# Soft Soil Improvement by Using Stone Columns Reinforced with Lateral Geotextile Discs

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***Abstract:*** In recent years stone columns are being mostly used for the improvement of soft clays, loose sands and silty soils mainly for the flexible pavements like oil storage tanks, embankments etc. which can allow some settlements. Stone columns increase the process of consolidation by acting as vertical drains. Sometimes, Stone columns itself may not give sufficient load bearing capacity due to the insufficient lateral confinement offered by the surrounding soils. In such cases, these stone columns may be reinforced with suitable geosynthetic material. Stiffness of geosynthetic and angle of internal friction of stone column material gives a better understanding of the physical performance of the clay bed. In this study, the behavior of soft marine clay improved with end bearing stone columns was experimentally investigated and analyzed. This stone column was made with Silica-Manganese slag and Sand and was reinforced with lateral geotextile circular discs placed at a spacing of D (5cm) where D is the stone column diameter. The results indicate that the stone column improves the strength of soil and have significant influence on the load bearing capacity of the soil. The results also showed that the settlement was reduced considerably by introducing the reinforcement and also with increasing the embedment length.

***Index Terms*** **- Geotextile, Marine clay, Silica-Manganese slag, Stone column, Load carrying capacity.**

## I. INTRODUCTION

India has vast coastal area having highly compressible clayey soils which are having very low bearing capacity and causes major problem to the structures. Ground improvement by using stone columns is one of the alternate to increase the load bearing capacity of the soils and to reduce the settlements of the structures. Load transfer theory was first derived by Greenwood [1] and developed by numerous researchers over a period of four decades. Malarvlzhi and Ilamparuthi [2] studied the single stone column behavior by varying the L/D ratios and encasing the stone column with geogrid and the results were compared with the conventional stone columns. The results indicate that the load carrying capacity increases with increasing the length of stone column and also with the stiffness of the encased material. The bulging was observed effectively to a depth of 4D from the top of the column. The author has also done the FEM analysis and compared the results with experimental results. From the numerical analysis they found that the bulging was extended from 2.5 to 6 times the diameter of the stone column. A.P.Ambily and S.R.Gandhi [3] compared the load settlement behavior from the experimental results with the FEM analysis. The analysis was carried out by loading the stone column area alone and column area surrounded with clay bed. Maximum bulging was observed at 0.5 to 1 time the diameter of stone column for the first case and failure did not observed for the latter case. The load settlement behavior for the entire area loaded case was linear and the test results were well compared with the FEM analysis. K. Ali, J.T. Shahu and K.G. Sharma [4] investigated the floating and end bearing stone columns reinforced with lateral geotextile discs by varying the reinforcement length and found that the end bearing stone columns gives better performance than the floating stone columns. They found that the load carrying capacity increases with the decrease in spacing of the discs and also found that the D/2 spacing gives the best configuration. M.R. Dheerendra Babu et al. [5] have done the experiments on very soft soils improved with stone columns reinforced with circumferential nails placed along the circumference. The results showed that the effective length of nails was 3D to 4D and also found that the performance of stone column improved with the number of nails. Kumar Rakesh and Jain P.K. [6] conducted the experiments on soft ground improved with varying fiber contents and found that 1.0% of fiber with 30mm length is the optimum content for facilitating the proper mixing and to improve the load carrying capacity of the soil. Kausar Ali et al. [7] carried out the experiments on composite soils improved with floating and end bearing stone columns of varying lengths and found that the end bearing columns gives good performance than floating stone columns and the increase in bearing capacity is not significant when the length exceeds 6D. When the L/D ratio is greater than ten, floating columns performs as good as end bearing columns. Most of the works done so far are limiting to the stone column material as stone aggregates. Whereas, in this study an attempt has made to utilize a material called Silica-Manganese slag as stone column material and the void space between the aggregates was filled with the sand. This column was also reinforced with geotextile circular discs placed laterally within the stone column and the Load versus Settlement behavior was studied.

## II. MATERIALS 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.

### 2.1. Marine Clay

Marine clay was collected from Visakhapatnam port trust, Andhra Pradesh, India. This marine clay is highly compressible inorganic clay. The soil was dried and passed through 4.75mm sieve and was used for the study. Marine clay used in this study is shown in Fig. 1. Properties of marine clay are given in Table 1.

Table 1: Properties of Marine Clay

| Property of Marine clay | Value/Classification |
|---|---|
| Fines content (Silt+ Clay) | 94% |
| Liquid limit (WL) | 72 % |
| Plastic limit (WP) | 36 % |
| Plasticity Index (IP) | 36 % |
| Maximum dry unit weight | 14.2 $kN/m^3$ |
| Optimum Moisture Content (OMC) | 29.5% |
| Soil classification (Indian Standard Classification) | CH |
| Shear strength of soil (in kPa) at 54 % water content | 15.0 |
| Specific Gravity | 2.50 |

Fig. 1 Marine Clay sample

### 2.2. Silica-Manganese slag

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. 2. This was collected from Sri Maha Laxmi Smelters (Pvt.) Limited, Garbham. The properties of Silica-Manganese slag are given in Table 2.

Table 2: Properties of Silica-Manganese Slag

| Property | Value |
|---|---|
| Water absorption (%) | 0.49 |
| Specific Gravity | 2.79 |
| Unit weight of compacted slag ($kN/m^3$) | 16.7 |

Fig. 2 Silica-Manganese Slag

### 2.3. Sand

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.

### 2.4. Geotextile circular discs

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 and was used within the stone column. The Geotextile circular discs are shown in Fig. 3. Tensile strength and mass of the geotextile are 4.5kN/m and 100$g/m^2$ respectively.

Fig. 3 Geotextile circular discs

## III. EXPERIMENTAL PROCEDURE

Experimental program was carried out which includes the construction and testing of clay bed, ordinary stone column and reinforced stone columns.

### 3.1 Preparation of Clay bed

The marine clay used in this study was air dried and pulverized and sieved through 4.75mm sieve. This soil was mixed with required quantity of water 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 (200mm). 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.

### 3.2 Construction of unreinforced Stone Column

Stone column was constructed with Silica-Manganese slag and Sand. The proportion was selected in such a way that the voids within the aggregates are filled with the Sand. 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 required height of 200mm which is prepared similar to the procedure used in the above section. The stone column was then prepared within the pipe in 50mm layers by giving the constant blows throughout for all the layers to maintain constant density. After completion of each layer, the pipe was slowly lifted simultaneously so that there will be an overlap of 5mm between the top of the layer and the bottom of the pipe. The aggregates were compacted with a steel rod of 10mm diameter from a height of fall of 100mm to maintain the uniform density throughout. 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.

### 3.3 Construction of reinforced stone columns with circular geotextiles discs

Stone column was constructed with Silica-Manganese slag and Sand. The proportion was selected in such a way that the voids within the aggregates are filled with the Sand. 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 required height of 200mm which is prepared similar to the procedure used in the above section. 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 stone columns, the geotextile discs were placed at specified intervals (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.

## IV. TESTING OF CLAY BED/STONE COLUMN

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. 4.

Fig. 4 Testing of Stone column

## V. 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.

### 5.1 Load-Settlement response of Plain Clay bed

The ultimate load carrying capacity was determined by drawing double tangent to the load-settlement curve obtained from load test on plain clay bed as shown in Fig. 5. The ultimate load carrying capacity of the clay bed is 28kg. The settlement at the ultimate load is 7.5 mm.


Fig. 5 Load-Settlement curve for Clay bed

### 5.2 Load-Settlement response of unreinforced stone column

Tests were conducted for the Silica-Manganese slag column alone and slag with Sand and the load-settlement curve were obtained. The ultimate load carrying capacity with stone column alone is 48 kg and that of Slag + Sand is 53kg. The settlement at the ultimate load has been reduced to 7.0 mm and 6.8 mm respectively for the Slag alone and Slag+Sand columns respectively. The ultimate load capacity is increased by 71% and 89% 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.

### 5.3 Load - Settlement response of reinforced stone columns

Tests were conducted for the stone columns of Silica-Manganese Slag with Sand 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/4D) and ultimate load carrying capacities and corresponding settlements were determined. Fig. 6 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 104%, 108%, and 115% for the reinforcement lengths of D, 2D and 3D/4D respectively compared to the unreinforced stone columns. Whereas the increment was 96%, 104%, and 118% 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 6.7mm, 6.3mm, 5mm respectively for the reinforcement lengths of D, 2D and 3D/4D respectively.

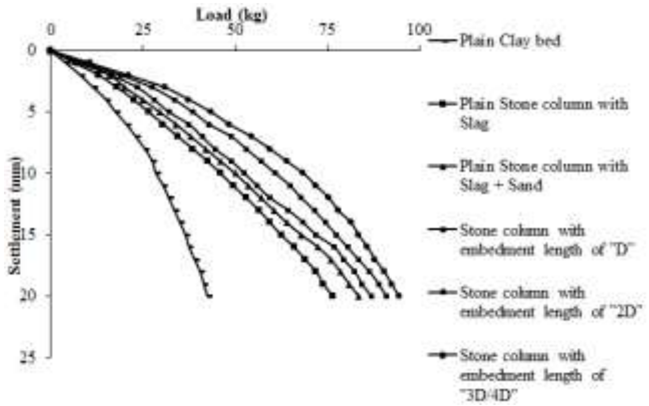


Fig. 6 Load-Settlement curve for Clay bed, unreinforced and reinforced stone columns

## VI. 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. 7 shows the bulging curves of unreinforced and reinforced stone columns with varying reinforcement depths. For the unreinforced stone columns, the maximum bulging of 11mm was observed at the center of the stone column. This maximum bulging was reduced to 9mm for the stone column with Slag+Sand. This was further reduced by introducing the reinforcement and reached to the maximum bulging of 8.5mm, 7mm and 5mm for the reinforcement lengths of D, 2D and 3D/4D respectively. But the maximum bulging was observed near/just below the renforcement.

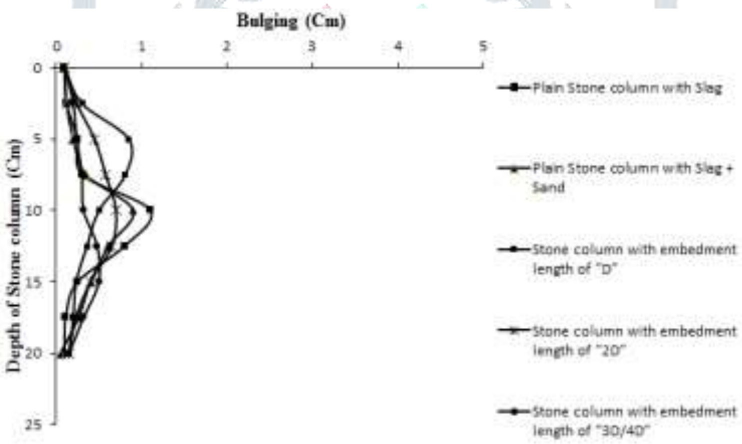


Fig. 7 Bulging curves for unreinforced and reinforced stone columns.

## VII. CONCLUSIONS

1. Inclusion of Silica-Manganese Slag with Sand column increased the load carrying capacity of plain clay bed by about 89%.
2. The load carrying capacity and stiffness of the stone column are increased by providing the lateral reinforcement with geotextile circular discs.
3. Load carrying capacity increases with increase in reinforcement length. This increment was reached to 118% when the column was reinforced for full length.
4. Load carrying capacities of the stone columns reinforced with circular discs are increased considerably up to the reinforcement length of 3D and later the increment was negligible.
5. The settlement is decreased when the stone column is reinforced with geotextile and also with reinforcement length. The settlement decreases from 7.5mm to 5mm when the clay bed was reinforced with geotextile for full length.
6. In general the maximum bulging was found to be below the end of the reinforcement length. For unreinforced and fully reinforced columns, maximum bulging was found at the middle of the stone column.

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