AN INNOVATIVE APPROACH TO INCREASE THE BEARING CAPACITY OF STONE COLUMNS

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ABSTRACT: Stone columns are being used to improve the bearing capacity and reduce the settlement of a weak or soft soil. Under a vertical load the top of the stone column bulges and the capacity of the stone column is derived from the depth of bulging. The higher the depth of bulging the greater is the load carrying capacity. As such researchers have tried skirted stone columns. The capacity of the stone column also increases with decrease in diameter of bulging. Geosynthetic encased stone columns have been used to achieve this goal. Both the methods have their inherent merits and demerits. In the present study an innovative technique of using a soil-cement stabilized bed over the stone column has been tried to increase the capacity of the stone columns. The technique is easy, economic and does not require any skilled labour. The technique reduces the extent of bulging and increases the depth of bulging. In the present study the thickness of the soil cement stabilized bed is varied and the effect of thickness of the bed on improvement of capacity of stone column is studied. It is observed that the capacity can be increased by 5 times and the amount of bulging can be reduced by 25 percent.

KEYWORDS: Stone column, bulging failure, stabilized bed, cement.

1 INTRODUCTION

Due to the scarcity of land and explosion of population, the marshy land is now being used for construction. The marshy land usually comprises of soft to very soft clayey soil. Piles are normally being used in this land to carry the load of a super structure. For a low rise construction, the cost of piles may be very high and people often use some ground improvement technique. Installation of stone columns is one of the very promising techniques of improvement of soft soil, but its use is limited for residential buildings because of high risk of settlement. It is reported that the stone columns may reduce the expected settlement upto 50%. The bearing capacity of stone column normally depends on the depth and amount of the bulging. If somehow the depth of bulging can be increased, then the bearing capacity of stone column is also increased. Many researchers (Murugesan and Rajagopal (2006), Chungsk Yoo (2010), Pulko et al. (2011), Keykhosropur et al. (2012), Fattah and Majeed (2012), Deb and Mohapatra (2013), and so on) used geosynthetic or geogrid encased stone columns (GESC) to reduce the amount of bulging as well as to increase the depth of bulging. Some researchers (Deb et al. (2008), Afshar and Mahmoud Ghazavi (2014)) used geosynthetic material in layers as reinforcement. Stone column jacketing with tubular mesh was also used as a reinforcement to strengthen the soft soil (Black et al., 2007)). All these techniques are not widely used because of some inherent deficiencies.

In the present study, an innovative technique of using a cement stabilized loamy soil bed over the stone columns has been tried. The loamy soil has both cohesion and angle of internal friction. Upon mixing with five percent cement by weight and a specified quantity of water this soil gives a very hard mass upon compaction. This hard mass is placed below the footing where the induced stress intensity is very high. Obviously the load intensity on stone columns becomes minimum and thus the extent of bulging is also minimum. The thickness of the soil-cement stabilized bed plays a major role in load carrying capacity of the stone column. In the present study effect of thickness of the stabilized soil bed has been studied. Results show that cement stabilized soil bed can increase the load carrying capacity by more than 5 times. Moreover, bulging of the stone column is also reduced by twenty five percent.

2 EXPERIMENTAL INVESTIGATION

2.1 Material used

In the present study three types of locally available materials, namely, clay for preparation of clay bed, stones of size 2 – 6 mm for preparation of stone columns, red-loamy soil popularly known as tilla soil for preparation of stabilized soil cement bed were used. Ordinary Portland cement was used to make the cement-stabilized bed. The properties of the clay are shown in table 1. For determination of shear strength, of the clayey soil, a series of unconfined compressive strength (UCS) tests were conducted on cylindrical
specimens of 38 mm diameter and 76 mm height at different moisture contents and density. The properties of stones are presented in table 2. The properties of locally available c-φ soils are shown in table 3.

Table 1 Properties of clayey soils

<table>
<thead>
<tr>
<th>Specific gravity</th>
<th>Bulk unit weight</th>
<th>Liquid limit</th>
<th>Plastic limit</th>
<th>Unified system classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.43</td>
<td>1.72</td>
<td>62%</td>
<td>35%</td>
<td>CH</td>
</tr>
</tbody>
</table>

Table 2 Properties of stones

<table>
<thead>
<tr>
<th>Stone size</th>
<th>c</th>
<th>Angle of internal friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 to 6 mm</td>
<td>0</td>
<td>37.27°</td>
</tr>
</tbody>
</table>

Table 3 Properties of c-φ soils

<table>
<thead>
<tr>
<th>Liquid limit</th>
<th>Plastic limit</th>
<th>OMC</th>
<th>MDD</th>
<th>Cohesion, φ</th>
<th>USCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.75%</td>
<td>21.04%</td>
<td>15%</td>
<td>1.82</td>
<td>0.1 kg/cm²</td>
<td>30.8° Clayey sand (SC)</td>
</tr>
</tbody>
</table>

2.2 Preparation of clay bed

To prepare the clay bed, one steel tank of size 90 cm x 90 cm x 90 cm was used. Before placing the clay in the tank, one polythene sheet was attached on the inner side of the tank to avoid the friction between the tank and the soil. Then the soft clayey soil was placed in layers with uniform compaction for each layer. In all tests, water content was maintained around 42% and the corresponding unconfined compressive strength is obtained as 22 kPa. The unit weight of the clay bed was tried to be maintained constant for all the tests. The thickness of the clay bed was taken as 900 mm for normal test and 700 mm for tests with soil-cement stabilized bed.

2.3 Construction of stone column

After making the clay bed, the centre point of the clay bed was found to apply the load. An auger of diameter 50 mm was used to make the hole for column installation. The auger was gradually inserted into the clay bed up to a depth of 400 mm and then taken out carefully. The bore hole was cleaned with the auger. The stone column materials of size 2 to 6 mm were poured into the hole in layers with uniform compaction of each layer. To compact the stones inside the hole, one tamping rod of diameter 10 mm was used. Considering the minimum value of length/diameter ratio (l/d) as 4 to control the bulging failure mode (Barksdale and Bachus, 1983), the height of the stone column was taken as 400 mm so that the l/d ratio for the present study becomes 8. To bring the field condition in model, seven stone columns in triangular pattern to represent the single stone column (IS 15284 part-1, 2003) were constructed. The spacing between the stone columns was taken as 2.5 times the diameter. The footing was placed over the middle stone column.

2.4 Preparation of soil-cement stabilized bed

To prepare the soil-cement stabilized bed over the stone column, the locally available c-φ soil and ordinary Portland cement were used. The thickness of soil-cement bed was varied as 5, 10 and 15 cm. For different thickness of soil-cement bed, the weight of soil and cement were calculated separately. Usually for all the tests the proportion of cement was taken as 5% of dry soil by weight. Optimum quantity of water was added to the soil-cement mix to obtain a hard substance difficult to crack with thumb pressure. The soil-cement was then placed over the stone column in layers. Each layer was compacted with a square hammer with a uniform compaction energy.

2.5 Loading arrangement

One steel plate of diameter 110 mm and thickness 6 mm was used as footing. The diameter of the loading plate was selected so that the pressure bulb of the footing remains within the periphery of the boundary of the seven stone columns. The size of the steel tank is four times the diameter of the fictitious circle passing through the peripheral six stone columns. Thus it is assumed that the boundary of the steel tank has a minimum effect of the capacity of stone columns. The footing i.e. the steel plate was placed at the centre of the tank over the middle stone column. In case of stone column with soil-cement stabilized bed, the footing was placed over the soil-cement bed at the centre of the tank. The uniform distributed load was applied through the circular footing. The load was applied with the hydraulic jack of capacity 10 ton. The laboratory plate load test was conducted in each case to find out the bearing capacity of the stone column under different conditions. Figure 1 shows the experimental set up of the conducted tests. As shown in figure 1, two LVDTs of capacity 25 mm and 50 mm were placed at diametrically opposite ends of the plate to measure the settlement corresponding to a certain load. The load cell and the LVDTs were connected to a data acquisition system which can measure 20 data per second. Total five laboratory tests were conducted. First test was conducted on footing resting directly over the clay bed without any stone column. Second test was conducted on footing resting over stone column without any soil-cement stabilized bed. The last three tests were conducted on footing resting over soil-cement stabilized bed of thickness 5, 10 and 15 cm overlying the stone columns.
2.6 Test procedure

The test procedure of plate load test involves application of load and determination of settlement of stone column. In all the cases, the load was applied in equal increments and was maintained till the settlement is less than 0.02 mm/hour. The loading was continued till the total settlement attained a value equal to 20% of the footing diameter.

3 RESULTS AND DISCUSSION

3.1 Load-settlement behavior

The result of the plate load test was expressed in the form of load versus settlement graph. The load-settlement behavior of clayey bed, clayey bed reinforced with stone column and clayey bed reinforced with stone column and soil-cement stabilized bed with different thicknesses are shown in figures 2 and 3. A single figure does not distinctly show the load settlement curve of the footing resting over clay bed, hence two figures are shown. From figure 2, it is seen that the load carrying capacity of the clay bed increases with installation of stone columns and the capacity increases further with installation of soil-cement stabilized bed. The bearing capacity of soft soil is increased by almost 2.5 times after installation of stone column and bearing capacity is further increased by 5 times after placing the soil-cement stabilization bed over stone column. In figure 3, the load settlement plot of stone column with 10 cm thick soil-cement bed is compared with that with 15 cm thick soil cement bed. It is observed that with increase in thickness of the soil cement bed, the load carrying capacity of stone column also increases. However, upto a settlement of 11 mm i.e. ten percent of the diameter of the footing the load carrying capacity is almost same for 10 cm thick and 15 cm thick soil-cement stabilized bed. Thus it can be concluded that the optimum thickness of soil cement stabilized bed is 10 percent of the diameter of the footing for a settlement upto 10 percent of the diameter.
An innovative approach to increase the capacity of stone columns using cement stabilized local soil

stone column. But after placing the soil-cement stabilized bed over the stone column, the depth of maximum bulging was noticed at a depth of 3.5 to 4.5 times the diameter of the stone column and the amount of maximum bulging was 1.1 times its diameter. Therefore it is observed that by placing the soil-cement bed over stone columns, the amount of bulging can be reduced and the depth of bulging can be increased. The percentage reduction of the bulging diameter is around 25% due to installation of the soil-cement stabilized bed. Figure 4 shows a comparison of the bulging of the central stone column.

![Comparison of bulging](image)

**Fig. 4** Bulging of central stone column

4 CONCLUSIONS

Based on the results of all the experiments, the following conclusions are drawn:

(a) Stone column increases the bearing capacity of soft soil up to 2 to 2.5 times and reduces the settlement up to 1/6 times. The placement of soil-cement stabilized bed over stone column further increases the bearing capacity up to 5 times and reduces the settlement up to 1/6 times of the improved soil, i.e. up to 1/36 times the settlement of normal soil.

(b) As the thickness of soil-cement bed increases, the bearing capacity of the stone column also increases. However the optimum thickness of the soil-cement stabilized bed is about ten percent of the footing diameter up to a settlement of ten percent of the footing diameter.

(c) Use of soil-cement bed over stone column lowers the depth of bulging as well as decreases the amount of bulging. For a stone column, the bulging occurs up to a depth of 4 times of the diameter of the stone column and maximum amount of bulging is 1.5 times the diameter of stone column. But in case of stone column underlying a soil-cement stabilized bed, the bulging occurs at a depth of six times its diameter and amount of bulging equals to 1.1 times its diameter. Thus a reduction of 25% of bulging is possible with the present innovative technique.

(d) It is possible to use the present technique for construction of foundation of low rise buildings resting over very soft soil, thereby eliminating the high cost of construction of pile foundations.

References


