Model tests on group of geosynthetic encased stone columns

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ABSTRACT: Stone columns, which are most common ground reinforcing elements, may need strength enhancement particularly when they are installed in extreme soft soils. This is because of the low lateral confinement from the surrounding soft soil (upon which the mobilisation of structural capacity of stone column depends). Confining the stone column within a geosynthetic encasement has proved to be one of the ideal forms of strengthening the stone columns as it has many other advantages also. The research on this technique is still reeling in the investigation of the performance of individual stone columns through load tests. This paper attempts at the investigation of performance of the group of encased stone column through laboratory model studies. Load tests were performed on the group ordinary stone column and group of stone column encased in woven and nonwoven geotextile. The improvement in the bearing capacity of clay bed treated with stone column was found to increase by 3 to 5 times due to the encasement. The increase in the stress concentration on stone column due to encasement was also quantified.

1 INTRODUCTION

Stone columns are being widely used as ground reinforcing elements for variety of structures. The stone columns are nothing but vertical columnar elements formed below the ground level with compacted and uncemented stone fragments or gravels or sand. Since the pioneering work by Greenwood (1970), there have been so many researches based on stone columns reported in the literature. It is very well established in literature that the stone columns derive their axial load capacity from the lateral confining pressure offered by the surrounding soils. In very soft soils the efficacy of the stone columns will be very less owing to the low lateral confinement from the surrounding soil, which imparts the necessary axial capacity to the column. McKenna et al. (1975) reported cases where the stone column was not restrained by the surrounding soft clay which lead to excessive bulging and also the soft clay squeezed into the voids of the aggregate. In such situations, the stone aggregate in the column may need to be confined together for its improved performance. One ideal method for confining the stone column could be achieved by wrapping the individual stone columns using suitable geosynthetic, Figure 1.

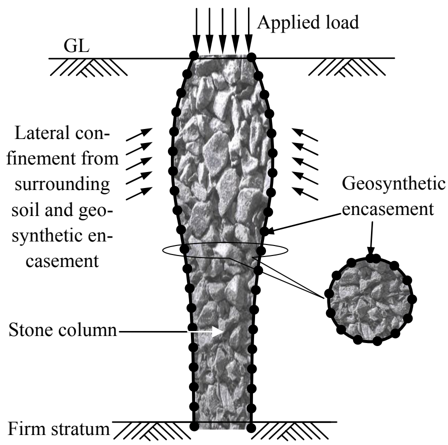

Figure 1. Geosynthetic encased stone column – schematic

This encasement holds the stone column intact as a single unit and imparts additional confinement to the stone column and brings in several advantages like increased stiffness of column, preventing the loss of stones into the surrounding soft clay, preserving the drainage and frictional properties of the stone aggregates etc. as described by Raithel et al. (2002), Alexiew et al. (2005) etc.

The concept of encasing the stone column by wrapping with geosynthetic was first proposed by Van Impe in the year 1985 (Van Impe 1989). Following this there have been quite good amount of research on bringing out the beneficial effects of the geosynthetic encasement. Nevertheless researches on this technique are still in exploring the performance of individual stone column through laboratory model tests (di Prisco et al. 2006, Murugesan and Rajagopal 2007, Malarvizhi and Ilamparuthi 2007, Black et al. 2007, Wu and Hong 2008, Gniel and Bouazza 2008) or based on analytical investigations (Murugesan and Rajagopal 2006, Wu et al. 2009). Through laboratory tests Murugesan and Rajagopal (2009) investigated the improved performance of encased stone columns subjected soil induced shear movements. This paper attempts on investigating the performance of group of encased stone columns through laboratory model test performed on the group of stone column with and without encasement. The results lead to the understanding on the quantitative improvement in the bearing capacity of the clay soil treated with geosynthetic encased stone columns. Also the increase in the stress concentration on the stone column due to encasement was also explored.

2 DESCRIPTION OF EXPERIMENTS

The group of stone columns studied in this research was installed in a clay bed prepared in a large test tank of plan dimensions 1.2 m×1.2 m and 0.85 m in depth. For every load test the clay bed of 0.6 m was prepared afresh by slurry consolidation method (for details readers may refer Murugesan 2007) to have same properties for successive tests. The properties of clay bed for are given in Table 1.

Table 1. Properties of clay soil

Properties	Value
Liquid limit	49%
Plastic limit	17%
Plasticity Index	32%
Specific Gravity	2.59
In-situ moisture content	47±1%
In-situ vane shear strength	2.5 kPa
Consistency Index	0.06
Dry unit weight	11.56 kN/m^3
USCS classification symbol	CL
Degree of Saturation	96%

The stone aggregates used to form the stone columns were angular granite chips, uniformly graded and of size passing 10 mm sieve and retained in 2 mm sieve. The peak angle of frictional resistance of stone aggregate determined from direct shear tests was found to be 41.5° within a normal pressure of 300 kPa. The unit weight of the stone fill in the stone column was maintained constant through out all the tests close to 1.6 gm/cc.
Two types of geosynthetics, woven geotextile and nonwoven geotextile were used to encase the stone columns in the present study. The tensile strength properties of these geosynthetics determined from standard wide width tension tests (ASTM- D4595, 1986) are listed in Table 2. As the geosynthetics were stitched to form the tube for encasing the stone column, the seam strength of the geosynthetic was also determined with geosynthetic specimens having a seam at mid-length.

Table 2. Properties of geosynthetics used for the encasement

Strength properties	Woven geotextile	Nonwoven geotextile
Ultimate tensile strength (kN/m)	20	6.83
Ultimate seam strength (kN/m)	4	5.1
Initial modulus (kN/m) (based on seam strength)	17.46	12

The stone columns were installed by displacement method, and were extended up down to the bottom of the tank. Hence all the stone columns were of length 0.6 m. Twelve 75 mm diameter stone columns were installed in a triangular pattern at a spacing of 150 mm centre to centre which forms an area replacement ratio of 0.227. The central three stone columns were loaded through a 10 mm thick loading plate having a diameter of 248.2 mm which just inscribes the three stone columns as shown in Figure 2.

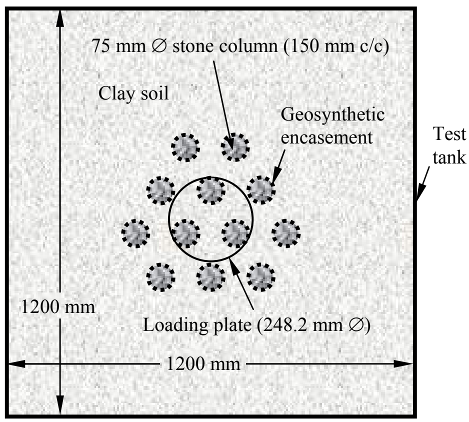

Figure 2. Plan view of group of stone columns

2.1 *Load tests on stone columns*

The stone columns thus formed in the clay bed were subjected to vertical loading at the top of the column through a loading plate displaced at a constant strain rate of 1.2 mm per minute. The loading plate was displaced by a jack fixed on a reaction loading frame. Figure 3 shows the photograph taken during one of the load tests.

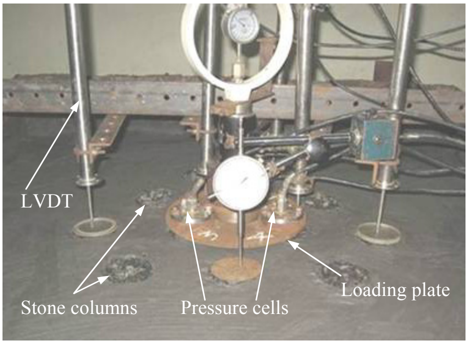

Figure 3. Photographic view of load test on group of stone columns.

The loads corresponding to different displacements (in the stone column) were measured through a pre-calibrated proving ring (having accuracy of 0.8 N). As the loading is quick it is essentially undrained loading which simulates the loading condition immediately after the construction. The pressures on the stone column and the soft clay soil were measured using pressure cells fitted to the loading plate. The load tests on the group of stone columns were performed on the group ordinary stone columns (OSC), and geosynthetic encased stone columns (ESC) encased in woven and nonwoven geotextile. From these tests the improved performance of the group of ESCs over OSCs was quantified.

3 RESULTS AND DISCUSSIONS

Figure 4 shows the pressure settlement responses from the load test on the group of stone columns with and without encasement. The response of the group of ESCs encased in the woven geotextile shows a linear behaviour without any significant sign of failure even for a settlement of up to 40 mm. On the other hand, the group of OSCs has shown a clear sign of failure in their pressure-settlement response. This may be due to the excessive bulging of the stone column due to loading. In the case of encased stone column with nonwoven encasement, the response is softer than that of the woven geotextile encasement owing to the lesser modulus of the geotextile material itself. The load test on the group of ESCs with nonwoven geotextile was repeated once for consistency in results. There is a reasonably good match between the repeated tests. This shows the consistency in different tests. By comparing the responses of group of OSCs and that of ESCs, it could be observed that for the present case the bearing capacity increases by 3 to 5 times due to the encasement. In general the ESCs show strain hardening behaviour whereas the OSCs show plastic failure beyond a certain load limit.

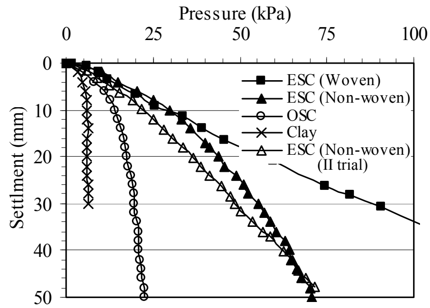

Figure 4. Pressure settlement responses of group of stone columns

The pressure on the individual stone column was measured by the pressure cells attached to the loading plate. The attachment of pressure cells to the loading plate is schematically described in Figure 5.

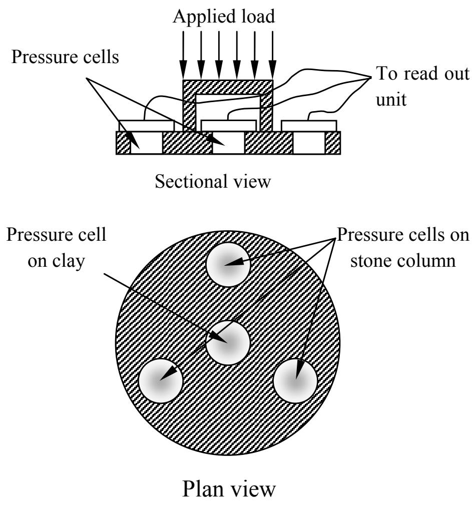

Figure 5. Schematic of the loading plate fitted with pressure cells

The stress concentration factor on the stone column is calculated as the ratio between the pressures on the stone column and the total pressure on the loading plate. The stress concentration factor versus the settlement in the loading plate is shown in Figures 6 and 7. From the figures it could be observed that the stress concentration factor on the ESC is about five times that on the soil. The ratio of the stress transferred to the clay soil is only about 0.3 to

0.6 times that of the total stress pressure on the loading plate. Moreover it could be observed from the Figure 7 that the stress on the intervening clay soil between the ESCs is less than that corresponding to that with OSCs. This indicates that the ESCs behave similar to semi rigid columnar elements, which carry higher percentage of total load and transferring smaller fraction to the surrounding soil. The stress concentration factor is only 2 for the OSCs after the final mobilisaton of the system at higher settlements, which occurs at settlements of about 2.5% to 3.0 % of the column length. The stress transferred to the intervening clay soil between OSCs is higher compared to that on the clay soil between ESCs. The peaks in the stress concentration curves at initial pressure levels were thought to be due to the quick loading through strain controlled displacement of the loading plate.

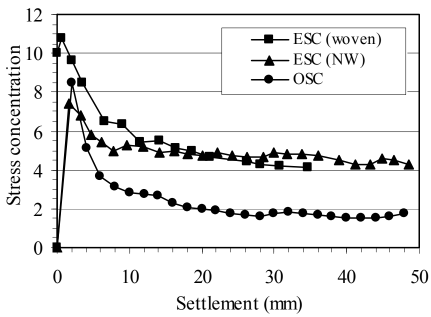

Figure 6. Stress concentration on the stone columns with settlement

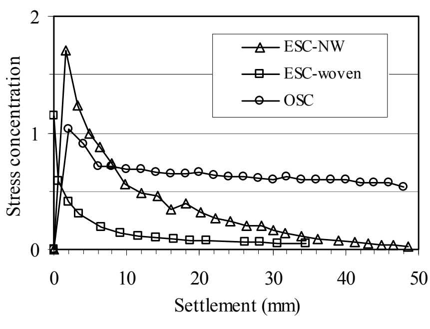

Figure 7. Stress concentration on the clay surface settlement

CONCLUSIONS

This paper attempted on studying the behaviour group of geosynthetic encased stone columns. The results of the load tests on the group of stone columns with and without encasement give some important insight into the performance of the group of geosynthetic encased stone columns. The major conclusions that can be drawn from this research work are as follows.

1. For the present laboratory case there has been an additional improvement in the bearing capacity of stone column treated ground by 3 to 5 times due to the encasement of stone columns.
2. The encased columns have much higher stress concentration compared to that of ordinary columns. It is also found that due to encasement, columns act like semi-rigid piles transmitting lesser stresses on adjoining clay surface compared to the columns without encasement.

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