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Improvement of Marine Clay Performance Using Silica-Manganese Slag Stone Column Reinforced with Geotextile

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Abstract: - Stone columns have proven to be the most suited technique for improving the bearing capacity of weak or soft soils and are used worldwide. The stone column is most popular and cost effective ground reinforcing technique which is used for flexible structures like oil storage tanks, embankments, raft foundations etc. This technique is used for improving the strength parameters like bearing capacity and reduces the settlements. The strength of the composite soil may further be increased by reinforcing the stone columns by geotextile. In the present study, laboratory model tests have been carried out on floating stone column with and without geotextile. In this study Silica-Manganese Slag and Sand is used as the stone column material and was reinforced with geotextile with different encasement lengths of D, 2D, 3D & 4D. The tests indicate that the load carrying capacity increases by replacing the Stone aggregates with Silica-Manganese Slag and also increases with the increase of encasement length and settlements have been decreased.

Keywords*:-* Geo-textile, Marine clay, Silica-Manganese slag, Sand, Stone column.

I. INTRODUCTION

The prime requirement for the development of any country is the sufficient infrastructure of buildings, roads, tunnels, bridges and other civil engineering works. India has a vast area of soft soils along its long coast which are highly compressible with low bearing capacity. For the construction of high rise buildings and other important structures, the soft soil is bye passed by providing the pile foundation resting on firm strata. But for low rise buildings and other flexible structures such as liquid storage tanks, rail/road embankments, factories etc. that can tolerate some settlements, ground improvement techniques are normally considered as economical. Stone columns is one of the most suited technique and used worldwide. This technique is simple, cost effective and economic in installation. For treatment of soft soil, when stone column is installed in soft soil, the confinement offered by surrounding soil may not be adequate and different modes of failure occurs like bulging, sliding and general shear failure. To avoid lack of confinement, stone column is reinforced with geotextile, due to this bearing capacity of ground improves. In this study model tests have been performed on Stone columns encased with different encasement lengths of D, 2D, 3D, 4D by replacing the stone column material with Silica-Manganese Slag and Sand.

S.R. Gandhi et al. [1] carried out the experimental studies to evaluate the behaviour of stone column by varying spacing, shear strength of soft clay, moisture content. The test results indicate that the failure is by bulging of the column with maximum bulging at 0.5 to 1 times the column diameter below the top. Karun Mani et al. [2] studied to improve soil stability, including its salient features, design parameters, major functions and drawbacks and found out that stone columns improves the bearing capacity and reduces the settlement of weak soil strata. J.T. Shahu et al. [3] studied the effect of reinforcement and l/d ratio on the bearing capacity of the composite soil and found that the bearing capacity of composite soil increases with the increase in column length but the increase is not significant when the length exceeds beyond six times the column diameter. Kausar Ali et al. [4] conducted model tests on single floating as well as end-bearing stone columns with and without encasement by providing geosynthetic encasement over varying column length and found that the tests indicate that the encasement over the full column length gives higher failure stress as compared to the encasement over partial length of column for both floating and end bearing columns. Further, the performance of end-bearing columns was found to be better than the floating columns. R. Shivashankar, et al. [5] investigated to improve the performance of stone columns in extremely soft soils is being suggested by reinforcing the stone columns with vertical nails driven along the circumference. They found that the behaviour of composite ground is further improved with the number of nails. The depth of embedment of nails required to significantly enhance the performance of the stone columns is 3*D* to 4*D*. N. Hataf et al. [6] studied the improvement of the bearing capacity of stone columns reinforced with geosynthetics. Stone columns consist of a stiffer material or aggregates, compared to the surrounding soils which are usually vibrocompacted into the soil. These columns increase the bearing capacity of the soil significantly. P.K. Jain et al. [7] Studied to improve the load carrying capacity on single granular pile. Tests were performed with different diameters of granular piles with and without geogrid encasement and concluded that the increase in the load carrying capacity also increases as the diameter of the granular pile increases. S.N. Malarvizhi et al. [8] studied the performance of soft clay bed stabilized with single stone column and reinforced stone column having various slenderness ratios using different type of encasing materials and found that encasing the stone column with geogrids resulted in an increase of load carrying capacity irrespective of whether the column is end-bearing or floating. In case of floating columns the l/d ratio has less influence on the capacity of column for the lengths studied in this investigation. S. Murugesan et al. [9] investigated the performance of the encased stone column and evaluated through experimental studies and numerical simulations. Pressure settlement response of geosynthetic encased stone columns generally shows linear behaviour not indicating any catastrophic failure unlike the conventional stone columns.

Siddharth Arora et al. [10] conducted tests on floating granular piles constructed in soft black cotton soil and found that the ultimate load carrying capacity of the granular pile increases as L/d ratio increases in both the cases i.e. without and with geogrid encasement. Siva Gowri Prasad. S et al. [11] performed tests on stone columns with and without geotextile encasement with different lengths of L/4, L/2, 3L/4 & L and found that the tests indicate that the bearing capacity increases with increase of encasement length. Siva Gowri Prasad. S et al. [12] conducted tests on floating stone columns by introducing lateral circular discs of geo-textile within the column at different spacings and found that load carrying capacities with D/2 spacing shows better performance than D spacing. Uttam Kumar et al. [13] investigated the effect of diameters of geosynthetic encased sand columns in soft soil deposit during loading. The load responses of sand columns are also investigated with the variation of encasement length of the column. He found that the performance of smaller diameter sand column is superior to that of bigger diameter sand column. Y. Mohammed et al. [14] studied the value of the stress concentration ratio, *n*, which is defined as the ratio of vertical stress acting on the stone column to that acting on the surrounding soil. They found out that the value of stress concentration ratio *n* increases with increasing shear strength of the treated soil.

II. MATERIAL USED

Basic materials used for this study are Marine clay, Stone aggregates, Silica-Manganese slag, Sand, Geotextile. Marine clay is collected from Visakhapatnam port trust. The soil is highly compressible inorganic clay and need to be improved. The properties of marine clay are given in Table: I.

Table I: Properties of Marine clay

Property of soil	**Values**
Fines content (Silt+ Clay)	94%
Liquid limit (W_L)	72 %
Plastic limit (W_P)	26 %
Plasticity Index (I_P)	46 %
Optimum Moisture Content (OMC)	29.5%
Maximum Dry Density (MDD)	14.2 kN/m^3
Soil classification (as per Indian Standard)	CH
Unconfined compressive strength (in kPa) at 41 % water content	30.0
Specific Gravity	2.49

Silica-Manganese slag is used as the stone column material, which is produced during the primary stage of steel production. It is collected from Sri Mahalaxmi Smelters (Pvt.) Limited near Vijayanagaram and the aggregates of sizes between 4.75 mm and 10 mm have been taken for the present study. The properties of Silica-Manganese slag are given in Table: II. Stone aggregates used to compare the results with the Slag are crushed stone aggregates collected from quarry near Rajam, Andhra Pradesh. The compacted density of the aggregates is 15.9kN/m^3.

Table II: Physical properties of Silica-Manganese slag

Property	**Value**
Specific Gravity	2.79
Water absorption (%)	0.49
Density (kN/m^3)	16.7

Sand is used to fill the air voids between the aggregates in stone column and also used as a blanket of 20mm thickness on the clay bed. This sand is sieved from 4.75mm sieve. This is clean river sand collected from Nagavali River, Srikakulam (Dt).

Geotextile is used as the reinforcing material for encasing the stone column and is collected from Ayyappa Geo-textile installers, Vishakhapatnam. This sheet is stitched to form the tube for encasing the stone column. Mass of the geotextile is $100g/m^2$ and Tensile strength is 4.5kN/m.

III. EXPERIMENTAL STUDY

Model tests are conducted on Clay bed, Plain stone column with Stone aggregates, Slag, Slag+ Sand and a series of reinforced stone columns. For reinforced stone column, the reinforcement is provided with geotextile with different encasement lengths of D, 2D, 3D, 4D. The air dried and pulverized clay sample was mixed with required quantity of water. The moisture content (41%) required for desired unconfined compressive strength of 30kPa was determined by conducting several vane shear tests on cylindrical specimen of 76mm height and 38mm depth. Slag and Sand are used as the stone column material in proportions of 60:40. The proportion of Slag and Sand are selected such that the voids in the aggregates (40%) are filled with the Sand. The complete test setup and schematic diagram of loading frame with a typical stone column diagram is shown in Fig.1 and different modes of application of reinforcement is shown in Fig. 2.

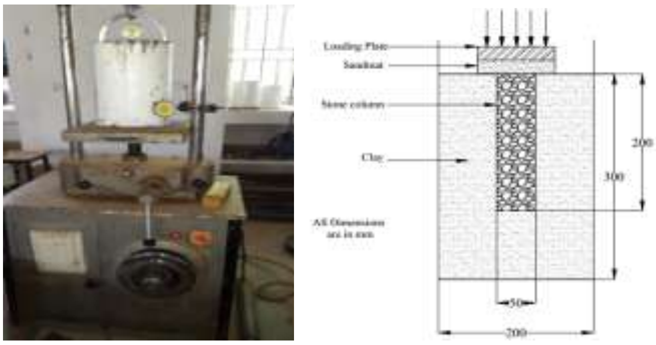

Fig. 1: Test setup with loading and Schematic diagram of loading frame.

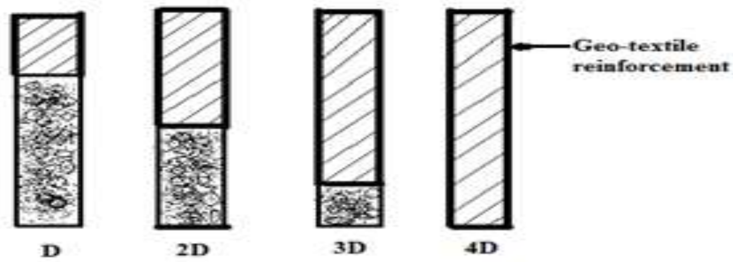

Fig. 2: Different modes of application of reinforcement of encasement lengths D, 2D, 3D, 4D.

A. Preparation of soft clay bed

The air dried and pulverized clay sample is taken and it is mixed with required quantity (41%) of water. The clay is thoroughly mixed to a consistent paste and is filled in the tank in 50 mm thick layers to the desired height (H) of 200mm by hand compaction such that no air voids are left in the soil. Before soil is filled in to the tank the silicon grease is applied in the inner surface of the tank for reducing the friction between the soil and the tank. After compaction of clay bed, it was covered with wet gunny cloth and left for 24 hours for moisture equalization and was tested.

B. Construction of plain stone column (Stone aggregates/Slag/Slag+Sand)

Before construction of stone column, grease is applied in the inner surface of the tank for reducing the friction between the soil and the tank. Clay bed is prepared to a depth of 100mm and on this surface the perspex pipe of outer diameter 50 mm and 1 mm thick was placed at properly marked centre of the clay bed. Before placing the pip, grease is applied to the outer surface. 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. The stone column was casted in steps by compacting the stone column material by using a 10 mm diameter steel rod with 10 blows from a height of fall of 100 mm. After compaction of each layer the pipe is lifted such that there will be 5mm overlap between the two layers and withdrawing the casing pipe simultaneously for every 50 mm of depth along the length of column. After completion of construction of stone column it is left covered with polythene cover for 24 hours to develop proper bonding between the stone chips of the column and the soft soil.

C. Construction of Stone column with geotextile encasement

Before construction of stone column, grease is applied in the inner surface of the tank for reducing the friction between the soil and the tank. Clay bed is prepared to a depth of 100mm and on this surface the perspex pipe of outer diameter 50 mm and 1 mm thick was placed at properly marked centre of the clay bed. Before placing the pip, grease is applied to the outer surface. 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. The stone column was casted in steps by compacting the Slag and Sand by using a 10 mm diameter steel rod with 10 blows from a height of fall of 100 mm. For constructing the stone column reinforced for length of 3D. The process of compacting the stone column is continued up to the remaining unreinforced length of D from the surface of the clay bed and the pipe is taken out. The pipe is encased with the geo-textile for a length of 3D and the pipe is placed in position and then the stone column is casted in steps of 50mm layers by using the above procedure. For the other reinforced lengths of D, 2D and 4D the same procedure is followed. After completion of construction of stone column it is left covered with polythene cover for 24 hours to develop proper bonding between the aggregates and the soft soil.

D. Clay bed/Stone column Testing

The Clay bed/Stone column to be tested is taken and a sand blanket of 20 mm thick was laid on the surface of clay bed. The perspex circular disc of 12 mm thick and having diameter of 100 mm which is double the diameter of stone column is placed at center of the bed and is subjected to strain controlled compression loading in a conventional loading frame at a rate of settlement of 0.24 mm/min. For every 1mm settlement, corresponding loads are noted up to 20 mm settlement.

E. Post test analysis

After completion of the test, the stone column material from the column were carefully taken out and a thin paste of Plaster of Paris was poured into the hole to get the deformed shape of the column, and kept it for 24 hours. The soil outside the stone column was carefully removed and the hardened Plaster of Paris is taken out and the deformation properties are studied.

IV. RESULTS AND DISCUSSIONS

Tests were conducted on Plain Clay bed, Plain Stone column with Stone aggregates, Silica-Manganese Slag, Slag + Sand, reinforced stone column for an encasement length of D, 2D, 3D, and 4D. The Load carrying capacity & settlement is determined by drawing a double tangent to Load - Settlement curve. Fig. 3 shows the Load-Settlement curves of Clay bed and Stone columns having different encasement lengths.

The ultimate load carrying capacity of the plain stone column with Stone aggregates and Slag have been increased by 21% and 32% respectively as compared with clay bed. The load carrying capacity of the Slag is increased by 9% compared to the Stone aggregates.

The load carrying capacity of stone column with Slag+ Sand have been increased by 14%, 23%, 48%, 58% by reinforcing with the encasement lengths of D, 2D, 3D, and 4D respectively.

When the clay bed is improved with plain stone column with Slag the settlement decreased from 7.5mm to 6.8mm. When the stone column is reinforced with different reinforcement lengths of D, 2D, 3D and 4D, the settlement is further decreased to 6.5cm, 6.4cm, 5.5cm and 4.5cm respectively.

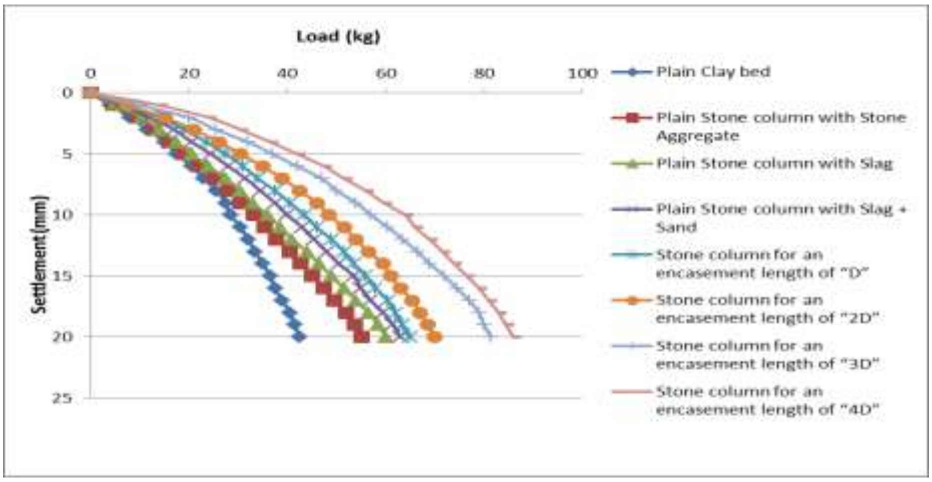

Fig. 3: Load-Settlement curves of Clay bed and Stone columns having different encasement lengths

V. BULGING ANALYSIS

When the clay bed is improved with plain stone column with Stone aggregates, Slag and Slag + Sand, the maximum bulging of 1.1cm, 1.0cm and 0.81cm occurs respectively and is found at the middle of the stone column.

When the stone column is reinforced with different encasement lengths of D, 2D, 3D & 4D, the maximum bulging of 0.70cm, 0.36cm, 0.32cm and 0.18cm were found respectively and the bulging occurs at depth just below the reinforcement depth. When stone column is loaded in soft soil, bulging occurs due to lack of confinement. Fig. 4 shows the bulging of deformed stone columns of different encasement lengths and Fig.5 shows the deformations of different stone columns.

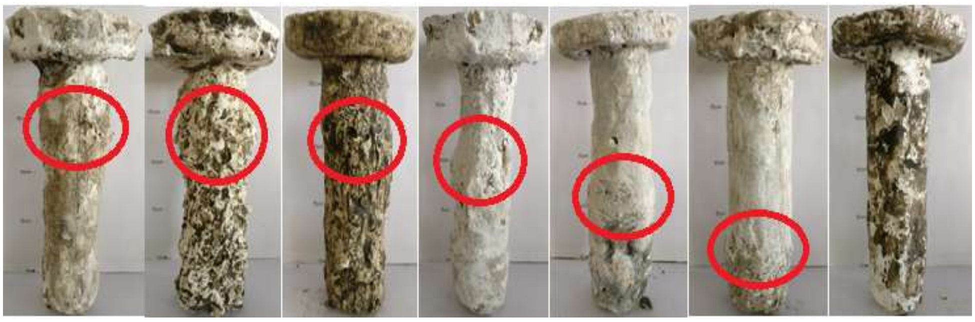

Fig. 4: Bulging of Stone column (Plain stone column with Stone aggregates, Slag, Slag+ Sand, Reinforced stone columns with encasement lengths of D, 2D, 3D, 4D respectively)

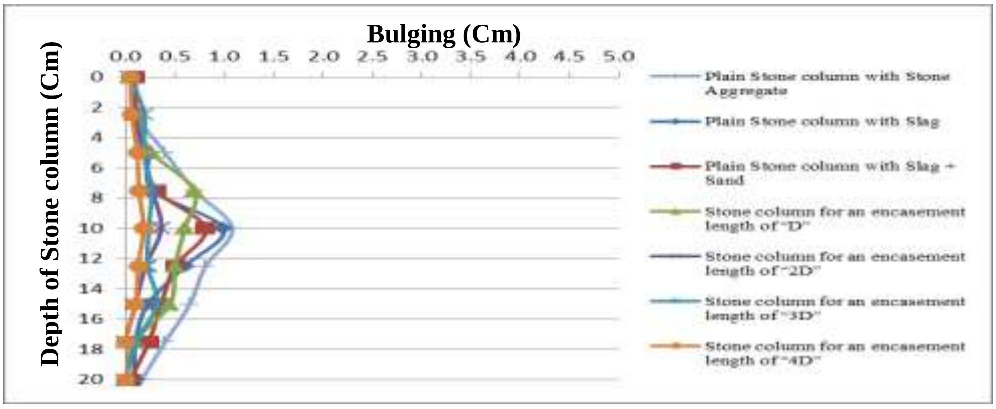

Fig. 5: Deformations of stone columns.

VI. CONCLUSIONS

1. The load carrying capacity is increased by improving the clay bed with the stone column by 32%.
2. Load carrying capacity of the stone column with reinforcement is increased by increasing the reinforcement length from D to 4D by 39%.
3. Maximum bulging has been found at half of the length of stone column for unreinforced column and for all reinforced columns, bulging is found just below the reinforcement depth.
4. The settlement is decreased with inclusion of stone column and also with the reinforcement. This decrease in settlement for full reinforcement length is about 40% when compared to the plain clay bed.

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