Effect of vertical loading and penetrating depth on the bearing capacity of encased stone column.

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Abstract : Installation of stone columns to the ground is one of the most effective ground improvement techniques to improve the bearing capacity of soft soil and reduced the settlement of clay. The use of stone columns has proved to be an economical and technically viable ground improvement technique for construction on soft soils. The installation of stone column in a very soft clay deposit they may not be deriving significant load bearing capacity due to low lateral confinement which leads to excessive settlement and bulging of stone column due to low lateral confinement. A recently adopted method of improving the performance of ordinary stone columns is being suggested by encasing the ordinary stone columns with geogride. Geosynthetic encased stone columns is the new technique that is used to overcome the limitations of ordinary stone columns. It gives extra confinement to the stone columns especially when the columns are constructed in soft soils. In this research, finite element analyses are carried out using the software PLAXIS 2D to find the influence of geosynthetic encasement under an embankment as well as stone column. This study aims to find the effect of encasement on settlement behaviour and vertical deformations with respect to ordinary stone column with and without geogride having a ratio of height of stone column to thickness of clay bed h/H.

IndexTerms - Soft Clay, Stone Column, Settlement of clay, Embankment, FEM, Geosynthetics etc.

I. INTRODUCTION

Soft clays are known to have high compressibility, low stiffness and low shear strength. Even though there are different ground improvements techniques, stone columns are considered to be the most versatile method. But in case of very soft clay, stone columns exhibit squeezing that results in excessive bulging of stone columns. When structures like storage tanks are to be constructed on such soft soils they may undergo large settlement, both in terms of total settlement and differential settlement. Since stone columns acts as reinforcement in soils, it helps restricting the settlement of the ground. The recent development in stone columns is encasing individual stone columns by geosynthetics. Encasing stone columns with geosynthetics prevent excessive bulging and squeezing of stone into the surrounding soft soils and thus impart higher load carrying capacity with less settlement. Extensive studies were undertaken by many researchers to find the response of soft ground improved with stone columns. Improved performance of geosynthetic encased stone columns (GESC) over ordinary stone columns (OSC) has been again verified by previous researchers by model testing, numerical investigations and by field studies. The potential of encasing columns with geotextiles for improved performance of stone columns initially analysed by Van Impe and Silence [1] and recognised that that encasement can impart with a significant improvement to the ground when compared to the ordinary stone columns. Stone columns have also been used to improve slope stability of embankments on soft ground. Several researchers have studied and worked on the experimental, theoretical and field study on the behavior of the stone column. However, only very limited information is available on design procedure for a given situation. This research is focused on floating stone column having a ratio of h/H with and without geogride to improving the settlement behaviour of soft clay and saving good quality of material and time of installation of stone column.

II. LITERATURE REVIEW

Several researchers have been worked on various theoretical, numerical, experimental and field study to identifying the behaviour of ordinary stone column due to different loading conditions. however, very little information is available based on design procedures that can be used for a given situations. The various methods are available to improving the settlement bahaviour of soft soil deposits like sand compaction column, stone column and deep mixed column etc. The stone column, or granular pile technique, has been widely adopted to improve the soft soils. Greenwood, 1970 concluded mechanical behaviour of soil below the ground surface. Then Van Impe and Silence (1986) concluded that improving the bearing capacity of weak hydraulic fill by means of geotextile. They also produced the analytical design techniques used to reuired geotextile tensile strength. Rajagopal et al. (1993) investigated the influence of geocell confinement on the strength and stiffness behavior of encased granular soils. Sharma et al. (2004) performed a series of laboratory tests to investigate the effect of laminated (horizontal layers) geogrid on the load bearing capacity and bulging reduction on granular column. Ayadat T. and Hanna A. M (2005) have reported the beenefit of encased stone column
installation in collapsible soil and concluded that by the increase in the stiffness of the geofabric materials the bearing capacity of a stone column will also increase. The load carrying capacity and the deformation characteristics of the composite mass were studied. Yoo and Kim (2009) presented the results of a comparative study on different finite element modeling approaches for modeling geosynthetic-encased stone column-reinforced ground for use in rapid embankment construction. Gniel and Bouazza (2009) observed that isolated columns failed by radial expansion beyond the level of encasement where as in partially encased group of column, bulging occurred along the full length of nonencased section. Kaliakin V. N. et al. (2010) have reported three-dimensional finite element analyses to simulate the behavior of a single granular column with and without encasement in very soft clay using the computer program ABAQUS. Yoo and Lee (2012) presented the results of an investigation on improvement in load carrying capacity and settlement reduction of a GEC using field-scale load tests. Also, the effect of the geogrid encasement length and column strain was studied.

III. RESEARCH OBJECTIVE

The main objective of the study is to reduce the gaps in the engineering knowledge of stone column. The focus is on the stone column constructed to floating in the improved ground where the toe does not reach the competent layer. A principal outcome of this research to produce recommendations on the design of floating stone columns for wide area loading as well as a small column group. A 2D finite element program plaxis-2d is used to carry out the numerical study. Due to the inadequate lateral confinement provided by very soft soils to the stone columns, the construction and the application of conventional granular columns became difficult. This problem can be solved by the application of geosynthetic encasement that provides lateral confinement to the columns material. The GEC method is considered as a recent improvement technique. Thus, there need be a better understanding the installation techniques of different groups of floating stone column or partially penetrated different groups of stone column having a ratio of height of stone column (h) to the thickness of clay bed (H) Example, ratio=h/H, with and without geosynthetic encased stone column.

I. RESEARCH METHODOLOGY

Plaxis is a finite element software package for the analysis of deformation and stability of Geotechnical Projects. The Advantage of the software is the simple graphical method of input for solving complex geometry problems. The most comprehensive part of using Plaxis in this paper for simulation of Geosynthetic Reinforced Stone Column RSC and Ordinary Stone Column OSC is that it provides detailed representation of results the calculation is automated based on geotechnical techniques.

3.1 Finite element analysis of stone column.

The analysis are carried out using an available package plaxis-2D to compare the load settlement behaviour of stone column with the model test and the parametric study. In this study considering the cylindrical unit cell dimensions are kept as diameter 420 mm and height 450 mm, plane strain analysis with 15 nodes triangular elements are used in these analysis, along with Mohr-Coulomb failure criterion to model elasto-plastic behavior of clay and stones & drained behavior assumed for clay & undrained for stone column to study the effect of partial penetration of stone column or floating stone column on the load settlement response, considering a ratios of height of stone column (h=250mm) to the thickness of clay bed H=450mm (e.g. h/H=0.55) under different loading conditions as shown in figure 3.1.1. Fixed support are assumed at the bottom of the mesh and roller support are used on the vertical boundary condition.

Fig. 1: The 5x5 group of encased floating stone column having a ratio of h/H=0.55.

Fig. 1 shows that 5x5 group of encased stone column having diameter of 25 mm with a ratio of h/H= 0.55. Assuming the stiffness of geosynthetic is 8000.
Table 1: Material properties of stone column and soft clay

<table>
<thead>
<tr>
<th>γunsat</th>
<th>γsat</th>
<th>C (kPa)</th>
<th>θ (°)</th>
<th>ψ</th>
<th>ν</th>
<th>E(kPa)</th>
<th>Rinter</th>
<th>Material</th>
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<td>5</td>
<td>21</td>
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<td>4000</td>
<td>0.7</td>
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<td>10</td>
<td>0</td>
<td>0.30</td>
<td>55000</td>
<td>0.9</td>
<td>Stone Column</td>
</tr>
</tbody>
</table>

3.2 Finite element analysis of an embankment

For the benefit of numerical analysis by Plaxis-2D, Mohr-Coulomb model has been chosen for all materials, however drained condition was selected for fill embankment and column, and undrained condition was selected for clay deposit. Due to symmetry, only half of the embankment was modeled to save computational time. As seen in this figure, a 16.5 m wide embankment having side slope of 1V:1.5H is constructed on 10m soft clay underlying by rigid layer. The total width of an embankment is 51.5 m as shown in fig. The boundary effect was investigated to extend the right boundary successively up to 35 m from the toe of the embankment. It was found that it would be sufficient to eliminate the boundary effects if the boundary was set at 35 m from the toe of embankments. The axisymmetric analysis has been used for various groups of stone column. Axisymmetric analysis using Plaxis 2D software in reinforced stone column are presented in Figures 3.2.1 and 3.2.2 etc.

A parametric study was performed to arrive at the critical parameters that define the behavior of the system. The parametric study comprised of all the elements which had an influence on the behavior of the system. The various aspects like lateral movements and the total settlements are studied. The standard units length (m), and time (days) are used. The geometry are drawn using geometric lines and standard fixities are then used to define the boundary conditions as shown in figures 3.2.1 and 3.2.2. Assuming geogrid stiffness 8000.

Fig. 2: Finite element analysis of an embankment with one fully & another floating stone column having a ratio of h/H=1 and 0.5 with geogride.

Fig. 3: Finite element analysis of an embankment of floating stone column having a ratio of h/H=0.8 with geogride.
Table 2: Material properties of stone column and soft clay and embankment fill.

<table>
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<tr>
<th>Material</th>
<th>γunsat</th>
<th>γsat</th>
<th>C (kPa)</th>
<th>Ø (˚)</th>
<th>ν</th>
<th>E(kpa)</th>
<th>Rinter</th>
<th>Kh (m/day)</th>
<th>Ky (m/day)</th>
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<tbody>
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<td>28</td>
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<td>0.30</td>
<td>2000</td>
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<td>7.36x10-5</td>
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<td>Stone Column</td>
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<td>0.30</td>
<td>100000</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
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IV. RESULT AND DISCUSSION

4.1 Result-1: Influence the effect on settlement of 5x5 group of floating stone column with and without geogride.

Graph 1: Settlement of 5x5 group of floating stone column on load versus settlement behaviour with and without geogride.

In order to investigate the effect of the 5x5 group of floating stone column with and without geogride on the performance on both the load carrying capacity and total settlement. The spacing between the floating stone column is 45 mm c/c and diameter of stone is 25 mm as shown in fig. 1. The ratio of h/H=0.55. The result indicating that ordinary stone column (without geosynthetic) indicating maximum settlement of 14.25 mm under the application of 250 KN load as shown in graph-1. Therefore, the geosynthetic encased floating stone column indicating reducing the settlement from 14.25 mm (OSC) to 11.83 mm (GESC) under the application of load 250 KN, without failure of encased stone column as shown in graph-1.

4.2 Result-2: Effect of one fully and another partially penetrated stone column with a ratio of h/H= 1 and 0.5 settlement behaviour of an embankment.

Graph 2: Effect on settlement behaviour of an embankment with one fully & another partially penetrated stone column.
To understand the long-term behavior for encased stone column supported embankments, the effect of change in stone columns length has been investigated, the stone columns diameter (d = 0.8 m), the stone column spacing = 2 m c/c. The current result shows that one fully penetrated stone column & another partially penetrated stone column having a ratio of 1 and 0.5 with & without geogrid as shown in fig. 2. The maximum settlement observed without geogride is 0.182 m & minimum settlement observed with geogride is 0.145 m during a period of 200 days. Thus, the amount of settlement reduced by 20.32% with geogride having a ratio of h/H= 1 and 0.5.

4.3 Result-3: Influence the effect of different ratio of h/H stone column of an embankment with and without geogride.

Graph 3: Influence the effect of different ratio of h/H stone column of an embankment with and without geogride.

To understand the long-term behavior for encased stone column supported embankments, the effect of change in stone columns length has been investigated, the stone columns diameter (d = 0.8 m), the stone column spacing = 2 m c/c. The current result shows that when the smaller diameter of end bearing stone column or floating stone column with and without geogrid affects the settlement behaviour of embankments as shown in fig. 3. The end bearing of ordinary stone column without geogride having a ratio of h/H=1 exhibits the maximum settlement of 0.157 m that of encased stone column with same ratio (e.g. h/H=1) exhibits the maximum settlement of 0.124 m during a period of 200 days. Thus, the amount of total settlement reduced by 21.01% with geogride having a ratio of h/H=1. Similarly, The floating ordinary stone column without geogride having a ratio of h/H=0.8 exhibits the maximum settlement of 0.195 m that of encased floating stone column with same ratio (e.g. h/H=0.8 ) exhibits the maximum settlement of 0.164 m during a period of 200 days. Thus, the amount of settlement reduced by 15.89% with geogride having a ratio of h/H=0.8. Finally, The floating ordinary stone column without geogride having a ratio of h/H=0.6 exhibits the maximum settlement of 0.239 m that of encased floating stone column with same ratio (e.g. h/H=0.6 ) exhibits the maximum settlement of 0.193 m during a period of 200 days. Thus, the amount of settlement reduced by 19.24% with geogride having a ratio of h/H=0.6. Therefore, geosynthetic helps to improved the bearing capacity and reduced the settlement for both end bearing and floating stone column.

CONCLUSIONS

1. With the use of geosynthetics, 20-50% increase in load carrying capacity and reduced settlement are observed in geosynthetic encased stone columns as compared to ordinary stone columns.
2. Partially penetrated stone column or floating stone column is more superior than fully penetrated stone column or end bearing stone column to saving both time and good quality materials.

3. Geosynthetic encased stone column reduces settlement almost better than ordinary stone column because the interaction between stone column and surrounding soil is more effective.

4. Encased stone column with geosynthetic enhanced the stability of the constructed of embankment on soft weak soil by improving the settlement behavior of an embankment.

5. The difference between end bearing and floating stone column are different but geosynthetic helps to improved the bearing capacity and reduced settlement for both end bearing and floating stone column.

6. The load capacity of the stone column can be increased by all-round reinforcement by geosynthetic. By geosynthetic reinforcement, it is found that the stone columns are confined and the lateral bulging is minimised.

REFERENCES


