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Model Tests on Soft Soil Stabilized with Geotextile Reinforcement

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Abstract: Stone column technique is proven to be the most suitable ground improvement technique for improving the soft soils. Out of other methods, stone columns technique is the most effective method for flexible structures like embankments, oil storage tanks etc. Soft soils stabilized with stone columns can be further improved by reinforcing the column with any geosynthetic material. In this study, Silica-Manganese slag mixed with Sand was used as the stone column material to improve the soft marine clay and geotextile material was used to reinforce the stone columns. This geotextile was made into circular discs and placed within the stone column horizontally at a spacing of 50mm (equal to the diameter "D" of the stone column). The results indicate that the soft soil can be improved with the stone column and can be further stabilized with the geotextile reinforcement.

Keywords: -Load carrying capacity, Marine soil, Sand, Silica-Manganese slag, Stone column

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I. INTRODUCTION

Soft soils are mostly located in coastal areas having poor shear strength. To improve these soils many techniques are available in which Stone column is the most preferable technique which consists of granular materials compacted in a cylindrical hole so that the load carrying capacity can be increased. Load carrying capacity and settlement analysis of the stone column was first proposed by Greenwood (1970). Deb et al. (2010) conducted the laboratory tests to find out the effect of geogrid reinforced sand bed on stone column. From this investigation, it was found that the load carrying capacity of the soft clay was significantly increased by including the geogrid in the sand bed above the stone column and also the bulge diameter was significantly reduced and the bulge depth was increased. Ambily and Gandhi (2007) reported the results of experimental investigation on sand columns carried out in model stone columns and loaded under triaxial conditions. Tandel et al., (2012) have done the experiments on stone columns of varying diameters and found that the smaller diameter columns are superior to large diameter columns because of mobilization of higher confining stresses in larger stone columns. Sharma et al. (2004) proposed the placing of horizontal geogrid layers in the upper region of the column to enhance the resistance against bulging. A.P. Ambily and S.R. Gandhi, Kempfert and Gebreselassi carried out experiments to evaluate the behaviour of stone column by varying spacing, shear strength of soft clay, moisture content etc. Madhav presented an overview of recent contributions for the analysis and design of stone columns. Madhav et al., have proposed the simple approach to evaluate shear stresses at granular pile/soil interface based on the unit cell concept. Mohammed Y. Fattah et al. carried out the experiments to study the stress concentration ratio, n, which is defined as the ratio of vertical stress acting on the stone column to that of the surrounding soil. S.R. Gandhi et al. have done the experiments to study the behaviour of stone column by varying the spacing, shear strength of soft clay and moisture content and found that the failure occurred by bulging of the column with maximum bulging at 0.5 to 1 times the diameter of the column below the top. Most of the works done so far are related to the stone columns reinforced with geosynthetic materials used as reinforcement material to the stone columns. This study consist stabilization of floating stone columns using Silica-Manganese slag as stone column material and reinforced with the laterally placed geotextile.

II. MATERIAL USED

Marine clay, Silica-Manganese slag, Sand and Geotextile were used in this study. The sources, preparation and the properties of the materials are discussed below.

Marine clay was collected from Visakhapatnam port trust, Andhra Pradesh, India. This marine clay is highly compressible inorganic clay. The soil was dried and sieved through 4.75mm sieve and was used for the study. Fines content (Silt+ Clay) of the soil is 94%, Specific Gravity is 2.50, Liquid limit (WL), Plastic limit (WP) and Plasticity Index (IP) are 72%, 36%, 36% respectively. Maximum dry unit weight is 14.2 kN/m^3 and

Optimum Moisture Content (OMC) is 29.5%. The soil is classified as CH and Shear strength of soil at 54 % water content is 15.0 kPa which is used in this study. Marine clay used in this study is shown in Fig. 1(a).

Silica-Manganese slag was used as a stone column material in this study. This slag is produced during the process of steel production and obtained from smelting process in Ferro-alloy industry. Silica-Manganese slag used in this study is shown in Fig. 1(b). This was collected from Sri Mahalaxmi Smelters (Pvt.) Limited, Garbham. Water absorption, Specific Gravity and Unit weight of compacted slag are 0.49%, 2.79 and 16.7kN/m^3 respectively.

River sand was used to fill the voids within the slag aggregate which was collected from Nagavali River, near Srikakulam, India. This sand was also used as sand blanket of 20mm thick on the clay bed.

Stone column was reinforced with laterally reinforced non-woven geotextile material which is collected from Ayyappa Geotextile installers, Vishakhapatnam, India. This geotextile was cut in to circular discs of diameter equal to the diameter of stone column (50mm) and was used within the stone column. The Geotextile circular discs are shown in Fig. 1(c). Tensile strength and mass of the geotextile are 4.5kN/m and 100g/m^2 respectively.

(a) (b) (c)

Figure 1 Materials used in this study

III. EXPERIMENTAL STUDY

Model tests were conducted on clay bed, plain stone column and stone column reinforced with geotextile circular discs and the load carrying capacities of the stone columns were compared with the clay bed.

Preparation of Clay bed

The marine clay used in this study was air dried, pulverized and sieved through 4.75mm sieve. This soil was mixed with required water content (54%) to make it in to paste to get the required shear strength (15kPa). After adding the water to the soil, it was thoroughly mixed to form like a paste and filled in layers of 50mm thick into the steel tank of desired diameter (200mm) and height (300mm). The compaction was done with a wooden hammer such that there will not be any air voids with in the clay bed. The inner surface of the tank was cleaned and greased before preparation of the clay bed to reduce the friction between the soil and the tank. After preparation of the clay bed, it was kept for 24 hours for the moisture equalization and was tested to find out the load carrying capacity of the pure clay bed. For making the stone columns, the clay bed was prepared freshly for every test.

Preparation of plain stone column with Slag+Sand

After the clay bed was prepared to a depth of 10cm, a PVC pipe having its outer diameter 50mm and 1mm thick was placed at properly marked centre of the clay bed in the tank. Around this pipe, clay bed was then filled in the tank in 50 mm thick layers to the desired height of 300mm by hand compaction such that no air voids are left in the soil. Silica-Manganese Slag and Sand are used as the stone column materials. Plain stone column was constructed with Silica-Manganese Slag+Sand. The proportion was selected in such a way that the voids within the aggregates are filled with the Sand. The stone column was casted in steps by compacting the Slag+Sand mix and withdrawing the casing pipe simultaneously for every 50 mm of depth along the length of column. After compaction of each layer, the pipe is lifted gently to a height such that there will be an overlap of 5mm between the surface of the aggregate and the bottom of the casing pipe. The column material was compacted by using a 10 mm diameter steel rod with 10 blows from a height of fall of 100 mm. After completion of the stone column, the composite soil with the column inside was again left covered with polythene cover for 24 hours to develop proper bonding between the column material and the soft soil.

Preparation of geotextile reinforced stone column

After the clay bed was prepared for a depth of 100mm at the bottom, a PVC pipe of 5cm outer diameter and 1mm thick was placed at the center of the tank and the clay bed was prepared to the outside of the pipe in 50mm layers up to the remaining height of 200mm which is prepared similar to the procedure used to prepare for the plain stone column. Reinforced stone column was constructed for different reinforcement lengths and was prepared in two stages i.e. unreinforced and reinforced portions. To construct the fully reinforced (D) stone columns, the geotextile discs were placed at specified intervals of "D" within the stone column material and the compaction was done similar to the unreinforced column. To construct the partially reinforced stone column (D/2D/3D), bottom unreinforced portion was constructed similar to the unreinforced portion and the upper reinforced portion was constructed by placing the geotextile discs at specified intervals. After completion of the stone column, it was kept for 24 hours for moisture equalization and to improve the bonding between the aggregates and the clay bed.

Testing of Clay bed

After preparation of the clay bed/ stone column, load tests were conducted to study the load-settlement behavior. Sand blanket of 20mm thick was placed on the surface of the clay bed and load was applied with a strain rate of 0.24mm/min to a settlement of 20mm and the applied load was observed from proving ring at every 1mm settlement. Loading arrangement used in this study is shown in Fig. 2 and mode of application of Geotextile discs is shown in Fig. 3.

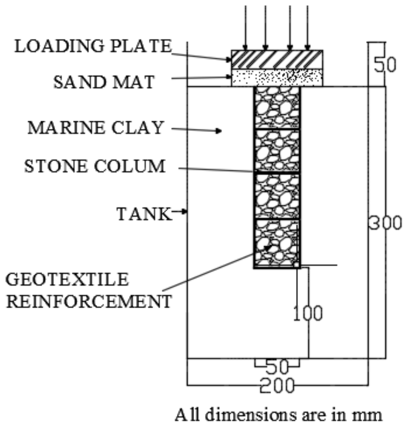

Figure 2 Loading arrangement

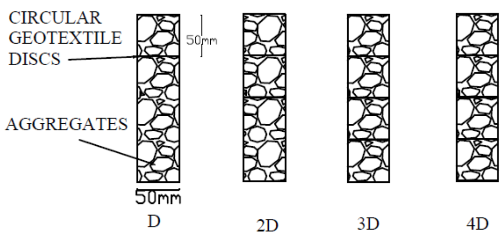

Figure 3 Mode of application of Geotextile discs

IV. RESULTS AND DISCUSSIONS

After the load tests were conducted for the clay bed, unreinforced and reinforced stone columns, load-settlement graphs were drawn and the ultimate load and corresponding settlements were determined by drawing double tangent method.

Load-Settlement response

The ultimate load carrying capacity was determined by drawing double tangent to the load-settlement curve. The ultimate load carrying capacity of the clay bed is 28kg. The settlement at the ultimate load is 7.5 mm.

Tests were conducted on Silica-Manganese slag column alone and Slag with Sand and the load-settlement curves were obtained. The ultimate load carrying capacity with stone column alone is 37 kg and is that of Slag+Sand is 40kg. The settlement at the ultimate load has been reduced to 7.2 mm and 7.0 mm for the Slag alone and Slag+Sand columns respectively. The ultimate load carrying capacity is increased by 32% and 43% respectively for the Slag alone and Slag+Sand columns respectively compared to the plain clay bed. Load carrying capacity for the unreinforced columns shows better load carrying capacity than clay bed. This is because of the densification of the clay bed by inclusion of stiffer Silica-Manganese Slag and Sand.

Tests were conducted for the stone columns of Silica-Manganese Slag with Sand mix and were reinforced with circular geotextile discs. Load-settlement curves were drawn for all the reinforced stone columns of varying reinforcement lengths (D, 2D, 3D and 4D) and ultimate load carrying capacities and corresponding settlements were determined. Fig. 4 shows the Load-Settlement curves of clay bed, unreinforced and reinforced stone columns. The ultimate load carrying capacities of the geotextile reinforced stone columns were increased by 14%, 22%, 36%, and 43% for the reinforcement lengths of D, 2D, 3D and 4D respectively compared to the unreinforced Slag stone columns. Whereas the increment was 50%, 61%, 80%, and 89% respectively compared to the plain clay bed.

Settlements were also observed corresponding to the ultimate load carrying capacities from the Load-Settlement curves. The settlements were reduced considerably for the unreinforced and reinforced stone columns compared to the plain clay bed. The settlements for the reinforced stone columns were observed to be 6.8mm, 6.6mm, 5.8mm and 5.5mm for the reinforcement lengths of D, 2D and 3D and 4D respectively.

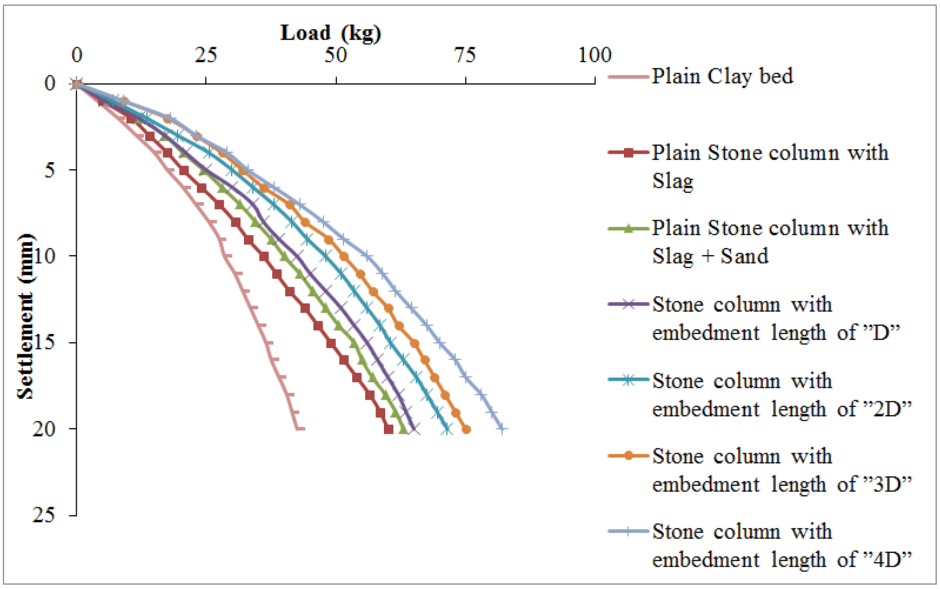

Fig. 4

V. BULGING ANALYSIS OF STONE COLUMNS

After the load tests were conducted, the slag aggregates were removed and the cavity formed in the clay bed was filled with a paste of plaster of paris and kept it for one day and the surrounding clay was removed to get the deformed shape. The deformations were measured at 2.5cm intervals along the length of the stone column and the bulging behavior of the stone columns was studied. A graph is plotted between the depths versus bulging of the column. Fig. 5 shows the bulging curves of unreinforced and reinforced stone columns with varying reinforcement depths. For the unreinforced stone columns, the maximum bulging of 10mm was observed at the center of the stone column. This maximum bulging was reduced to 8.1mm for the stone column with Slag+Sand. This was further reduced by introducing the reinforcement and reached to the maximum bulging of 7.0mm, 6.5mm 6.0mm and 4.0mm for the reinforcement lengths of D, 2D and 3D and 4D respectively.

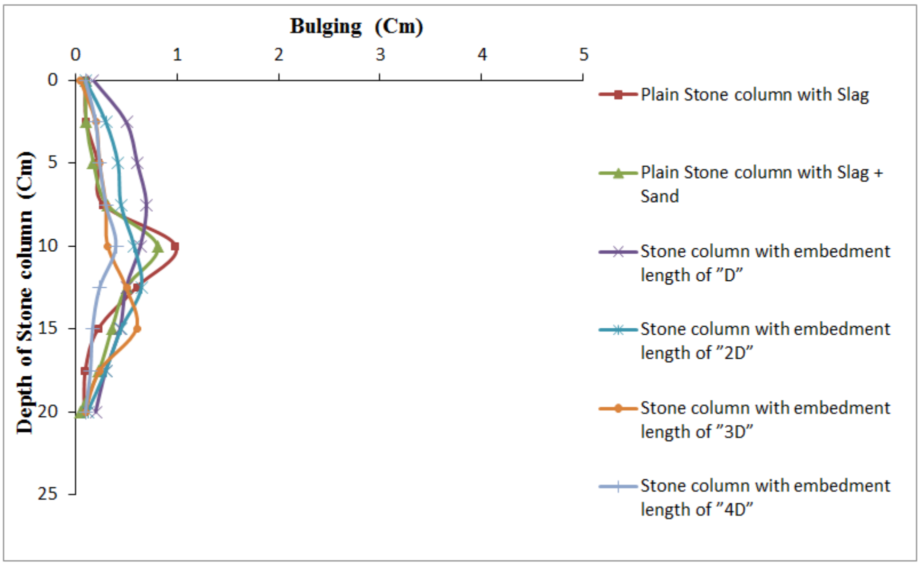

Fig. 5

VI. CONCLUSIONS

From the present study, the following conclusions were derived.

1. Load carrying capacity of the soft clay can be increased by introducing the stone column and also by adding the sand to the stone column by minimizing the voids between the aggregates. Load carrying capacities are increased to 32% and 43% by improving the soil with the Slag column and Slag+Sand column respectively.
2. Stone column performance can be increased by introducing the lateral geotextile discs within the column.

3. Load carrying capacity can be increased by increasing the embedment length of reinforcement.
4. Settlements can be reduced by improving the soil with stone column and also with the reinforcement length. Settlement of the clay bed was reduced from 10mm to 4.0mm by reinforcing the soil with the reinforcement length of 4D.
5. Bulging of the stone column can be reduced by introducing the reinforcement and also with the reinforcement length. Bulging of the plain stone column was reduced from 7.5mm to 5.5mm by reinforcing with geotextile to a length of 4D.
6. The maximum bulging for the unreinforced stone column was found at the middle of the column. Whereas for the reinforced columns, the maximum bulging found below the end of the reinforcement.

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