Indian Journal of Science and Technology, *Vol 9(30), DOI: 10.17485/ijst/2016/v9i30/99186, August 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Improvement of Soft Soil Performance using Stone Columns Improved with Circular Geogrid Discs

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Abstract

Objective: To study the load carrying capacity and settlement behavior of the soft soils improved with lateral reinforced stone columns. **Methods/Analysis:** In this study, the soft soil is reinforced with stone columns by providing lateral circular geogrid discs within the column. The tests were conducted on plain clay bed, plain stone column and stone column with geogrid by placing reinforcement at two different spacing i.e., at D and D/2 over full column length and investigated the effect of reinforcement to improve the properties of the clay bed. **Findings:** By improving the soft soil with stone column, the ultimate load of the soil has been increased by about 117% and is increased by 16% and 41% by placing the circular geogrid reinforcement at D spacing and D/2 spacing respectively as compared with stone column alone. This results shows that the spacing of the reinforcement is influencing the ultimate load of the stone column. The settlement of the soil has been decreased by providing the stone column and further decreased by providing the geogrid reinforcement. **Novelty/ Improvement:** Lateral Reinforcement with geogrid discs increases the load carrying capacity of the soft soil and also it varies with varying the spacing of the reinforcement.

Keywords: Consolidation, Geogrids, Marine Clay, Pulverized, Perspex Tube, Reinforcement, Stone Columns, Stratagrid

1. Introduction

The stone columns or granular piles are increasingly being used as ground reinforcement elements for supporting a wide variety of structures including buildings and flexible structures. Although the use of pile foundation can meet all the design requirements, negative drag force and large length of the pile often result in prohibitive costs. The stone columns derive their load capacity from the confinement offered by the surrounding soil. In very soft marine soils this lateral confinement may not be adequate and the formation of the stone column itself may be doubtful.

Potential applications include stabilizing foundation soils to support embankments and approach fills, supporting retaining structures (including reinforced earth), bridge bent and abutment structures on slightly marginal soft to stiff clays and loose silty sands, landslide stabilization and reducing liquefaction potential of clean sands. Stone columns can also be used to improve slope stability of embankments on soft ground. Also, stone columns under proper conditions can greatly decrease the time required for primary consolidation. This ground improvement technique has been successfully applied to increase the bearing capacity and to reduce the settlement for foundation of structures like liquid storage tanks, earthen embankments, raft foundations, etc. where a relatively large settlement is permissible. In spite of the wide use of stone columns and developments in construction methods/equipment, present design methods are empirical and only limited information is available on the design of stone columns in codes/textbooks.

When the stone columns are installed in extremely soft soils, the lateral confinement offered by the surrounding soil may not be adequate. Consequently, the stone columns installed in such soils will not be able to develop

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the required load-bearing capacity. In such situations, the bearing capacity of the stone column can be improved by providing circular lateral discs of a suitable geogrid as a reinforcing material along the length of the stone column at a regular spacing. However in loose sandy soils below the water table, stone columns are useful to prevent the liquefaction during earthquake.

In this case, the load carrying capacity of the columns is increased by the frictional stresses mobilized on the surface of the geogrid owing to lateral movement of loose stone chips. In this paper an alternate method is suggested to enhance the performance of the stone columns by reinforcing with lateral circular discs by varying the spacing of the discs. The influence of the reinforcement with and without reinforcement is studied.

In[1] studied the behavior of stone column by varying spacing, shear strength of soft clay, moisture content etc[2]. Studied the effect of reinforcement and l/d ratio on the bearing capacity of the composite soil. In[3] investigated the effect of natural geotextile reinforcement in load carrying capacity of quarry waste column. In[4] used concrete debris for enhancing the load carrying capacity of the Stone Column. In[5] evaluated the effects of reinforcing stone columns by jacketing with a tubular wire mesh and bridging reinforcement with a metal rod and a concrete plug. In[6] suggested by reinforcing the stone columns with vertical nails driven along the circumference. In[7] studied the performance of stone columns with vertical nails driven along the circumference. In[8] studied the various importing acceleration with variation in column gravel drains distance[9] carried out the parametric study (L/d and the area replacement ratio) to investigate the behaviour of ordinary and encased floating stone columns. In[10] experimentally investigated the behavior of geogrid encased stone column. In[11] provided a review on ground improvement for using reinforced stone columns in geotechnical engineering project. In[12] presented the feasibility of using randomly oriented fiber reinforced granular piles to strengthen the expansive soil used fiber reinforcement. M.R. Malekpoor et al investigated the behavior of Compacted Lime-Soil rigid stone columns in soft soils. In[13] studied the behavior analysis of a typical element of soil in the vicinity of column during inundation. In[14] studied the utilization of stone column to improve the load capacity of sandy silt soil with clay in naturally consolidated state. In[15] demonstrated the relationship between the bearing improvement ratio and the area replacement ratio. In[16] studied the effects of stone column construction on the fundamental frequency of the sites are studied numerically.

2. Materials Used

The clay material is collected from port area at Vizag. The clay used for this study was sieved through 425 micron IS-sieve to remove the coarser fraction. Figure 1(a) shows the marine clay sample.

Crushed stone aggregate was collected from quarry, Penubaka near Rajam, Andhra Pradesh, India. Crushed coarse aggregate of size between 4.75 mm and 10 mm was sieved and used for the present study. The stone aggregate was compacted to a density of 1.59 kN/m^3 using a steel tamping rod of 900 g weight by compacting from a height of fall of 10 cm and by giving 10 blows. Figure 1(b) shows the coarse aggregate sample.

The sand used is clean river sand collected from Nagavali River near Regidi Amadalavalasa, Andhra Pradesh, India. The sand used as a blanket is sieved from 4.75 mm sieve. The specific gravity of this soil is 2.66.

The Geogrid material named as “SG 200” is collected from STRATA Global Geo Solutions, Hyderabad. STRATAGRID is a geogrid reinforcement for soil. These high performance geogrids are constructed of high molecular weight and high tenacity knitted polyester yarns with a proprietary coating. Stratagrid is engineered to be mechanically and chemically durable, in both the harsh construction installation phase and in the aggressive soil environment (PH range from 3-9). The Figure 1(c) shows the circular geogrids used in this study. Ultimate strength of the geogrid is 52.5 kN/m and Creep limited strength is 33.9 kN/m.

(a) (b) (c)

Figure 1. (a) Marine clay. (b) Coarse aggregate. (c) Geogrids.

3. Experimental Study

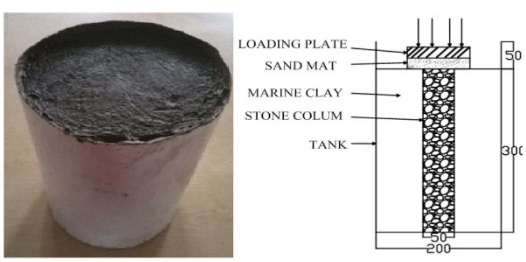
Index and engineering properties of marine clay are listed in Table 1.

Table 1. Index and engineering properties of marine clay

Property of soil	Values
Liquid limit	72.90%
Plastic limit	25.7%
Plasticity index	47.20%
Specific Gravity	2.49
Optimum Moisture Content (OMC)	29.5%
Maximum Dry Density (MDD)(in g/cc)	1.42
Unconfined compressive strength (in kPa) at 35% water content	30

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. After adding the water to the clay powder, it was thoroughly mixed to a consistent paste. This paste was then filled in the tank in 50 mm thick layers to the desired thickness by hand compaction such that no air voids are left in the soil. The compacted soil is left for 24 hours and covered with wet gunny cloth for moisture equalization. Before filling the soil in the tank, the inner surface of the tank wall was first coated with grease to minimize the friction between soil and the tank wall. For each load test, a fresh clay bed was prepared in the test tank and stone columns were installed in it. The Figure 2(a) shows the clay bed prepared in the cylindrical tank used in this study. Tests were conducted on stone columns formed in a clay bed of 200 mm diameter and 300 mm height. Figure 2(b) shows the Schematic view of stone column foundation for test.



(a) (b)

Figure 2. (a) Clay bed. (b) Schematic view of stone column.

3.2 Construction of Stone Column

After preparing the clay bed, an open-ended Perspex tube of external diameter of 50 mm and 1 mm thick was inserted into the clay bed by applying hydraulic pressure. The inner and outer surfaces of the casing pipe was properly cleaned off and grease is applies to the outer surface. The pipe was pulled out by rotating slightly. The stone column was casted in steps by compacting the stone 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 5 mm between the surface of the stone chips and the bottom of the casing pipe. Each layer was compacted by giving 10 blows with a height of fall of 10cm using a tamping rod of 900 g weight. 5% of water is added to the coarse aggregate to avoid the absorption of water in the clay bed. 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. Figure 3(a) shows the insertion of pipe in to the clay bed to make the central hole. Figure 3(b) shows the clay bed with central hole and Figure 3(c) shows the clay bed after construction of stone column.

(a) (b) (c)

Figure 3. (a) Inserting open ended tube into the soil. (b) Clay bed with central hole. (c) After construction of stone column.

3.3 Placing of Reinforcement at different Spacings

Goegrids were used as the reinforcement in the stone column. Stone column was casted by compacting stone chips in layers of spacing equal to the diameter of the stone column (5 cm) as specified in Section 3.2 and the circular geogrids were introduced between the layers by pushing the circular geogrids to the desired position with another pipe of diameter less then the casing pipe. The same procedure was followed in the case of 2.5 cm spacing (D/2) of geogrids but blows were given after every two layers.

3.4 Stone Column Testing

After construction of stone column, a sand blanket of 20 mm thick was laid on the surface of clay bed and load was applied through the 12 mm thick Perspex circular footing having diameter double the diameter of the stone column 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 0.24 mm/min to ensure undrained condition up to a maximum footing settlement of 20 mm (Figure 4).

(a) (b) (c)

Figure 4. (a) Placing of geogrids. (b) Testing of stone column.

4. Results and Discussions

The following are the results obtained by performing the different lab tests. The below Figure 5 shows the load-settlement curve obtained from load tests on clay bed, clay bed with stone column alone, clay bed with stone column reinforced with geogrids at 5 cm (d) spacing and 2.5 cm (d/2) spacing. Figure 6 Load-settlement curves showing the double tangent curve reinforced with geogrids at 5 cm spacing. The ultimate load carrying capacity in each case was determined by drawing double tangent to the load settlement curve.

4.1 Load Settlement Response of Plain Clay Bed

Figure 5 shows the load-settlement curve obtained from load tests on clay bed. The ultimate load carrying capacity in each case was determined by drawing double tangent to the load settlement curve which is shown in figure. The ultimate load carrying capacity of the clay bed is 37.8 kg. The settlement at the ultimate load is 9 mm.

4.2 Load Settlement Response of Clay Bed with Stone Column Alone

Figure 5 shows the load-settlement curve obtained from load tests on clay bed with stone column alone. With the installation of stone column the load penetration curve shows a better load carrying capacity. This is because of the densification of the clay bed by stiffer coarse aggregate inclusion. The ultimate load carrying capacity for clay bed without stone column is 37.8 kg and with stone column alone is 82 kg. This shows the increment of 117% to that of clay bed alone. The settlement at the ultimate load has been reduced to 5.3 mm.

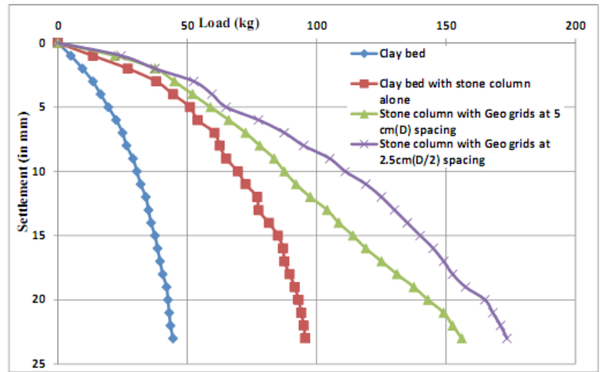


Figure 5. Load-settlement curves of clay bed, clay bed with unreinforced stone column and reinforced with geogrids at 5 cm and 2.5 cm spacing.

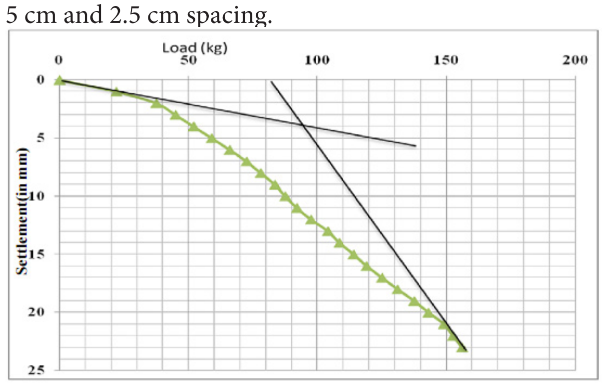


Figure 6. Load-settlement curves showing the double tangent curve reinforced with geogrids at 5 cm spacing.

4.3 Load Settlement Response of Clay Bed with Stone Column Reinforced with Geogrids at 5 cm (D) Spacing

Further the stone column is reinforced with geogrid discs placed horizontally at spacing equal to the diameter of the stone column (5 cm) and the load settlement response is observed. Figure 5 shows the load settlement response of clay bed with stone column reinforced with geogrid at spacing of 5 cm. The ultimate load carrying capacity determined from load settlement curve is 95 kg. The ultimate load carrying capacity is increased by 16% compared to unreinforced column. In this case, the increase in load carrying capacity compared to plain clay bed is about 151%. The settlement at the ultimate load has been reduced to 4 mm.

4.4 Load Settlement Response of Clay Bed with Stone Column Reinforced with Geogrids at 2.5 cm (D/2) Spacing

Now the stone column is reinforced with geogrid at spacing equal to the half of the diameter of the stone column (2.5 cm) and the load settlement response is observed. Figure 5 shows the load settlement response of clay bed with stone column reinforced with geogrid discs at 2.5 cm (D/2) spacing. The ultimate load carrying capacity determined in this case is 116 kg.

In this case provision of reinforcement for full depth at 2.5 cm spacing increases the load carrying capacity to 41% compared to the unreinforced stone column. When compared with plain clay bed it has been increased to 207%. The settlement at the ultimate load has been reduced to 3.8 mm.

The ultimate load carrying capacity of the stone column is increased by reinforcing with geogrids. This increment is 151% in case of D spacing and 207% in case of D/2 spacing. From these results the column reinforced with reduced spacing is more beneficial. The settlement also reduced from 9 mm to 3.8 mm for plain clay bed and reinforcement with D/2 spacing respectively. The ultimate load carrying capacities and settlements obtained are given in Table 2.

Table 2. Ultimate load and settlement values at different test conditions

Test condition	Ultimate load (in kg)	Settlement (in mm)
plain clay bed	37.8	9
clay bed with unreinforced stone column	82	5.3
clay bed with stone column reinforced with geogrids at 5 cm (d) spacing	95	4
clay bed with stone column reinforced with geogrids at 2.5 cm (d/2) spacing	116	3.8

5. Conclusions

The conclusions derived from the present study are listed below.

- Inclusion of stone column increases the load carrying capacity of the soil by about 117% by densifying the soil.
- The ultimate load of the stone column reinforced with geogrids at 5 cm (D) spacing and 2.5 cm (D/2) spacing has been increased by 16% and 41% respectively as compared with the stone column alone and 151% and 207% as compared with the plain clay bed. So the improvement in load carrying capacity of reinforced column also depends on the spacing of reinforcement. The geogrids placed at D/2 spacing shows better performance than D spacing.
- The settlement of the soil has been reduced from 9 mm to 5.3 mm by placing the stone column alone in the soil. The settlement of the soil at the ultimate load has been further reduced to 4 mm and 3.8 mm by inclusion of geogrid at a spacing of 5 mm (D) and 2.5 mm (D/2) respectively.
- The load carrying capacity and stiffness of the stone column can be increased by lateral reinforcement of column using geogrids by mobilization of frictional stresses on the surface of geogrids.

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