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Improvement of Marine Clay Performance Using Geo-Textile Encased Stone Column

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ABSTRACT
The use of stone columns is a popular ground reinforcing technique for flexible structures like raft foundations, oil storage tanks, embankments etc. The stone column technique is a cost effective method of improving the strength parameters like bearing capacity and reduce the settlements. When stone columns in soft soil are loaded, it undergoes excessive bulging due to low lateral confinement. To avoid this excessive bulging, stone column is encased with geotextile. In the present study tests were performed with and without encasement of geotextile. Stone column is encased with geotextile with different lengths of encasement like L/4, L/2, 3L/4 & L. The tests indicate that the bearing capacity increases with increase of encasement length.
***Keywords* -** Geo-textile, Marine clay, Silica-Manganese slag, Stone column.

I. INTRODUCTION

India has large area of soft soils along its long coast which is highly compressible and low bearing capacity. For the construction of high rise buildings and other structures pile foundation is most suitable ground improving technique. But for low rise buildings & flexible structures like rail road embankments, oil storage tanks, factories etc. stone column is of the most suited technique. Stone column installation is economic, simple and cost effective and used for the treatment of soft soils. When stone columns are installed in soft soils, the confinement offered by the surrounding soil may not be adequate and different modes of failure like bulging, sliding and general shear failure occurs. To avoid the lack of confinement, bearing capacity of composite ground is improved by encasing the stone column using geotextile. In this study model tests are performed with different encasement lengths of L/4, L/2, 3L/4 and L.

J.T. Shahu et al. [1] studied the effect of reinforcement and l/d ratio on the bearing capacity of the composite soil. Kausar Ali et al. [2] performed the model tests on single floating as well as end-bearing stone columns with and without encasement. K.G. Sharma et al. [3] evaluated the relative improvement in the failure stress of the composite ground due to different configurations of the reinforcement. Shivashankar R et al. [4] investigated the improvement in performance of stone columns reinforced with vertical circumferential nails. S.N. Malarvizhi et al. [5] 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. K.G. Sharma et al. [6] evaluated the relative improvement in the failure stress of the composite ground due to different types of reinforcement. P.K. Jain et al. [7] studied the improvement of load carrying capacity of granular piles with and without geogrid encasement. Nabipour N et al. [8] studied the improvement of the bearing capacity of stone columns reinforced by geosynthetics. Uttam Kumar et al. [9] investigated the effect of diameter of geosynthetic encased sand columns in soft soil deposit during loading. Siddharth Arora et al. [10] discussed the results of tests conducted on floating granular piles constructed in soft black cotton soil. Karun Mani1 et al. [11] discussed in detail about stone column technique to improve soil stability, including it’s salient features, design parameters, major functions and drawbacks. Mohammed Y. Fattah et al. [12] 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. [13] studied the stiffness and deformation behavior of the improved ground for various column spacing, shear strength of soft clay, moisture content etc.

II. MATERIALS USED

Three basic materials used for this study are marine clay representing the soft soil to be improved, crushed stone chips of Silica-Manganese slag used to form the stone column material and geotextile which is used as the reinforcing material for encasing the stone column. The properties of these materials are given below. Fig: 1(a), 1(b) and 1(c) shows the Marine clay, Silica-Manganese slag and Geotextile respectively.

2.1 Marine clay

Marine clay is collected from Visakhapatnam port trust at EQ-3 berth near Gnanapuram road area. The soil is highly compressible inorganic clay. The properties of marine clay are given in Table: 2.1

Table: 2.1 Properties of Marine clay

Property of soil	**Values**
Liquid limit (W_L)	72.9%
Plastic limit (W_P)	25.7%
Plasticity Index (I_P)	47.24%
Optimum Moisture Content (OMC)	29.5%
Maximum Dry Density (MDD)	1.42g/cc
Soil classification (as per Indian Standard)	CH
Unconfined compressive strength (in kPa) at 35% water content	30.0
Specific Gravity	2.49

2.2 Silica-Manganese slag

Silica-Manganese slag is produced during the primary stage of steel **production**. This slag is collected from Sri Mahalaxmi Smelters (PVT) Limited near Garbam (vill), Garividi (mandal), Vijayanagaram (Dt) 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: 2.2

Table: 2.2 Physical properties of Silica-Manganese slag

Property	**Value**
Specific Gravity	2.79
Water absorption (%)	0.49
Density (g/cc)	1.88

2.3 Sand

Sand is 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, Sankili, Regidi Amadalavalasa (mandal), Srikakulam (Dt).

2.4 Geotextile

Geotextile used in this study is collected from Ayyappa Geo-textile installers, Lankelapalem, 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.

Fig: 1(a) Marine clay Fig: 1(b) Silica-Manganese slag Fig: 1(c) Geotextile

III. EXPERIMENTAL STUDY

Model tests are conducted on plain clay bed, unreinforced stone column and stone column reinforced with geotextile encasement. The procedures used for the preparation of clay bed and stone columns are described in the headings 3.1 to 3.5.

3.1 Preparation of soft clay bed

The air-dried and pulverized clay sample was mixed with required quantity of water. The moisture content (35%) required for the desired shear strength was determined by conducting several vane shear tests on a cylindrical specimen of 76 mm height and 38 mm diameter. After adding the water to the clay powder it was thoroughly mixed to a consistent paste and this paste was filled in the tank in 50 mm thick layers to the desired height of 200mm by hand compaction such that no air voids are left in the soil. Before filling the soil in the tank, the inner surface of the tank wall was first coated with silicon grease to minimize the friction between soil and the tank wall. For each load test, the clay bed was prepared afresh in the test tank and stone columns were installed in it. After preparation of clay bed, it is left for 24 hours and covered with wet gunny cloth for moisture equalization. The Figure: 2 shows the clay bed prepared in the cylindrical tank used in this study. Test has been conducted on this clay bed of 200mm diameter and 200mm height.

Fig: 2 Preparation of soft clay bed

3.2 Construction of Stone column

For ordinary end bearing columns a Perspex pipe having its outer diameter 50 mm (diameter of the stone column) and 1 mm thick was first placed at properly marked centre of the tank's bottom. The inner and outer surface of the casing pipe was properly cleaned off and 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 by hand compaction such that no air voids are left in the soil. Silica-Manganese slag is used as the coarse aggregate (stone column material) in this study. 5% of water is added to the coarse aggregate to avoid the absorption of water in the clay bed. The stone column was casted in steps by compacting the coarse aggregate chips 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 stone chips and the bottom of the casing pipe. The aggregates were compacted by using a 10 mm diameter steel rod with 10 blows from a height of fall of 100 mm. After compacting each layer, the pipe is lifted such that there will be 5mm overlap between the two layers. 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 stone chips of the column and the soft soil. Fig: 3(a) shows the clay bed before construction of stone column and Fig: 3(b) shows the clay bed after construction of stone column.

3.3 Construction of Stone column with geotextile encasement

For constructing the stone column with reinforcement, the inner surface of the cylindrical tank is applied with grease and the Perspex pipe having outer diameter of 50mm is cleaned off both the inner and outer surfaces and the grease is applied at the outer surface. The Perspex pipe is placed exactly at the centre of the tank bottom and clay bed is filled around the pipe with layers of 50mm height up to the top of the clay bed. The clay bed is compacted by using wooden hammer with hand compaction such that no air voids are left in the soil. Silica-Manganese slag is used as the stone column material in the present study. The stone column is casted in steps of 50mm layers by compacting each layer by using 10 mm diameter steel rod with 10 blows from a height of fall of 100 mm. After compacting each layer, the pipe is lifted such that there will be 5mm overlap between the two layers.

For constructing the stone column with a reinforcement length of L/4, the process of compacting the stone column is continued up to a length of 3L/4 from the bottom of the tank and the pipe is taken out. The pipe is encased with the geotextile for a length of L/4 and the pipe is placed in position and then the stone column is casted in steps of 50mm layers by using the above procedure. After completion of the stone column, the tank is covered with a polythene cover and kept it for 24 hours. The same procedure is followed for different lengths of stone column like L/2, 3L/4, L.

Fig: 4 Stone column with encasement

3.4 Stone column testing

After construction of stone column, load was applied through the 12 mm thick perspex circular footing having diameter double the diameter of the stone column (10cm) which represents 25% area replacement ratio. Models were subjected to strain-controlled compression loading in a conventional loading frame at a fast rate of settlement of 0.24mm/min to ensure undrained condition up to a maximum footing settlement of 20 mm. The applied load on footing was observed by a proving ring at every 1 mm settlement. A complete test set up arrangement is shown in fig: 5(a) and fig: 5(b) shows the schematic view of stone column with loading arrangement.

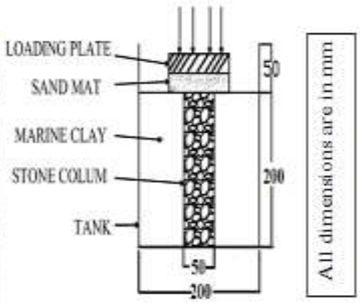

Fig: 5(a) Test setup arrangement Fig: 5(b) Schematic view of stone column

3.5 Post test analysis

After completion of the test, the Silica-Manganese slag chips from the column were carefully picked out and a thin paste of Plaster of Paris was poured into the hole and kept it for 24 hours to get the deformed shape of the column. 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, Clay bed with unreinforced Stone column, Clay bed with stone column for an encasement length of L/4, L/2, 3L/4 and L. The ultimate load carrying capacity & settlement is determined by drawing a double tangent to load settlement curve. Figure: 6 shows the results obtained by conducting the different model tests in laboratory.

Inclusion of stone column increased the load carrying capacity of the soil. The ultimate load carrying capacity of the unreinforced stone column is increased by 50% as compared with clay bed.

The load carrying capacity of stone column having different encasement lengths of L/4, L/2, 3L/4, L has increased by 15.6%, 29.4%, 37.2% and 43.1% respectively as compared with that of stone column alone.

When the clay bed is improved with unreinforced stone column the settlement decreased from 7.5mm to 7mm. When the stone column is reinforced with different lengths of L/4, L/2, 3L/4 and L, the settlement decreased to 6.8mm, 6.2mm, 5mm and 4mm respectively.

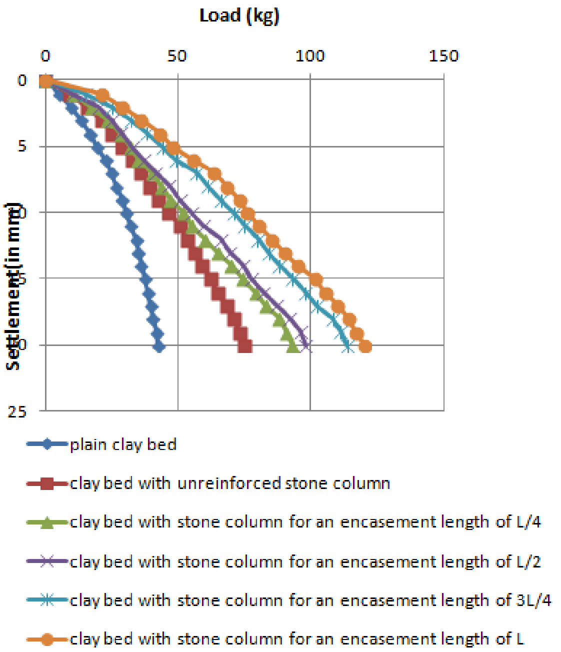

Fig: 6 Load-Settlement curves of clay bed and stone columns having different encasement lengths

Table: 4.1. Ultimate load vs Settlement values for different test conditions

Test condition	Load (kg)	Settlement(mm)
Plain Clay bed	34	7.5
Clay bed with unreinforced Stone column	51	7.0
Clay bed with stone column for an encasement length of L/4	59	6.8
Clay bed with stone column for an encasement length of L/2	66	6.2
Clay bed with stone column for an encasement length of 3L/4	70	5
Clay bed with stone column for an encasement length of L	73	4

V. BULGING ANALYSIS

When the clay bed is reinforced with stone column, the bearing capacity of soft soil is increased and the bulging is decreased. When the clay bed is improved with unreinforced stone column, the maximum bulging of 1.5cm occurs at a depth of D/2. When the stone column is reinforced with geotextile, the bulging is decreased compared to the ordinary stone column. When the stone column is reinforced with different lengths of L/4, L/2, 3L/4 and L, the maximum bulging of 1.0cm, 0.9cm, 0.68cm and 0.3cm 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: 7 shows the bulging of deformed stone columns of different encasement lengths.

(a) (b) (c) (d) (e)

Fig: 7 Deformed shapes of stone columns
Fig: 7(a) shows Ordinary stone column and
Fig: 7(b), 7(c), 7(d), 7(e) shows Stone columns with reinforcement depths of L/4, L/2, 3L/4, L.

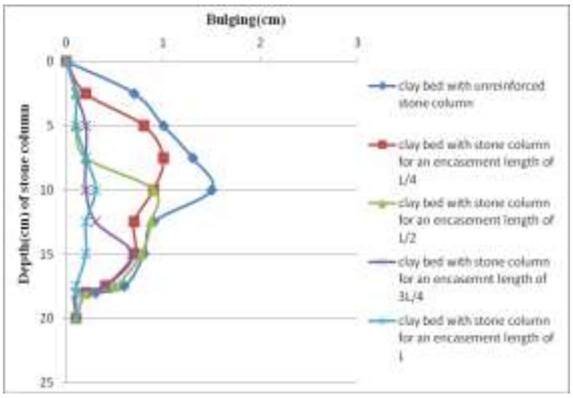

Fig: 7.1 bulging analysis of stone column

VI. CONCLUSIONS

The conclusions derived from the present study are listed below

1. The load carrying capacity is increased by improving with the stone column by 50% compared to plain clay bed.
2. Load carrying capacity of the stone column with reinforcement is increased by increasing the reinforcement length from L/4 to L by 24%. Whereas the rate of increment is reduced by increasing the depth of column and is less than 10% when it is reinforced with a length of more than L/2.
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 47% when compared to the plain clay bed.

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