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Experimental And Numerical Analysis of Geosynthetic Encased Tapered Stone Columns

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Abstract. Various researches have been carried out on stone columns of cylindrical shape alone. It is seen that when stone columns are installed in soft soils, they undergo excessive bulging. As seen from the various studies, maximum bulging occurs at 1.5 D to 2D from the top of the stone column(where D is the stone column diameter). This can however be controlled by increasing the top bearing area of stone column by introducing a tapered shape to it. Stone columns installed in very soft soils will have very low lateral confinement and hence have limited load carrying capacity and undue settlement. The strength and stiffness can be enhanced by encasing individual stone columns with suitable geosynthetic. In this investigation , load settlement response of geosynthetic encased tapered stone columns were studied.. From the plate load test results, a parametric analysis of the load settlement behavior of geosynthetic encased tapered stone columns were done. Results show that settlement decreased and bearing capacity increased as tapering and encasement was introduced to the stone columns. Numerical analysis was performed using Abaqus software. The finite-element analysis was successful in forecasting the model test results with reasonable accuracy. A group analysis of encased tapered stone columns were done and the buckling behavior of stone columns in group were studied.

Keywords: Tapered Stone column, Ground improvement, Bearing capacity, Geosynthetic encasement, Numerical Analysis

1 Introduction

The land available for the development of commercial, housing, etc. are scarce in urban areas. As a result, the use of land having weak strata is necessary. Hence the geotechnical engineers are challenged by the presence of different problematic soils having varied engineering characteristics. Some of these area are covered with thick soft marine clay deposit with high compressibility and low shear strength. Among the various ground improvement techniques available, the final choice among the methods depends on the overall economy in total foundation cost. Stone columns are one of the extensively used methods to improve the bearing capacity of poor ground and reduce the settlement of structures beneath it. It offers a sustainable and economical alternative to deep foundation solutions. In all recent studies , tests were conducted on stone columns having cylindrical shape. Stone columns normally fail by bulging, which normally occurs at its top. This can however be minimized by increasing the top bearing area to the stone columns. Addition of geosynthetic encasement will increase the load carrying capacity of stone columns by many folds due to the additional confinement from the geosynthetic and it also prevents the lateral squeezing of stones when the stone column is installed in some extremely soft soils, leading to minimal loss of stones and quicker installation. This research focusses on the stabilization of soil by introducing geosynthetic encased tapered stone columns of different dimensions. A group analysis of encased tapered stone columns were also done.

2 Methodology

The experimental programme consisted of laboratory plate load tests ,carried out to compare the advantages of encased tapered stone columns. A circular test tank of 600mm diameter and 400mm depth was used for the test.The soil sample used for the test consisted of fine sand and known percentage of clay with known effective stress state. Numerical analysis was carried out using Abaqus 6.14-2 software to compare load-settlement behavior with the model tests and for parametric analysis.

2.1 Materials used

The basic materials used for the study are fine sand, kaolinite clay, stones and geosynthetics.

Fine sand. P-sand was used for the test. The properties of the sand obtained are presented in the following table 1.

Table 1. Properties of sand

Properties	Values
Specific gravity, G	2.60
Maximum density (kN/m^3)	20.10
Minimum density (kN/m^3)	14.49
Effective particle size,D_{10}(mm)	0.1
Uniformity coefficient (Cu)	4
Coefficient of curvature (Cc)	1

Kaolinite clay. The clay used for the test was collected from English India clay limited, Thiruvananthapuram.The soil is classified as CH as per Indian standards. The properties of clay obtained are presented in table 2

Table 2. Properties of kaolinite clay

Properties	Values
Specific gravity, G	2.69
Liquid limit(%)	72
Plastic limit(%)	25
Plasticity index(%)	47
Maximum dry density(kN/m^3)	13.73
Optimum moisture content (%)	34.48
Percentage clay, silt, sand (%)	64.2, 28.4, 7.4

Stones. Crushed stones of particle size ranging from 2mm to 10mm were used to construct stone columns. The properties of the stones used are given in table 3.

Table 3. Properties of crushed stones

Properties	Values
Specific gravity,G	2.65
Maximum density(kN/m^3)	15.75
Minimum density(kN/m^3)	15.31
Effective particle size,D_{10}(mm)	2.70
Uniformity coefficient(Cu)	2.815
Coefficient of curvature(Cc)	1.077

Geosynthetic. Seamless woven geotextile was used for the test. The properties of the geotextile used is as given in table 4.

Table 4. Properties of Geotextile

Properties	Values
Elastic modulus (MPa)	325
Apparent opening size (μm)	<75
Thickness(mm)	0.3
Cross plane flow rate(l/m^2/s)	15

2.2 Preparation of model test

90% of fine sand and 10% of clay was taken in a container and mixed until uniform color was obtained. The water content was maintained as 15% in all the tests The soil was then filled in the tank in 3 layers, each layer given 25 blows using a rammer. The stone columns were installed by displacement technique. Both tapered and cylindrical hollow steel casings were required for the preparation of stone columns. Casings were made by using 2mm thick steel plate. For the smooth driving of casings into the soil , conical shoes made with cement mortar were used. Concrete shoes were placed beneath the casing during the driving operation for installation of stone columns. The photograph of the casings and concrete shoe. The stones were filled into the casing by maintaining a constant height of fall simultaneously as the casing were withdrawn. A light compaction effort was adopted to ensure proper density of the stone chips. The procedure was repeated until the column is completed to the full height. To construct encased stone columns, geotextile was stitched to the required shape with the help of steel casings. After the encasement along with the casing was pushed through the soil, the casing was removed and the stones were carefully discharged.

2.3 Model testing procedure

The model tests were performed on soil alone and also on soil reinforced with stone columns. A steel plate of 12cm diameter and 2cm thickness was used as footing. Two dial gauges were fixed to measure the settlement of the footing. Load was then applied through a hydraulic jack of 8t capacity. The jack was placed such that the centre of the footing coincided with the centre of the hydraulic jack. The schematic diagram and photograph of the test setup is shown in figure 1.During every load increment the readings of the two dial gauges were noted.

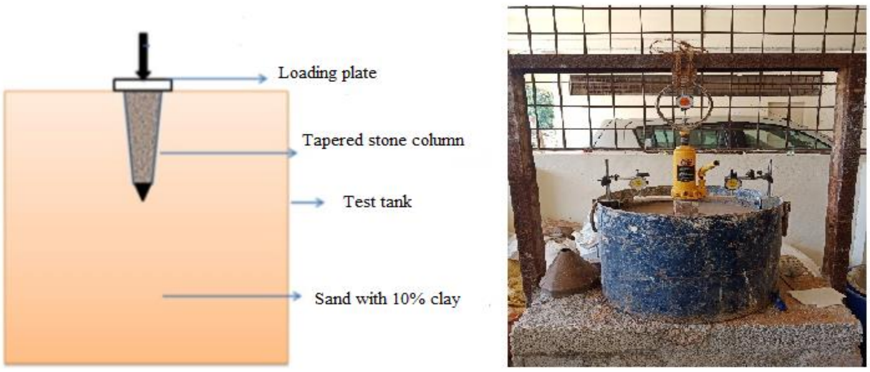

Fig.1. Schematic diagram and photo of test setup

3 Experimental Analysis

The investigation focusses on the effect of encasement and tapering effect of the stone columns. The results are represented in the form of non-dimensional parameters P/ϒB and S/B (where P=applied load , ϒ=bulk density of soil, B=width of footing and S= vertical settlement). The presentation of the results have been done in a similar manner to Ali et al.(2014).

3.1 Effect of geotextile encasement on tapered stone columns

A total of 4 plate load test have been conducted on encased stone columns to estimate the effect of encasement on the stone columns. The results of untreated soil and soil reinforced with tapered stone columns are compared with encased tapered stone columns as seen in figure 2. There is an increase in bearing capacity from approximately 125% to 425% when encasement was provided on Tapered stone column of size 30-24-150. Based on the results, the increase in bearing capacity of soil reinforced with encased stone columns is due to the increase in stone column's confinement, which inhibited column bulging. The effect of tapering on bearing capacity is given by Siyoos et al.(2015). The settlement reduced by about 8.34% when geosynthetic encasement was provided. A comparative study of stone columns improved using geosynthetics is presented by Ali et al.(2014).

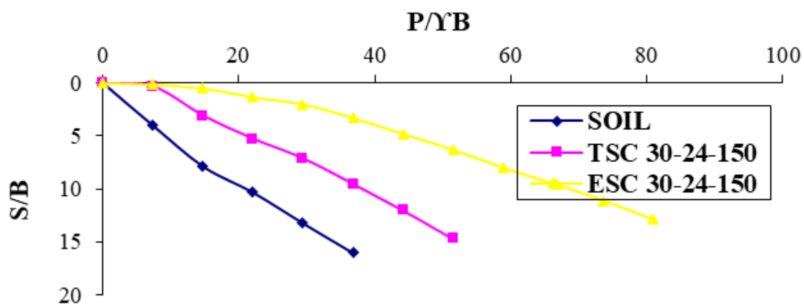

Fig.2. Effect of geotextile encasement on tapered stone columns

3.2 Effect of top diameter and length of encased tapered stone columns

Figure 3 shows the stress settlement behaviour of soil and soil treated with encased tapered stone columns .As the area of encased stone column increases from 20-16 to 30-24, the bearing capacity value increases from 237.5% to 425% approximately. As the area of the stone columns increases , the bearing capacity of geotextile encased tapered stone columns increases. The lateral bulging was decreased due primarily to the added confinement by the encasement. The confinement stresses inferred from the ring tension force developed in the geosynthetic encasement are larger when the area replacement ratio is smaller. An increase in length of the column from 150mm to

200mm , for a column of size 30-24, the bearing capacity increased by 112.5% whereas for a column of size 20-16, the bearing capacity increased by 137.5%. The approximate settlement reduction values for column of size 20-16 is 61.3% and 76.19% for 150mm and 200mm length respectively and for column of size 30-24 is 78.57% and 88.89% for 150mm and 200mm respectively. It is seen also that the bearing capacity increases when the length of encased stone column increases.

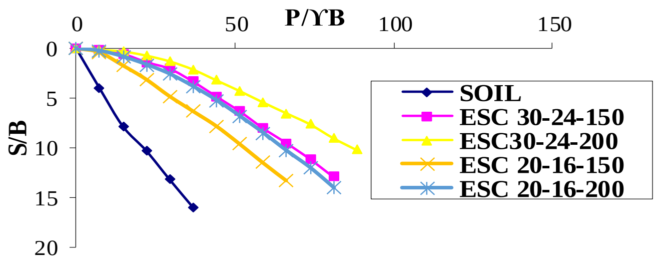

Fig.3. Effect of top diameter and length of encased tapered stone columns

3.3 Group analysis of geotextile encased tapered stone columns

Three model tests were performed on encased tapered stone columns of size 30-24-150mm with different spacing ratios of 2.5d, 3d and 4d.(where d is the top diameter of the stone column). The stone columns were arranged in a triangular pattern as shown in figure 4. Figure 5 shows that greater improvement in bearing capacity was observed when spacing between the column was 2.5d and lowest improvement for a spacing of 4d. This is on account of decrease in area ratio.(area of clay foundation replaced by stone column).It was observed that the bulging of inner column was very much reduced in group analysis. The reduction in settlement of 2.5d , 3d and 4d spacing of the encased tapered stone columns are observed as 88% , 75% and 74.4% of that of unreinforced soil.

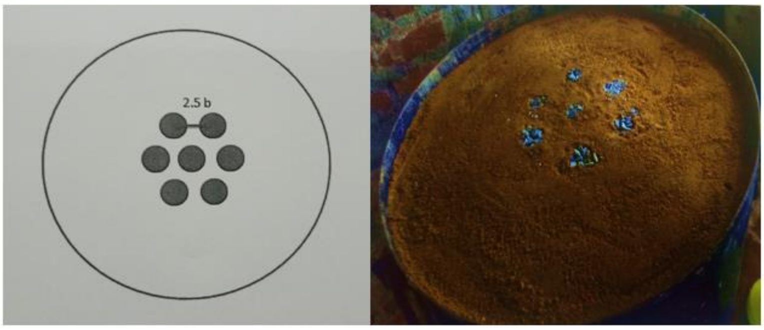

Fig.4. Schematic arrangement of stone column group and photograph of the test setup

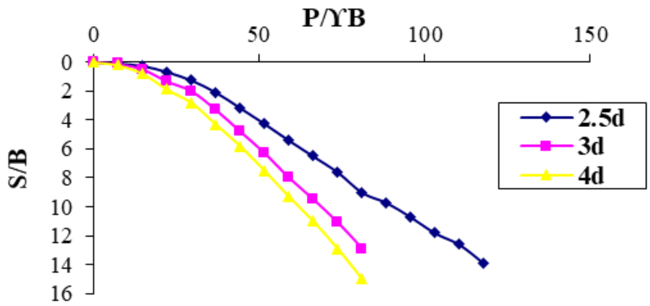

Fig. 5. Group analysis of Geotextile encased tapered stone columns

4 Finite Element Analysis

Numerical analysis was carried out using Abaqus 6.14-2 software to compare load-settlement behavior with the model tests and for parametric analysis. The package was validated using by J.T.Shahu and Y.R.Reddy(2011). The finite element discretization shown in Figure. 6 compares the results obtained from the model test and based on ABAQUS6.14-2 analysis, which matches well.

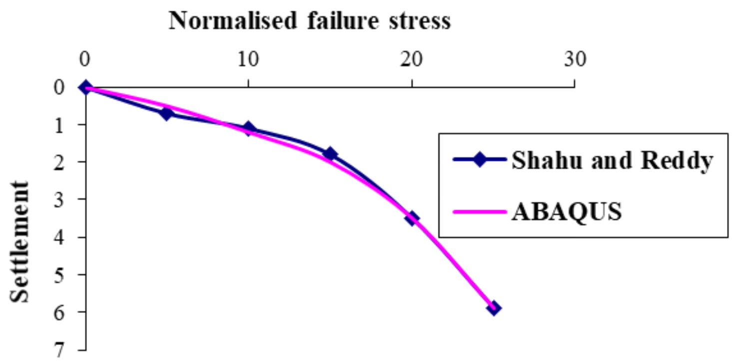

Fig.6. Validation of Abaqus 6.14-2 with Shahu J.T. and ReddyY.R. (2011)

4.1 Comparison of laboratory test and FEM analysis

Axisymmentric analysis was carried out using Mohr Coulomb criterion by considering the elasto plastic behaviour of soil and stones. The properties of the stones, soil and the tank are as given in the table 5. The geosynthetics were modeled as geogrid element by incorporating only the axial stiffness parameter. A comparison between the stress- settlement behaviour of laboratory model and Abaqus results were done.

And the results were found to be in close correlation. Hence extended parametric analysis on encased stone columns can be done using the Abaqus package.

Table 5. Input properties used

Parameter	Properties			
	Sand	stones	tank	Geotextile
Modulus of Elasticity(kPa)	25000	48000	$2*10^8$	325000
Poissons ratio	0.35	0.3	0.3	0.3
Angle of internal friction(°)	38	47	-	-
Density (kN/m^3)	15.7	15.4	-	-

4.2 Group analysis

Abaqus analysis was performed by adding an additional array of stone columns to the group analysis. This was done to find the effect of deformation of stone columns in the inner array due to the introduction of the outer array of columns. Figure 7 shows the arrangement of stone columns. It is seen that the inner stone columns shows little deformation whereas the stone columns in the outer array shows more deformation. This is on account of the stiffness of the soil surrounding the inner stone columns due to confinement effect of the newly introduced array of stone columns. The bending of the stone column depends on the position of the columns in the group. The bending stress increases as one moves from the centre column to a peripheral column.

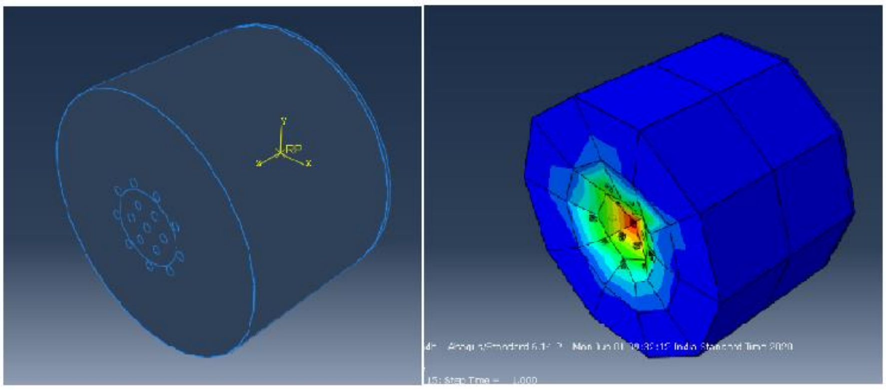

Figure 7. Assembly and Displacement of encased stone column group

4.3 Comparison of stress contours

Stress contours of soil, circular stone column, tapered stone columns with and without encasement were obtained using Abaqus software. The stress was transmitted to the bottom of the tank in case of loading done to soil alone while in the case of reinforced soil with stone columns the intensity of pressure transmitted to the soil was reduced. Comparison of circular and tapered stone columns of same volume suggest improvement in bearing capacity of tapered stone column due to greater top bearing area leading to reduced bulging. From the pressure bulb study it can be proved that there is a considerable reduction in the stress values at a particular depth when the soil is reinforced with encased tapered stone columns. Figures 8 and 9 shows the variation of stresses values at depths of 0.5B, 1.0B and 1.5B (where B is the width of the footing).

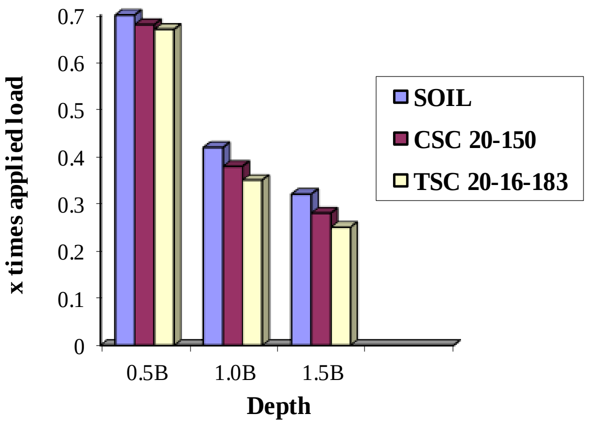

Fig.8. Comparison of stress contour of soil , Circular Stone Column and Tapered stone column at different depths

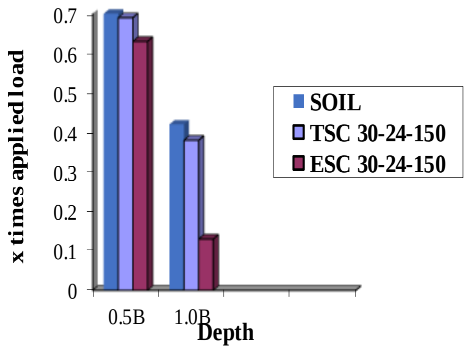

Fig.9. Comparison of stress contour of soil ,Tapered stone column and Encased Tapered stone column at different depths

5 Conclusions

1. For the same volume of tapered stone columns and circular stone columns, tapered stone column shows an increase in bearing capacity than circular stone column. This is because, in tapered stone columns, the top bearing area is more than that of circular stone columns, which enables it to take more stress leading to reduced settlement of the soil.
2. Geotextile encasement provides lateral confinement to the stone columns against bulging by mobilisation of hoop stress. The effect of geotextile encasement improved the bearing capacity of tapered stone columns by 300% and a reduction in settlement by 8.34%.
3. Settlement was found to reduce and the bearing capacity was found to increase as the length of the geosynthetic encased tapered stone column increases.
4. In the group analysis, optimum spacing between the stone columns was obtained as 2.5d .It was observed that the bulging of inner column was very much reduced in the group analysis.
5. Analysis was performed by adding an additional array of stone columns to the group analysis. The inner stone columns shows little deformation whereas the stone columns in the outer array shows more deformation. The bending stress increases as one moves from the centre column to a peripheral column.
6. From the pressure bulb study it can be proved that there is a considerable reduction in the stress values at a particular depth when the soil is reinforced with encased tapered stone columns.

Future Work

Field plate load tests may be carried out on group of Geosynthetic encased tapered stone columns to evaluate the applicability of this method in the field.

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