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Parametric Study on Bearing Capacity of Geosynthetic Encased Stone Column Installed in Soft Clay

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Abstract— **Soft clays exhibit high compressibility and inadequate bearing capacity, which can be improved by adopting ground improvement techniques like stone column. Stone column installation substitutes the soft soil with a material of greater strength and better drainage. Improved drainage accelerates the dissipation of excess pore pressure, thereby enhances the rate of consolidation, and increase the bearing capacity. Encasing the stone column by geosynthetics improves stiffness and strength of stone column. The present paper investigates the improvement in the bearing capacity of geosynthetic encased stone columns in soft compressible clay by conducting a numerical investigation using PLAXIS 2D. Parametric investigations are conducted for various factors viz. i) friction angle of column material, ii) length of encasement, iii) stiffness of geosynthetic material and iv) shear strength of the soft soil, of geosynthetic encased stone columns in soft compressible clay.**

Keywords— Bearing capacity, Geosynthetic Encased Stone column, PLAXIS 2D

I. INTRODUCTION

Generally, the construction of heavy structures such as buildings, bridges, storage tanks, etc. on weak soils involves extreme settlements or unsteadiness. In recent decades, different types of ground improvement techniques have been developed to make the foundation soil strong thereby reducing such problems. One of the effective methods is the use of stone columns, also known as granular columns or aggregate piers. It has been used successfully for the improvement of engineering properties of the soft soils such as load bearing capacity and reduction in differential and total settlements. Stone columns are also found to increase the slope stability and reduce liquefaction potential of loose or soft soils. These are highly effective in bearing loads spread over a wider area, such as observed in heavy structures. The granular material possessing better drainage properties compared to the soil, increases the rate of consolidation and minimizes post-consolidation settlements. Stone columns are commonly installed by methods like ramming, replacement and displacement [10], [12], [15].The granular column replacing the soft soil provides higher stiffness as well as shear strength for the soil-column assembly and thereby make the soil capable of bearing heavy structures. The improvement in soil properties by the installation of stone column is due to various reasons such as introduction of stiffer medium, densification of the surrounding soil during and after the installation process, improved drainage and prevention of excess pore pressure build-up, induced lateral stress in the soil, etc. Lack of lateral confinement for ordinary stone columns (OSCs) installed in weak soils limits its efficiency in settlement reduction [3] and makes it prone to fail in bulging. This occurs especially in the case of long columns (columns with length greater than four times the diameter). Studies prove that by confining the stone column by geosynthetics, lateral bulging can be reduced significantly thereby improving capacity of the stone column and surrounding soil to carry loads[14]. Vertical encasement can be provided either throughout the full length of the column or partially [8,14]. Also, the encasement provide higher stiffness for the column [3,11]. Providing horizontal layers of geosynthetics at proper spacing within the stone column also improves the load carrying capacity to a further extent [5].

Most of the studies in the field of ground improvement using stone column emphasizes on unit cell and full-scale analyses. The unit cell concept is suitable for single or isolated column and the full-scale analyses are applicable for group of columns. Several experimental studies, analytical studies [1], [2], [5], [13] and both [2], [4], [7], [8], [9] had been conducted to predict the settlement and bulging behaviour of stone column under loading. Numerical studies based on techniques like Finite element method have been conducted using programs such as PLAXIS to examine the behaviour of stone column by 2D, 3D, Axisymmetric and Plain strain modeling methods [2], [3], [5], [6], [7], [9], [11], [13]. The present study compares the load settlement characteristics of ordinary stone column (OSC) with that of geosynthetic encased stone column (GESC) in soft compressible clay by conducting numerical analyses in PLAXIS 2D. Also, the influence of different properties such as length of encasement, stiffness of geosynthetic material, friction angle of column material and shear strength of soft soil in improving the settlement characteristics are investigated.

II. NUMERICAL MODELING

Finite element program PLAXIS 2D is used to perform the analyses of Geosynthetic encased stone column embedded in a medium of soft compressible clay. The numerical analyses are done based on the experimental study by Ghazavi M & Afshar J N [8]. The load-settlement characteristics of Ordinary Stone Column (OSC) is compared to that of Geosynthetic encased stone column (GESC) of same dimensions, using an axisymmetric model. The same model is subjected to parametric studies to identify various factors controlling the behaviour of stone column-soil unit. 6 noded triangular elements were used for modeling the problem.

A. Constitutive model and parameters

Single stone column having diameter 100mm and length 500mm (l/d ratio of 5), installed in soft clay is modeled. A loading plate of diameter 200mm is considered. Both the stone column and the surrounding soil are modelled using Mohr Coulomb model. The input parameters required for Mohr-Coulomb model includes unit weight,cohesion, angle of internal friction, Young's modulus, poisson's ratio and dilatancy angle of soil and the granular material for column. The input parameters used in the simulation of column and soil are given in table 1. The geotextile forming the encasement for GESC is modeled as a 'geogrid element' assuming a linear elastic behaviour. The tensile stiffness(E_A) of the geotextile is considered as the input parameter for modeling. A geotextile of stiffness 35kN/m is considered in the current analyses. Fig. 1 shows the finite element model generated for the problem, with the deformed mesh after load application.

TABLE 1 SIMULATION PARAMETERS FOR THE MODEL

Material	Clay	Stone
Young's modulus (E kN/m^2)	600	40000
Poisson's ratio	0.47	0.3
Cohesion (kPa)	15	0
Dilatancy angle	0	0
Friction angle (^{0})	0	46
Dry unit weight (kN/m^3)	16.8	16
Saturated unit weight (kN/m^3)	19	19

B. Boundary Conditions

As shown in fig. 1, standard fixities are given for the model as the boundary condition. This is in compliance with the actual field condition. The bottom of clay bed and column are fixed and restricted to move both vertically and laterally. The sides of clay bed and the axis of the column are allowed to settle vertically but are restrained from lateral displacements. The side of the column (soil-column vertical interface) is not subjected to any displacement restrictions as it is expected to settle vertically as well as bulge laterally. In the laboratory experiment, the load-settlement characteristics are studied up to a settlement of 50mm. Hence, the influence of the loading plate is modeled as the prescribed displacement of 50mm, through a horizontal (radial in actual case) distance of 100mm from the axis of the soil-column model along the top surface of the model. Initially the prescribed displacement is defined and later it is activated during the loading phase.

C. Methodology

After the geometric modeling of the soil-column system, each material is defined by properly specifying the material properties as the input parameters as given in table 1. Defined materials are assigned to the corresponding materials in the geometric model. Then, the boundary conditions are given appropriately followed by discretization of the model, and generation of initial stresses based on the unit weight of materials. The entire analysis is divided into 2 stages- initial phase and the loading phase. The load is activated only during the loading phase, by defining the prescribed displacement of 50mm to the loaded area. Analyses are continued till the prescribed displacement of 50mm is reached at the specified region. Vertical settlement and lateral bulging corresponding to the loading can be observed from the deformed model after the analyses as shown in fig. 1. It shows the effect of loading on vertical settlement and lateral bulging is maximum in the immediate vicinity of loading. Towards the bottom and away from the axis, the effect reduces.

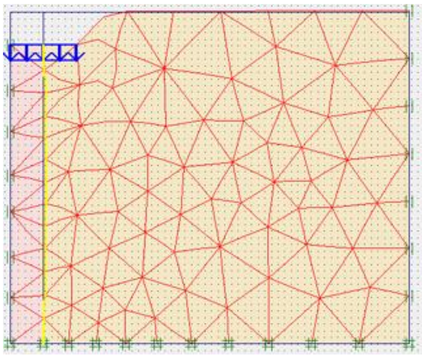


Fig. 1. Deformed mesh, showing the vertical settlement and lateral bulging

D. Parametric Investigations

The influence of various factors pertaining to the column as well as the foundation soil, on the ability to carry load and resist deformations can be identified by conducting parametric investigations.

a) Diameter of the stone column

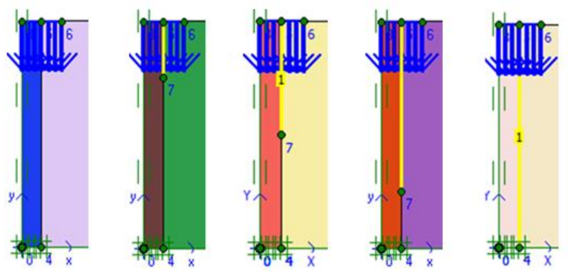
Isolated stone columns of diameter 60mm, 80mm and 100mm are used for the analysis. The length to diameter ratio is maintained as 5 for all the three cases. Hence the thickness of clay bed and the length of stone column are 300mm, 400mm and 500mm for the columns of diameter 60mm, 80mm and 100mm respectively. Vertical settlement behaviour of these columns are analyzed.

b) Friction angle of column material(φ)

Being one of the strength parameters, the angle of internal friction (φ) of the column material may affect the load-capacity of the stone column. Hence the angle of internal friction of the stones is increased as 38^0, 41^0 and 44^0 to investigate its effect on load carrying capacity of the encased column.

c) Length of encasement(l)

The vertical encasement can be provided fully or partially around the stone column. The lateral confinement provided for the column can be a determining factor for its load capacity and thus the encasing length of the geosynthetic used also. Cases are considered in which the geotextile is encased through full length as well as partially around the column as shown in fig. 2(L- length of the column). Fig. 2 shows the cases of no encasement (fig.2a), quarter length of the column encased (fig 2b.), half length of the column encased (fig 2c.), three-quarter of the column encased (fig 2d.) and full length of the column encased (fig.2e). Vertical settlement and lateral bulging of the column under different cases of encasement lengths as mentioned are studied.



a b c d e

Fig. 2. Length of encasement for the column(l)
a) without encasement b) l=0.25L c) l= 0.5L d) l= 0.75L e) l= L

d) Stiffness of geotextile(E_A).

The stone column can be wrapped with various types of geosynthetic materials available such as geotextiles, geogrids, etc. The nature and properties of the wrapping geosynthetic may affect the load bearing capacity of the column. The governing parameter of the geotextile used for the present study is its tensile stiffness. The influence of stiffness (E_A) of the encasing material on load-settlement characteristics of encased stone column is inspected by varying the stiffness over a wide range of values as 50kN/m, 250kN/m, 500kN/m and 1000kN/m.

e) Shear strength of clay

The load bearing capacity of the stone column depends on the lateral stress induced in the soil by the installation of the column. Cohesion or shear strength of the clay is an important parameter governing the development of lateral stress around the column by the soil. Hence it is vital to study the influence of shear strength or cohesion of the surrounding clay, on the load capacity of the column. The settlement characteristics of stone column is studied by considering the shear strength of clay as 7kPa, 15kPa, 30kPa, 40kPa, keeping other parameters constant.

III. RESULTS AND DISCUSSION

The results of axisymmetric analyses conducted on OSC and GESC shows that the encasement has a significant role in improving the bearing capacity of stone column as shown in Fig. 3. Also, from the study conducted on the load-vertical settlement behaviour of stone columns of different diameters, it can be observed that an increase in column diameter improves its load capacity. From the analysis conducted on columns of diameter 60mm,80mmand 100mm it is observed that for a given settlement a stone column of larger diameter can withstand heavier load as shown in Fig. 4. This can be attributed to the larger area provided by the stone column for bearing the load. From the study conducted to understand the influence of angle of internal friction, it is observed that as the angle of internal friction of column material increases, the load bearing capacity will also increase. Efficiency of the GESC is observed to be higher if the column material is compacted well to attain high angle of internal friction. Fig. 5 shows the effect of angle of internal friction of column material on the load-settlement characteristics.

Varying the length of encasement of stone column, it can be seen that the load bearing capacity increases and the lateral bulging reduces with increase in encasing length using the geotextile. Results are shown in Fig. 6 a, b. From fig. 6b, it is seen that by increasing the length of encased portion in the column, the zone of maximum lateral bulging can be shifted towards the bottom. Since the effect of loading reduces towards the bottom, the extend of lateral bulging will be minimum at the bottom. Hence increasing the length of encasement increases the load bearing capacity. The encasing material increases the overall stiffness of the column by mobilizing higher lateral stress. Hence, by increasing the stiffness of encasing material, vertical settlement of the column can be reduced as shown in Fig. 7. It is noted that stone column encased with geosynthetic having more stiffness value, have greater load bearing capacity.

Shear strength of clay contributes to the passive earth pressure developed in the soil-column assembly and hence affects the axial capacity of stone column. It can be noted that with increase in shear strength (cohesion) of clay the load carrying capacity of column will increase as given in fig.8

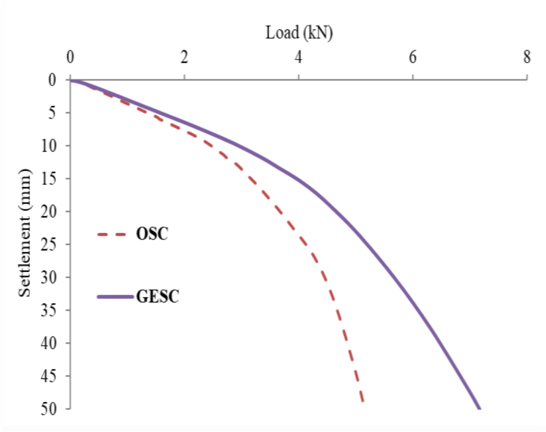


Fig. 3. Comparison of load-settlement characteristics of OSC and GESC

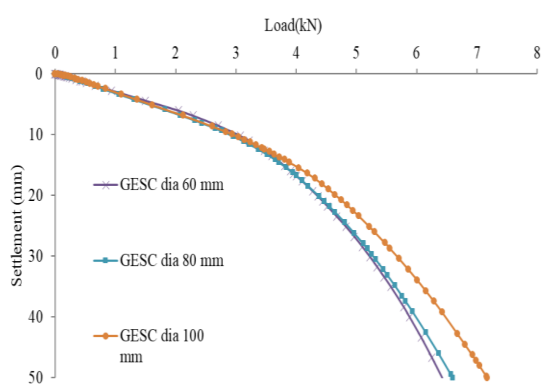


Fig. 4. Load-settlement characteristics of columns of different diameter

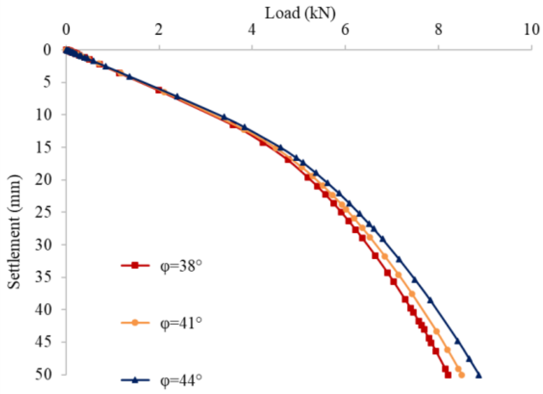


Fig. 5. Load-settlement characteristics showing the effect of varying the friction angle of the column material in GESC

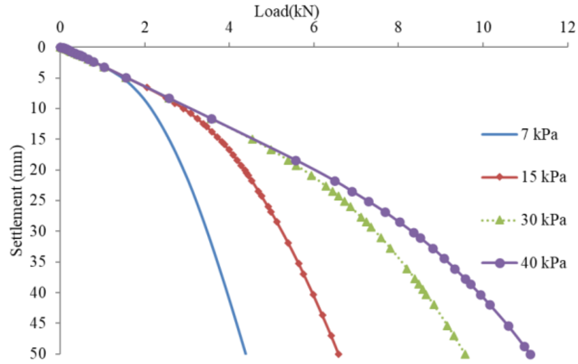


Fig. 8. Load-settlement characteristics of GESC showing the influence of shear strength of clay

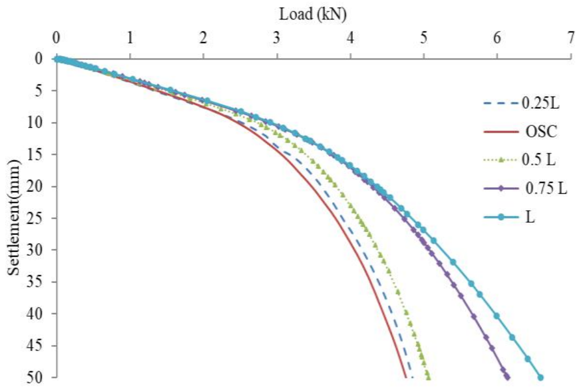


Fig. 6a. Load-settlement characteristics showing the influence of encasement length

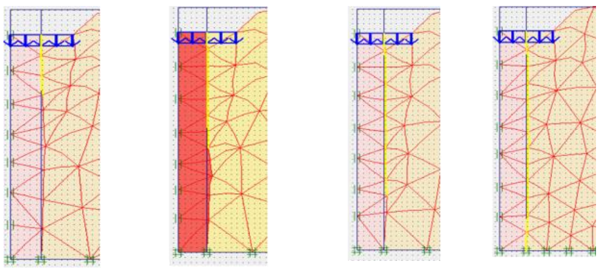


Fig. 6b. Lateral bulging of GESC with different encasing lengths

(0.25L, 0.5L, 0.75L, L)

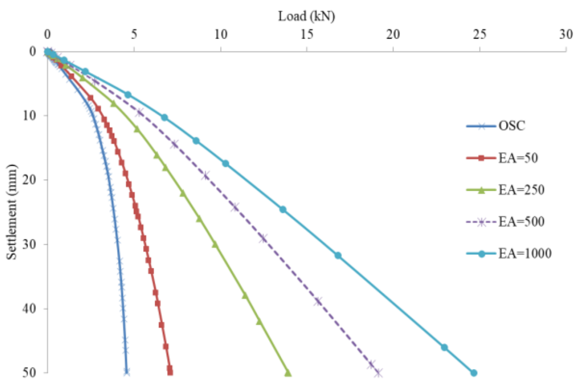


Fig. 7. Load-settlement characteristics showing the influence of stiffness of the geosynthetic encasement

IV. CONCLUSIONS

In this paper, the behaviour of stone column encased with geotextile is studied by conducting numerical investigations using the finite element program, PLAXIS 2D. Comparing the ordinary stone column (OSC) with a geosynthetic encased stone column (GESC), it can be observed that the encasement improves the load carrying capacity of the column. It is because of the increased stiffness provided by the encasement. Based on the numerical investigations conducted, it can be concluded that:

- Encasing the stone column with a geosynthetic material of stiffness 35kN/m, improves its load carrying capacity by 140 %.
- Increasing the length and stiffness of the encasement results in improved load bearing capacity of the column. Also, lateral bulging of the column can be reduced considerably by increasing the encasement length. Compared to a column with its half length encased, a fully encased column has shown an increase of 130.75% in the bearing capacity.
- The load carrying capacity of the stone column can be improved by compacting the column material to a higher degree which results in increased angle of internal friction.
- The shear strength of surrounding clay also influenced the behaviour of geosynthetic encased stone column (GESC). Stone columns installed in soil of higher shear strength/ cohesion will provide improved bearing capacity compared to those in soils of low cohesion.

REFERENCES

[1] Afshar, J.N. and Ghazavi, M., 2014. “Experimental studies on bearing capacity of geosynthetic reinforced stone columns”. Arabian Journal for Science and Engineering, 39(3), pp.1559-1571.

[2] Alkhorshid, N.R., Araújo, G.L.S. and Palmeira, E.M., 2018. “Behaviour of geosynthetic-encased stone columns in soft clay: Numerical and analytical evaluations”. Soils and Rocks, 41(3), pp.333-343.

[3] Almeida, M.S.S., Hosseinpour, I. and Riccio, M., 2013. “Performance of a geosynthetic-encased column (GEC) in soft ground: numerical

and analytical studies". Geosynthetics international, 20(4), pp.252-262.

[4] Ambily, A.P. and Gandhi, S.R., 2007. "Behaviour of stone columns based on experimental and FEM analysis". Journal of geotechnical and geoenvironmental engineering, 133(4), pp.405-415.

[5] Datye, K. R., and Nagaraju, S. S., 1985. "Ground improvement, Indian contribution to Geotechnical Engineering", XI International Conference on Soil Mechanics and Foundation Engineering, Indian Geotechnical Society, pp.121-125.

[6] Demir, A. and Sarıcı, T., 2016. "Bearing capacity and bulging behaviour of Geogrid encased stone columns".

[7] Fathi, E. and Mohtasham, R., 2016. "Numerical Analysis of the reinforced stone column by Geosynthetic on stability of embankment". In Proceedings of the World Congress on Civil, Structural, and Environmental Engineering (CSEE'16), Prague, Czech Republic–March (pp. 30-31)

[8] Ghazavi, M. and Afshar, J.N., 2013. "Bearing capacity of geosynthetic encased stone columns". Geotextiles and Geomembranes, 38, pp.26-36.

[9] Hataf, N., Nabipour, N. and Sadr, A., 2020. "Experimental and numerical study on the bearing capacity of encased stone columns". International Journal of Geo-Engineering, 11, pp.1-19.

[10] Lo, S.R., Zhang, R. and Mak, J., 2010. "Geosynthetic-encased stone columns in soft clay: a numerical study". Geotextiles and Geomembranes, 28(3), pp.292-302

[11] Malarvizhi, S.N., 2007. "Comparative study on the behaviour of encased stone column and conventional stone column". Soils and foundations, 47(5), pp.873-885.

[12] Marto, A., Moradi, R., Helmi, F., Latifi, N. and Oghabi, M., 2013. "Performance analysis of reinforced stone columns using finite element method". Electronic Journal of Geotechnical Engineering, 18, pp.315-323.

[13] Mohanty, P. and Samanta, M., 2015. "Experimental and numerical studies on response of the stone column in layered soil". International Journal of Geosynthetics and Ground Engineering, 1(3), pp.1-14.

[14] Mokhtari, M. and Kalantari, B., 2012. "Soft soil stabilization using stone columns—A review". Electronic journal of Geotechnical engineering, 17, pp.1459-1466.

[15] Murugesan, S. and Rajagopal, K., 2006. "Geosynthetic-encased stone columns: numerical evaluation", Geotextiles and Geomembranes, 24(6), pp.349-358.