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ABSTRACT

Nowadays, diminish in suitable sites for constructions become a big challenge for engineers and encouraged them to consider improving of the in situ soils. Out of all methods for ground improvement, stone column became more popular these days according to its simple construction and economic consideration. Installation of stone column especially in loose and fine graded soil causes increase in load bearing capacity and settlement reduction. On the other hand installation of stone column in very soft soils faces to some limitations and the soft soil particles may not clog into the stones successfully so further development in stone column installation is reinforcing the columns with geosynthetics or geogrids. This paper introduces the assumptions, procedures and results of the numerical analysis for simulating the behaviour of un-encased versus geogrid encased stone column in soft clay. Settlement and bearing capacity of stone columns and geogrid encased stone columns in terms of various diameters were selected as criteria for judgment and comparison of the behaviour of the ordinary and geogrid encased stone columns. The proposed evaluation is conducted with the aid of finite element software, PLAXIS V.8, and a reasonable agreement obtained between the experimental investigation and the finite element method.

KEYWORDS: stone column, geogrid, geosynthetics, finite element, ground improvement.

INTRODUCTION

Showing the evidence of feeble strength and compressibility are among the characteristics of soft soils according to which the necessity of ground improvement technique for this kind of soils is revealed. Because of the simplicity of its construction and through economic contemplation, stone column became a suitable method for improving weak strata. The mechanism is such that the bearing capacity is increased by means of bulging which causes the passive pressure to be generated in the surrounding soil (Greenwood, 1970). However in confront with very soft soils the stone columns have certain limitation as reduction in radial drainage due to clay particles' clog round the stones thus the installation of the stone columns need to be assisted with reinforcement such as geosynthetics, geogrid and so on (Raithel and Kempfert, 2000; Raithel et al., 2002). Encapsulating the stone columns with the geogrid of higher strength results in lateral captivity of the column and alternatively prevents the lateral displacement thus helps in increasing the bearing capacity besides precluding the loss of stone during the installation.

Van Impe (1985) was the first who proposed the concept of encasing the stone column. Raithel and Kempfert (2000) in the course of analytical and numerical studies analysed the performance of geosynthetic-encased sand columns. Malarvizhi and Ilamparuthi (2004) during a laboratory analysis on the performance of geosynthetic-encased stone column realised that the bearing capacity of the reinforced stone column increased 3 times in comparison with that of unreinforced for both floating and end bearing columns. Ayadat and Hanna (2005) carried out experimental study on geogrid encapsulated stone columns and concluded that by the increase in the stiffness of the geofabric materials the bearing capacity of a stone column will also increase. Gniel and Bouzza (2009) conducting some experimental tests, studied the influence of encasement's length on the encased stone column, they also by the unit-cell theory done numerical analysis to evaluate their work. Murugesan and Rajagopal (2009) evaluated the shear load capacity of non-reinforced and reinforced stone columns by generating lateral soil movements through laboratory tests. Yoo (2010) employed three dimensional finite element model of geosynthetic-encased stone columns installed in soft clay and analysed the effect of factors such as consistency of soft ground, the geosynthetic encasement length and stiffness and area replacement ratio.

RESEARCH METHODOLOGY

This study is conducted using data obtained from experimental investigation conducted by Malarvizhi and Ilamparuthi (2006). Based on obtained data by using finite element software Plaxis 2D an axisymmetric model of stone column configured and the load-settlement response of stone column defined in two alternatives of using geogrid encasement and without geogrid, detailed parametric analyses were performed by varying the diameter of the stone column and stiffness of the geogrid used for encasement.

Numerical Simulation

All the analyses in this investigation were performed using the finite element program (PLAXIS 2D). For design and analysis purposes, a cylindrical unit cell is considered, consisting of stone column and surrounding soil a working area of 400 mm width and 300 mm depth. In finite element models, the cylindrical unit cell can be idealized using axisymmetric model with radial symmetry around the vertical axis passing through the centre of the stone column; initially at the axis of symmetry the column had been modeled with diameters of 60, 40 and 30 mm and length of 300 mm (the columns modeled as end bearing. Later, analyses were performed using geogrid encasement. The geogrid encasement around the stone column was modeled as linear elastic material and discretised as continuum elements around the stone column (considering axisymmetric idealization). Detailed parametric analyses were performed by varying the diameter of the stone column and stiffness of the geogrid used for encasement. The finite element mesh was developed using 15-noded triangular elements for all the components in the system as shown in Figure 3.1. The boundary conditions along the vertical boundaries of the axially symmetrical model are fixed for the lateral deformations. The boundary condition allows vertical deformation.

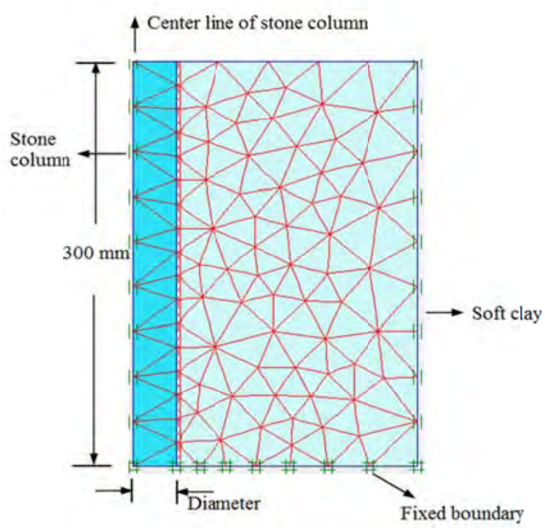

Figure 1: Typical finite element mesh

The clay was modeled using the soft soil model; the stone column was modeled as a Mohr-Coulomb material. The clay is treated as an undrained material and the stone as a drained material. The geogrid around the stone column was modeled as linear elastic material and discredited as continuum elements around the stone column (considering axisymmetric idealization).

Materials

The material properties selected in the analyses were based on the material properties that Malarvizhi and Ilamparuthi (2006) had used in their tests and are presented in table (1). In modeling the stone column without geogrid at the interface between the stone column and soft clay, interface elements have been used. This can be explained by the fact that the deformation of the column is mainly by general failure and which produces significant shear between clay and stone column. The interface has been modeled along the length of the column between stone column and soft clay in order to consider the compaction effect due to installation process.

Table 1: Material Properties and input parameters

Parameter	Clay	Stone Column
$E[kPa]$	—	2500
υ	—	0.35
$\gamma[kN/m^3]$	12	16
$\varphi^/[°]$	24	46
$c^{'}[kPa]$	3.5	0.1
$\psi[°]$	0	20
$k[m/day]$	2.39e-4	1

Parametric Analysis

In this section the influence of different parameters on the performance of the stone column is studied through 2D numerical analyses. To assign a load on top of the stone column Prescribed settlement approach, was considered. The prescribed settlement option allows to give a settlement and the load capacity is calculated based on the settlement. In this type of analysis the calculation is divided into three phases. In initial phase the stone column is modeled only and with the aid of prescribed displacement the allowable load was calculated due to 20 mm settlement. In second phase the diameter were changed to 40 and 30 mm and the effect of changing the diameter was evaluated, in third phase the stone column was reinforced with geogrid and the improvement due to geogrid encapsulation was investigated for 3 different diameters of 30, 40 and 60mm, and finally in the last phase the effect of geogrid stiffness was inspected by varying the geogrid stiffness of 50, 250, 500 and 1000 kN/m for 60mm diameter stone column.

RESULTS AND DISCUSSIONS

Influence of Size of Column on Load Capacity

Test was carried out on end bearing columns of 300 mm length of different diameters 30, 40 and 60mm. The loading was done on 2D, and the resulting load-settlement curves were compared in the Figure 2.

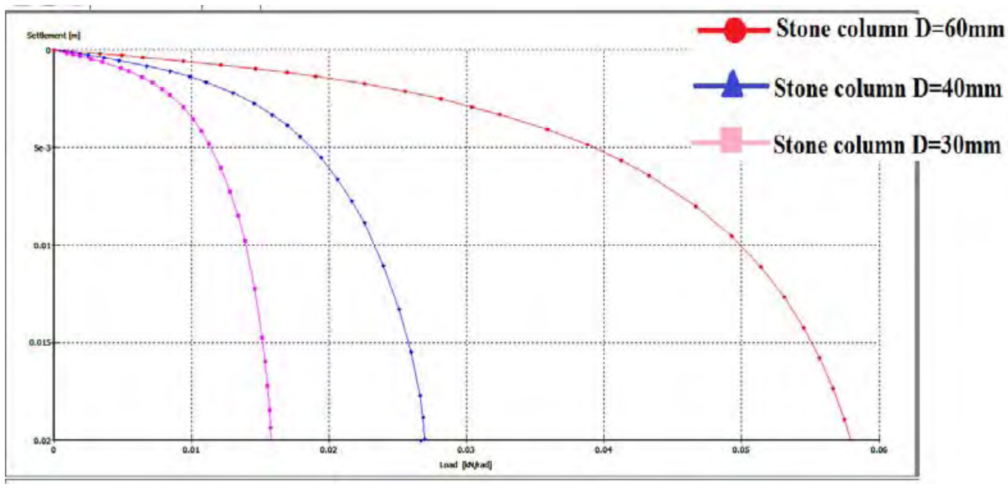

Figure 2: Load vs. settlement of stone columns with different diameters

It is seen from the load-settlement curve of the stone column that the load carrying capacity of the stone column increases by the increase of the column's diameter and for a specific settlement the stone column with bigger diameter can afford higher load than the smaller diameter stone column.

Table 2: Bearing capacity of stone column with different diameters

Stone Column	D=30	D=40	D=60
Bearing Capacity in 20 mm settlement	97.34	166.47	353.88

Influence of Geogrid on Load Carrying Capacity

To understand the encasement effect, stone columns and geogrid encased stone columns of 60mm diameter were compared with the corresponding columns of 30mm and 40mm diameters. Loading was done on 2D, and the resulting load-settlement curves were compared in the Figure 3.

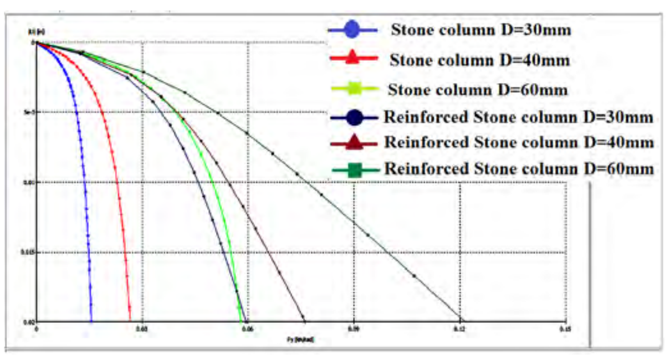

Figure 3: Load vs. Settlement of stone/reinforced-stone columns of different diameters

As it can be seen from figures 3, for reinforced stone column also by increase in column's diameter the load carrying capacity will increase, it is noteworthy that the results obtained from

FEM are in good agreement with the experimental results conducted by Malarvizhi and Ilamparuthi (2006) and the trend shows that the reinforced stone column will increase its strength in comparison with the non-reinforced subject and this increase is approximately to three times more than non-reinforced stone column.

Table 3: Bearing capacity of stone/reinforced-stone column with different diameters

Stone Column	D=30	D=40	D=60
Bearing Capacity (in 20 mm settlement)	97.34	166.47	353.88
Reinforced Stone Column	**D=30**	**D=40**	**D=60**
Bearing Capacity (in 20 mm settlement)	73.24	478.15	762.78

Influence of Geogrid Stiffness

The influence of the tensile stiffness of the geogrids used for encasement on the performance of the stone column was investigated by varying the stiffness of geogrid over a wide range of values (from 50 up to 1000 kN/m), while all other parameters were kept constant. Figure 5 shows the load- settlement behavior of 60mm diameter stone column encased with geogrid of different stiffness values.

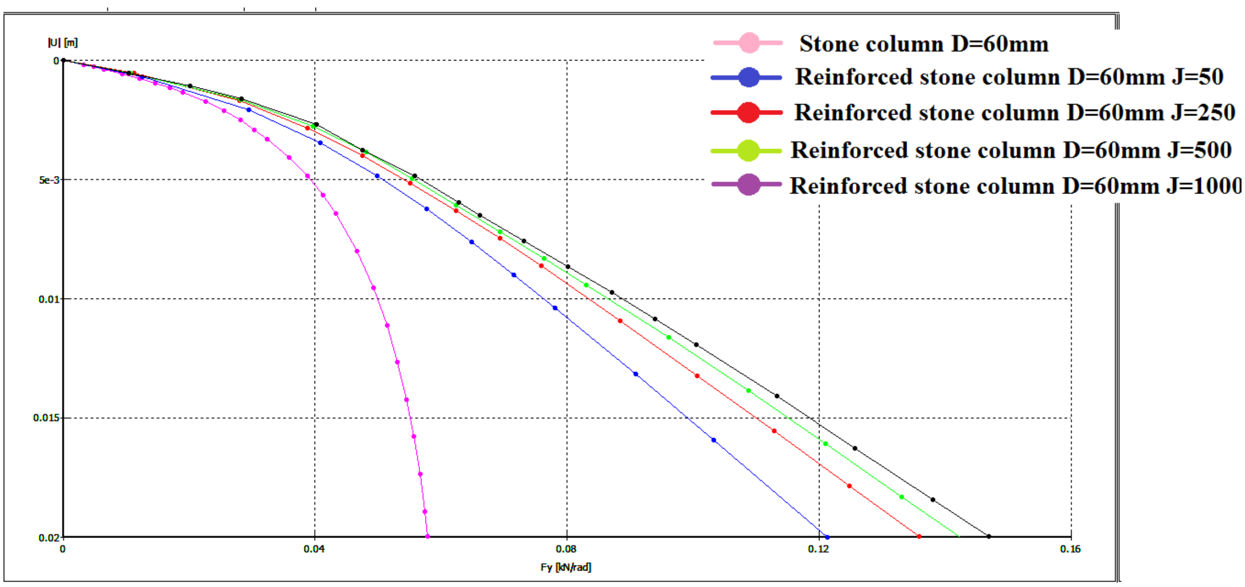

Figure 4: Load-settlement response of geogrid encased stone column of 60 mm diameter

Table 4: Bearing capacity of stone/reinforced-stone column with different stiffness of encasement

Stone Column	OSC	J=50	J=250	J=500	J=1000
Bearing capacity	353.9	762.78	855.47	894.71	923.74

The improved performance due to the encasement can be attributed to the enhancement of overall stiffness of the columns due to larger lateral stresses (confining stresses) mobilized in the column. As the stiffness of the encasing material increases the load carrying capacity of the composite column increases.

Bulging

The lateral bulging observed along the height of the stone column encased with geogrid of different stiffness values is shown in Figure 5.

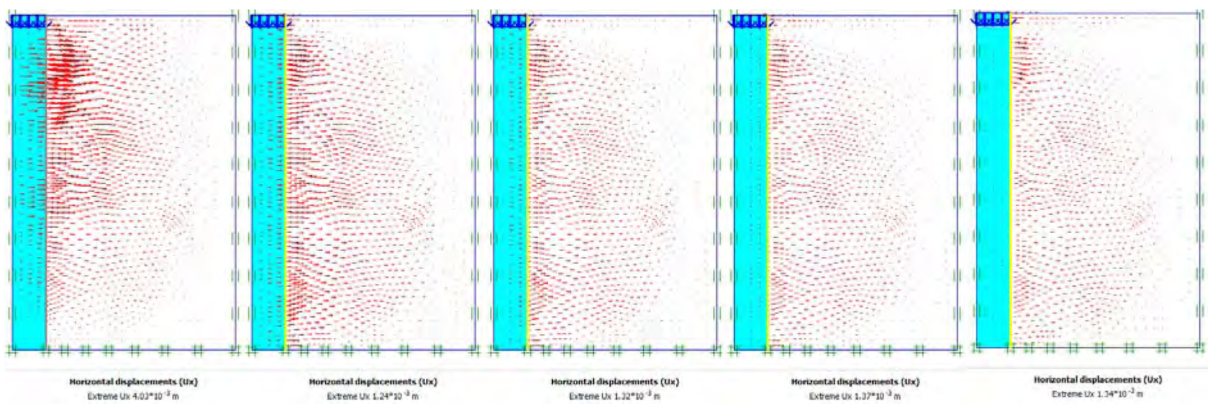

Figure 5: Bulging behavior of stone columns with different encasement stiffness values.

It is observed that in non-reinforced stone column, there is severe bulging near the ground surface up to a depth equal to twice the diameter of the stone column. On the other hand, the encased stone columns have undergone much lesser lateral expansion near the ground surface. The encased columns have undergone slightly higher lateral expansions at deeper depths as compared to the non-reinforced stone column. This could have happened because the applied surface load is transmitted deeper into the column due to encasement effects.

As the stiffness of the encasement increases the lateral stresses transferred to the surrounding soil are found to decrease. This phenomenon makes the load capacity of encased columns less dependent on the strength of the surrounding soil as compared to ordinary stone columns.

CONCLUSIONS

In this paper, the performance of stone columns encased with geogrid reinforcement was studied. The results from the parametric studies are presented to quantify the effect of stone column diameter and geogrid stiffness on load-settlement response of stone column, Based on the results obtained from this study, the following conclusions are made:

1. The load capacity of the stone column can be increased by the increase of the diameter of the column and for a specific settlement the stone column with bigger diameter can afford higher load than the smaller diameter stone column.
2. The load capacity and stiffness of the stone column can be increased by all-round encasement by geogrid. By geogrid encasement, it is found that the stone columns are confined and the lateral bulging is minimized.
3. The elastic modulus of the geogrid encasement plays an important role in enhancing the capacity and stiffness of the encased columns. The magnitude of loads transferred into the encased stone columns can be increased by using stiffer encasement this is due to the confining pressures generated in the stone columns are higher for stiffer encasements.

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REFERENCES

1. Ambily, A. P.; Gandhi, S. R. (2007) “Behavior of Stone Columns Based on Experimental and FEM Analysis. Geotechnical and Geoenvironmental Engineering," pp. 405-415.
2. Andreou, P.; Papadopoulos, V. (2006) “Modeling stone columns in soft clay Proceedings of the ICE - Ground Improvement,” pp. 189-198.
3. Ayadat, T. and Hanna, A. M. (2005) “Encapsulated Stone Columns as a Soil Improvement Technique for Collapsible Soil, Ground Improvement,” 4: 137-147.
4. Ayadat, T., Hanna, A. M., & Hamitouche, A. (2011) “Soil improvement by internally reinforced stone columns” Ground improvement, 161, pp. 55-63.
5. Elshazly, H. A.; Hafez D. H.; Mossaad M. E.(2007) “Settlement of circular foundations on stone-column-reinforced grounds,” Geotechnical and Geological Engineering, pp. 323-334.
6. Gäb, M., Schweiger, H. F., Kamrat-Pietraszewska, D., & Karstunen, M. (2009) “Numerical analysis of a floating stone column foundation using different constitutive models,” Geotechnics of Soft Soils - Focus on Ground Improvement - Proceedings of the 2nd International Workshop on Geotechnics of Soft Soils , pp. 137-142.
7. Greenwood, D.A. (1970) “Mechanical improvement of soils below ground surface,” Ground Engineering Proceedings Conference organised by the Institution of civil Engineers, pp. 161-186.
8. Gniel, J. and Bouazza, A. (2009) “Improvement of Soft Soils Using Geogrid Encased Stone Columns,” Geotxtiles and Geomembranes, 27: 167-175.
9. Malarvizhi N., Ilamparuthi K. (2004) “Load versus Settlement of Clay Bed stabilized with Stone and Reinforced Stone Column,” 3rd Asian Reg. Conf. on Geosynthetic, pp.322-329.

10. Malarvizhi, S.N., Ilamparuthi, K. & Bhuvaneshwari S. (2006) "Behavior of geogrid encased stone column and stone column stabilized soft clay bed," Physical Modelling in Geotechnics, 6, pp. 1489-1494.
11. Murugesan, S., & Rajagopal, K. (2006) "Geosynthetic-encased stone columns: Numerical evaluation," Geotextile and Geomembranes, 24, pp. 349-358.
12. Murugesan, S. and Rajagopal, K. (2009) "Studies on the Behavior of Single and Group Geosynthetic Encased Stone Columns," Journal of Geotechnical and Geoenvironmental Engineering, 136, 129-139.
13. Poorooshasb, H. B. & Meyerhof, G. G. (1996) "Analysis of behaviour of stone columns and lime columns,"Computers and Geotechnics, 20, pp. 47-70.
14. Raithel, M., Kempfert, H. G. (2000) "Calculation models for dam foundations with geotextile coated sand columns,"Proceedings of the International Conference on Geotechnical and Geological Engineering, GeoEngg, Melbbourne.
15. Raithel, M., Kempfert, H. G., Kirchner, A. (2002) "Geotextile-encased columns(GEC) for foundation of a dike on very soft soils,"Proceedings of seventh International Conference on Geosynthetics, Nice, France.
16. Tan, S. A. Tjahyono, S. & Oo, K. K. (2008) "Simplified Plane-Strain Modeling of Stone-Column Reinforced Ground," Geotechnical and Geoenvironmental Engineering, pp. 185-194.
17. Yoo, C. & Kim, S. B. (2009) "Numerical modelling of geosynthetic-encased stone column-reinforced ground," Geosynthetic International, 16, pp. 116-126.
18. Weber, T.M.; Springman, S.M.; Gäb, M.; Racansky, V.; Schweiger, H. F. (2009) "Numerical modelling of stone columns in soft clay under an embankment," Geotechnics of Soft Soils - Focus on Ground Improvement - Proceedings of the 2nd International Workshop on Geotechnics of Soft Soils , pp. 305-311
19. Zahmatkesh, A., Choobbasti, A. J. (2010) "Settlement evaluation of soft clay reinforced by stone columns, considering the effect of soil compaction," International Journal of Research and Reviews in Applied Sciences 3, pp. 159-166.