the soil and column, first two 10 cm soil layers has been poured in the tank and compacted using 20 strokes caused by dropping a 50 N weight attached to a wooden handle from a distance of 40 cm as the substrate layer.The next layerswere compacted with 10 strokes from 10cm distance to provide loose soil.

Toprepare the stone column an open ended hollow cylindrical pipe with a diameter of a little more than the diameter of the stone column was used.After that the cylinder was placed at its position and the surrounding was filled slowly with soil.

Figure 1.Laboratory setting for model testing.

Table 1. Physical properties of the soils tested.

Parameter	*Clay*	*Sand*
Friction Angle	26.0	35.0
Cohesion (KN/m^2)	5.0	0.0
Unit weight(KN/m^3)	15.0	16.0
Liquid Limit(%)	44.5	-
Plasticity Index (%)	20.0	-

Then until reaching up to the surface level the stone column filled with stone aggregates in 10 cm layers.After filling each layer the cylinder pulled out about 10 cm and aggregates were poured in and compacted with 40cm length rod.

Three types of aggregates were used to fill the stone columns. These are shown in Figure 2.

Stone columns with no reinforcement, half-length reinforcement and full-length reinforcement were prepared for testing. A commercially available geogrid was used for reinforcement.

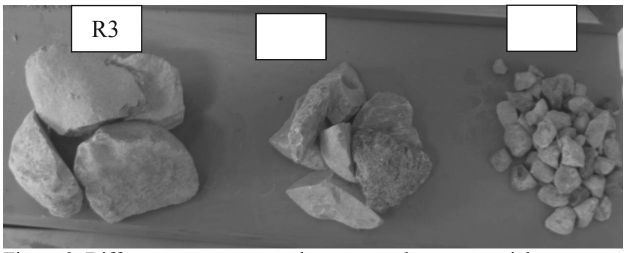


Figure 2. Different aggregates used as stone columns materials.

3 TEST RESULTS

Test results as load settlement curves for stone columns embedded in cohesive and granular soils are illustrated in Figures 3 an 4. In this figures f-Ri, h-Ri and no-Ri stand for full-length, half-length and no reinforced column, respectively.

Loads were normalized to maximum load obtained for unreinforced column in each case and settlements were normalized to radius of stone column.

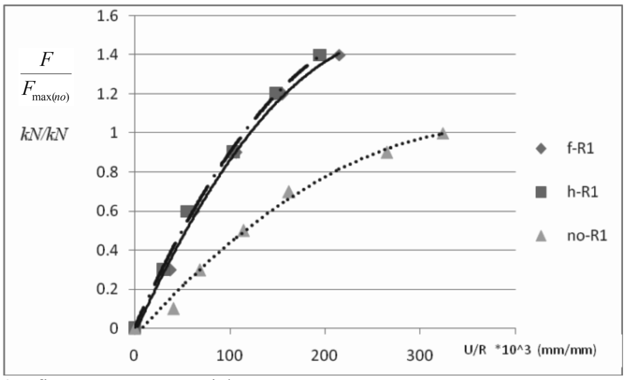
As it can be seen from these figures it is obvious that reinforcement improve the bearing capacity of stone columns in both cohesive and granular soils. The reinforcement however is more effective in cohesive soil than in granular soil.

Further numerical studies (not presented here) showed that the effect of viscosity is reduced with the increase in cohesion of soil which in turn caused increase in the confining pressure of surrounding soil. Therefore this results in decrease in stone column material to spread out within the surrounding soil.

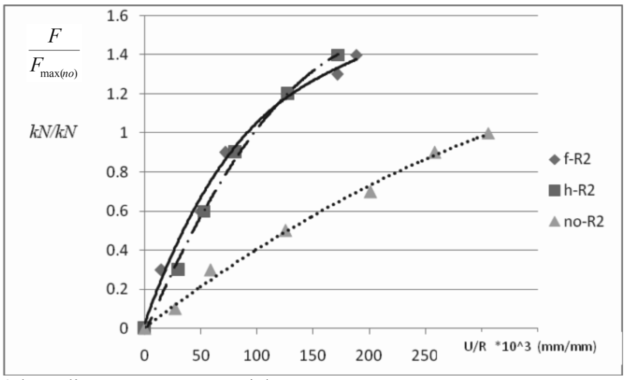
The most important variable in this study was to experimentally and practically examine the optimal lengthof reinforcementfor optimal strength. This was achieved by changing the length of reinforcement compared to the column length as full-length, half-length and non-reinforced.

Test results indicated that in both types of surrounding soils and for all sizes of column aggregate materials, it is enough to reinforce only half length of the column to achieve desired bearing improvement. However the Improvement ratein cohesive soils is more noticeable. This can be related to the fact that the confining pressure in the bottom of the column is higher than that in the upper parts of the column due to higher overburden pressure. By increasing the confining pressure in the upper parts of the column by installing reinforcement, the radial strain reduces and as the result, it reduces the side contact pressure between the soil and stone column. This in turn causes just vertical distribution of the stresses to the layer below the column and not distributing of stresses to the surrounding soil. This obviously causes more vertical deflections in the below layers of soil and less in the upper layers.

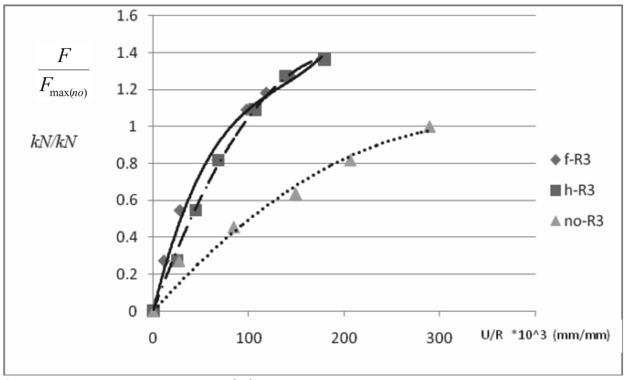
In the half-length reinforced column by increasing in stresses,a small amount of inflation on the side layers are observed which results in increase in lateral soil friction and so the stresses spreads over a larger surface of the soil and it results the deflection not to increase below the column but spread in larger area homogeneously.



3-a fine aggregate material

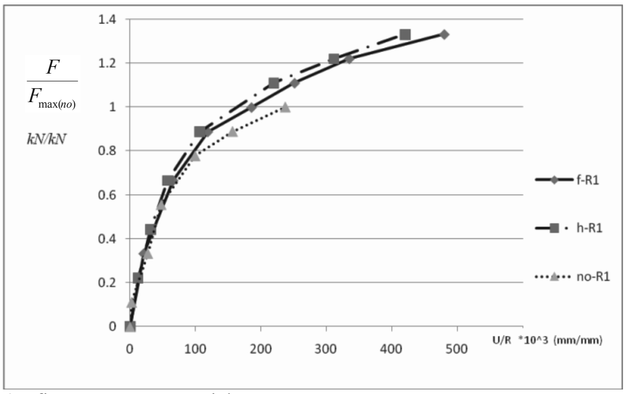


3-b medium aggregate material

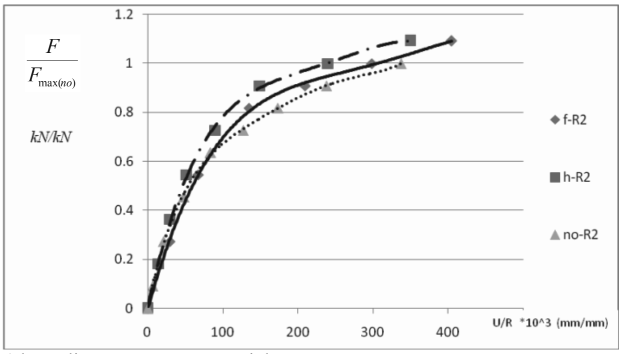


3-c coarse aggregate material

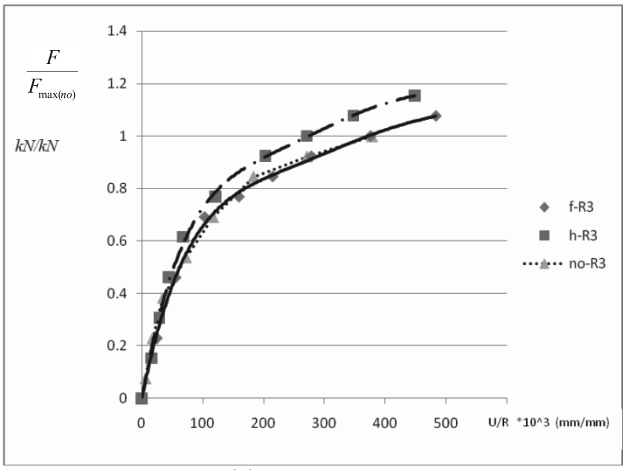
Figure 3. Test results for stone columns embedded in cohesive soil.



4-a fine aggregate material



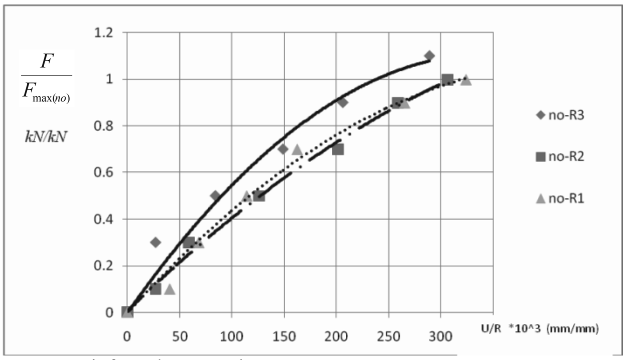
4-b medium aggregate material



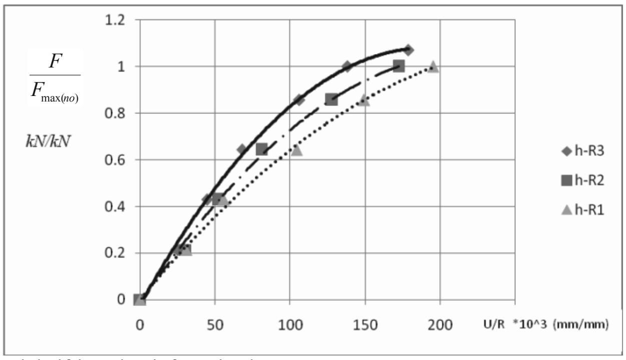
3-c coarse aggregate material

Figure 4.Test results for stone columns embedded in granular soil.

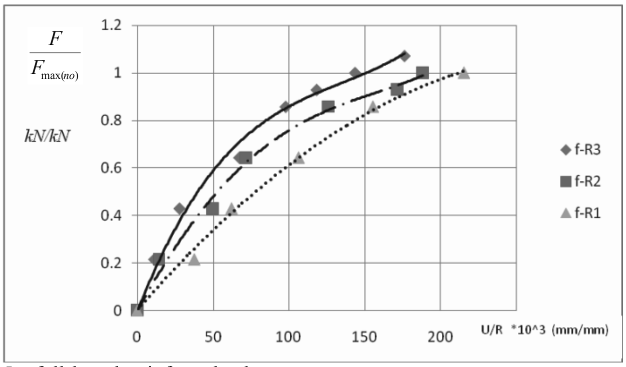
As it was mentioned earlier one of the variables in this study was the size of the column aggregate materials. The results of tests on the same stone column conditions but with different size of stone column materials are illustrated in Figure 5 and 6 for cohesive and granular surrounding soils, respectively.It can be seen that keeping all conditions constant, there was an increase in bearing resistance of the column with increasing grain size dimension of column material. However the improvement due to the use of geosynthetic reinforcement was the same for all column material sizes.



5-a non-reinforced stone column

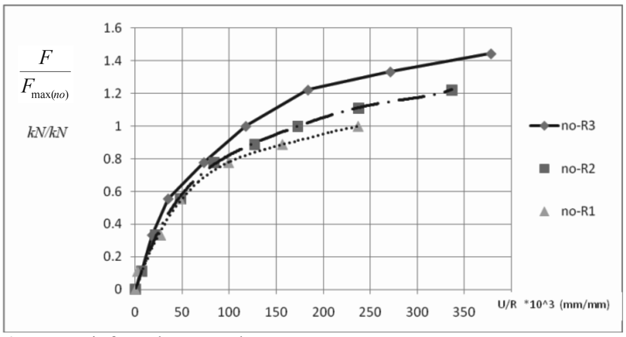


5-b half-length reinforced column

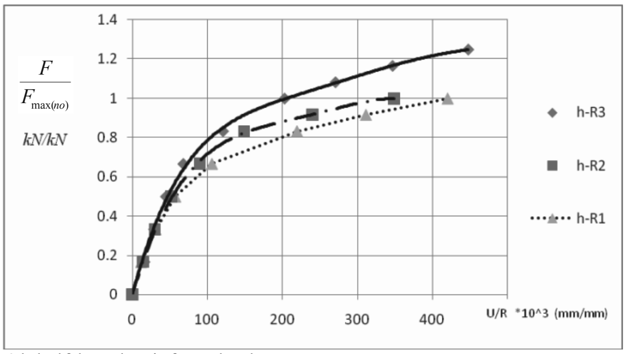


5-c full-length reinforced column

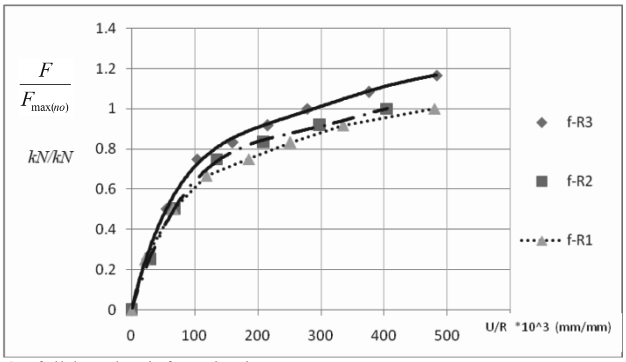
Figure 5. Test results for different stone columns materials embedded in cohesive soil.



6-a non-reinforced stone column



6-b half-length reinforced column



6-c full-length reinforced column

Figure 6. Test results for different stone columns materials embedded in granular soil.

4 CONCLUSION

One of the recent methods for increasing the bearing capacity of foundation soil is the use of vertical stone columns. Stone columns consist of a stiffer material or aggregates, compared to the surrounding soils, which are usually vibrocompacted into the soil. These columns increase the bearing capacity of the soil significantly. Compared to concrete or steel piles inclusion, for soil improvement, this technique is more economical and needs to be studied further. However, one of the major weaknesses in use of stone columns in loose soils is lack of confinement. This leads to use reinforcement to compensate low confinement pressure in these soils. Because of the lack of experimental studies on the behavior of reinforced stone columns, an experimental study has been performed. It was shown that the use of stone columns improves the soil bearing capacity, significantly. The results showed that encapsulating stone column with geosynthetic is more effective in cohesive soils compared to granular soils. Three types of stone column materials were used with different aggregate dimensions. The results of the experiments revealed that the coarser the aggregate the better behavior is expected for the stone column. Although the increase in grain size should not be more than two percent of stone column diameter. On the other hand, the behavior of stone column encapsulated by geosynthetic in its entire length was compared to partially encapsulated stone column behavior. The results showed that, reinforcing half height of stone columns in both types of soils, especially in clay, is the optimal encapsulating length. This finding is significant regarding the economical and efficiency of use of stone columns as a soil improvement technique.

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