Load Settlement Behavior of Stone Columns with Circumferential Nails

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ABSTRACT

The use of stone columns (or granular piles) has proved to be an economical and technically viable ground improvement technique for construction on soft soils. When the stone columns are installed in very soft clays, they may not derive significant load capacity due to low lateral confinement, which leads to excessive bulging. In this paper, a new method of improving the performance of stone columns in extremely soft soils is being suggested by reinforcing the stone columns with vertical nails driven along the circumference. Series of plate load tests are performed in laboratory in rigid unit cell tanks to investigate the improvement in performance of stone columns reinforced with vertical circumferential nails. It has been observed that these circumferential nails provide restraint to the lateral displacement of stones leading to improvement in the load carrying capacity.

1. INTRODUCTION

Treatment of soft soil or weak soil deposits with installation of stone columns or granular piles is very common amongst various ground improvement methods. Stone columns treated ground provides increased bearing capacity, significant reduction in settlement, free drainage, increase of liquefaction resistance etc. Along with these advantages, stone columns installation is simple, economic and cost effective, and can be used for treatment of most type of soils-loose sands to soft clays.

Stone columns derive their load carrying capacity from the lateral confining pressure from the surrounding soils (Greenwood, 1970; Hughes et al. 1975; Barksdale and Bachus, 1983). When the stone columns are installed in very soft clays, they may not derive significant load carrying capacity owing to low lateral confinement. In order to enhance the performance of stone columns when treating weak deposits, it is imperative that the tendency of the column to bulge should be restricted effectively. The existing popular method to overcome this situation is by encasing the stone columns with suitable geosynthetic (Geosynthetic encased stone columns) to impart the necessary confinement to improve their strength and stiffness. Alternatively, the stone columns are reinforced internally by stabilization of column material using concrete plugs, chemical grouting or by adding internal inclusions (geogrids, plastic fibers etc), which will stiffen the column and accordingly, it’s bearing capacity.

Although the external reinforcement in the form of encapsulating the column with a geofabric will prevent the column failing by bulging or by shear, it will not allow the column to dilate and accordingly to increase the in-situ stresses (Ayadat et al. 2008). This technique can be limited by the relatively large settlements that occur as a result of minimal compaction (to avoid damage to geotextile encasement material) received during installation and geotextile strain during loading (Gniel and Bouazza, 2009). Hence, there is a need to identify the effective and alternate methods which should be practically feasible to enhance the performance of stone columns in very soft soils.

An alternative method is suggested in this paper to enhance the performance of stone columns in extremely soft soils by reinforcing with vertical nails (small diameter steel bars) along the circumference of the stone column. Series of plate load tests are conducted in rigid unit cell tanks to investigate the effect of these nails on the load-settlement behaviour in a soft soil bed. The influences of parameters such as depth of nails from the ground level, the number of nails are being analyzed in this paper.
2. EXPERIMENTAL PROGRAMME

The behaviour of interior stone columns among a group of large numbers of columns is studied by assuming a unit cell concept where the deformations in clay are restrained within the unit cell represented by the equivalent area of each column. Many researchers (Ambily and Gandhi, 2007; Murugesan and Rajagopal, 2007; Gniel and Bouazza, 2009; Shivashankar et al. 2010) have used this concept of unit cell in their model testing to predict the behaviour of stone column in a large group.

Experiments were carried out on 90mm diameter stone columns surrounded by soft clay in cylindrical tanks of 780 mm high and 237 mm diameter to represent the required unit cell area (15% area replacement ratio) of soft clay around each column assuming triangular pattern of installation of columns. All the experiments were conducted on floating stone columns in soft soil in unit cell tanks so that \( L/D \) ratio (length of the column/diameter of the column) is minimum of 6, which is required to develop the full limiting axial stress on the column (Mc Kelvey et al. 2004). The total height of the clay bed placed in the tank was 8 times the diameter of the column. 4 mm diameter steel bars were used as nails. The depth of nails (\( H \)) was varied from 2 to 6 times the diameter of stone column, from the top and number nails (\( n \)) varied from 6 to 10. A typical test arrangement is shown in Figure 1.

![Fig. 1: Test Arrangement](image)

Properties of Materials Used
The soil used is of \( MH \) classification, obtained from New Mangalore Port Trust (NMPT) premises near Mangalore, India. The properties of soil are: specific gravity=2.62, liquid limit=68%, plastic limit=32%, maximum dry density=14.7 kN/m\(^3\), and optimum moisture content = 24.8%. Based on the preliminary tests on the soft soil, water content of 45% and dry unit weight of 12.7 kN/m\(^3\) were selected for the soft soil bed and the corresponding undrained shear strength of the bed was found to be 19 kPa. Aggregates varying from 2 to 10 mm particle size have been used to form the stone column. The sand used is clean river sand of size less than 4.75 mm. Circular steel bars of 4 mm diameter of required length were used as nails along the circumference of the stone columns.

Preparation of Soft Soil Bed and Construction of Stone Column
The inner surface of tank wall was applied with a thin coat of grease to reduce the friction between clay and the tank wall. Soil was filled in the tank in layers with measured quantity by weight and each layer was subjected to uniform compaction with a tamper. Thin open-ended seamless steel pipes of 90mm outer diameters and wall thickness 2 mm were used to construct the stone columns. After the soft soil bed was prepared for a depth of twice the diameter of the column, the steel pipe was placed at the centre of the soft soil bed and construction of soft soil bed and stone column were carried out simultaneously. Stones were charged into the hole in layers in measured quantities to achieve a compacted height of 50 mm. The pipe was then raised in stages ensuring a minimum of 5 mm penetration below the top level of the placed gravel. To achieve a uniform unit weight, compaction was done with a 2 kg circular steel tamper with 10 blows of 100 mm drop to each layer. The corresponding unit weight of stone column was found to be 16 kN/m\(^3\). The procedure was repeated until the column was completed to the full height. After the construction of stone column, the required number of nails was inserted at equal spacing along the circumference of the stone column. A sand layer of 30 mm thick was placed at the top to serve as a blanket where the entire area is loaded.

Test Procedure
In the field, the entire plan area of the stone column treated ground will be subjected to loading from the superstructure. The same was simulated in the laboratory by loading the whole area of the unit cell. The load was applied with the help of a loading frame, through a proving ring at a constant displacement rate of 0.0625 mm/min. A steel plate of 12 mm thickness and a diameter of 10 mm less than the inside diameter of the test tank was placed over the sand blanket. The loading was applied until the settlement exceeded 10 mm.

3. RESULTS AND DISCUSSIONS

Effect of Depth of Nails
Figure 2 shows typical load-settlement behaviour of soil
bed alone, soil bed treated with plain stone column (PSC) and soil bed treated with reinforced stone columns (RSC) with vertical circumferential nails of 4 mm diameter (8 numbers) for different depths of embedment (from 2D to 6D), for an area ratio of 15%. When the entire area is loaded, because of the confining effect from the boundary of the unit cell, failure does not take place even for a settlement of up to or beyond 10 mm. The load intensity required for a given settlement increased for the composite ground with RSC compared to that with PSC. The increase in load intensity for 10 mm settlement for composite ground with RSC with 2D, 3D, 4D, 5D & 6D (6D is full depth of stone column) depth nails are 45%, 90%, 110%, 118% & 118% more than that of untreated ground, compared to about 25% for PSC. This is due to increased anchorage of nails with the increased depth of embedment into the soil, and decreasing the bulging tendency of stone columns and hence increases in the load carrying capacity. For a significant improvement in load carrying capacity, the minimum depth of nails required is 3D to 4D. Full depth (6D) or 5D depth of embedment did not show much improvement (only 8%) compared to 4D depth nails. This shows that the confinement is essentially needed mainly in the zone where bulging takes place.

Effect of Number of Nails

Figure 4 shows typical load-settlement behaviour of soil beds treated with plain stone column (PSC) and reinforced stone columns (RSC) with vertical circumferential nails of 4 mm diameter (3D depth) for different number of nails (from 6 to 10), for an area ratio of 15%. The increase in load intensity for 10 mm settlement for composite ground with RSC with nails 6, 8 & 10 numbers are 48%, 90% and 102% more than that of untreated ground, compared to about 25% for PSC. As the number of nails increases the load carrying capacity increases. This is due to the increased confining effect on the granular material with the increase in number of nails. Figure 5 shows the variation of Bearing Capacity Ratio (BCR) with number of nails. The bearing capacity ratio (BCR) is seen to increase with increase in number of nails, with significant improvement for stone columns reinforced with 8 numbers of nails.

Degree of improvement can be expressed in terms of bearing capacity ratio, which is defined as ratio of load carrying capacity of improved ground to that of unimproved ground. From Fig. 3, the bearing capacity ratio (BCR) is seen to increase with increase in depth of nails, with significant improvement for 4D depth.

4. CONCLUSIONS

Based on the results of the investigation, the following conclusions are drawn:

1. The performance of stone columns installed in very soft soils can be significantly enhanced by reinforcing individual stone columns with vertical nails driven along the circumference.
(2) The depth of embedment of nails required to significantly enhance the performance of the stone columns is 3D to 4D. This shows that the confinement is essentially needed only in the zone where bulging tends to take place.

(3) The behaviour of composite ground is further improved with the number of nails. This is due to the increased confining effect on the granular material with the increase in number of nails.

REFERENCES


