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Stabilization of Marine Clays with Geotextile Reinforced Stone Columns Using Silica-Manganese Slag as a Stone Column Material

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Abstract:
Various techniques are used for improving in-situ ground conditions among which reinforcing the ground with stone column is one of the most versatile and cost effective technique. The presence of stone column on composite ground will impart lower compressibility and higher shear strength than that of native soil. Stone columns are used to improve the poor ground like soft marine clays, cohesive soils, silty soils, loose sand etc. This is the most popular technique used in flexible structures like road embankments, railway embankments and oil storage tanks. In the present study, the floating stone columns were reinforced by introducing lateral circular discs of geo-textile sheets within the column. Silica-Manganese slag which is a byproduct from ferro-alloy industries is used as the stone column material. The circular discs were placed at two different spacing (D and D/2) over varied reinforcement depths (0.25L, 0.5L, 0.75L and L). Laboratory tests have been performed on clay bed, ordinary floating stone column and reinforced stone columns to evaluate the improvement of load carrying capacity. After performing laboratory tests, the test results indicate that load carrying capacities of the stone columns reinforced with circular discs placed at D/2 spacing shows better performance than D spacing.
Keywords: *Geo-textile circular discs, Load, Marine clay, Reinforcement, Silica-Manganese slag, Stone column, Settlement*

I. Introduction

Vast areas covered with thick layers of fills or with layers of soft clay deposits are not suitable for the construction of a foundation. Due to increase of population in urban areas there is a need to improve the infrastructural facilities such as buildings, roads, tunnels, bridges etc. With the increasing size of urban areas and industrial zones, it is necessary to consider the possibilities of foundations on these areas. Construction of highway embankments using conventional design methods such as preloading, dredging and soil displacement techniques can often no longer be used due to environmental restrictions and post-construction maintenance expenses. Among all these methods, the stone column technique is preferred because they provide the primary aspect of reinforcement and thus improve the strength and reduces the deformation. Stone columns are nothing but vertical columnar elements formed by replacement of 10 to 35 percent of weak soil with coarse granular material, such as stone, sand and stone chips- sand mixture. These load bearing piles usually penetrate through the soft ground/weak strata and resting on firm/stiff strata called end bearing stone columns. Sometimes these are penetrating partially in to medium stiff soil and not resting on firm strata are known as floating stone columns. Apparently, the concept was first applied in France in 1830 to improve a native soil.

When the stone columns are installed in very soft clays, they may not give significant load carrying capacity to low lateral confinement. In order to improve the performance of stone columns when treating weak deposits, it is imperative that the tendency of the column to bulge should be reduced effectively. The existing popular method to overcome this situation is by encasing the stone columns with suitable geo-synthetic (Geo-synthetic 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 increase the load carrying capacity of column.

A. Zahmatkesh et al. [1] investigated the performance of stone columns in soft clay. Bora [2] et al. studied the behavior of clay bed reinforced with floating stone columns to understand the load deformation behavior. R. Gandhi et al.[3] in their experimental study, studied the behavior of single column and group of seven columns by varying parameters like spacing between the columns, shear strength of soft clay and loading condition. Malarvizhi S. N et al. [4] studied load versus settlement response of the stone column and geogrid-encased stone column. M.R. Dheerendra et al. [5] studied a new method of improving the performance of stone columns reinforced with vertical nails driven along the circumference. K.Balan et al. [6] investigated the effect of natural geo-textile reinforcement in load carrying capacity of quarry waste column. Kausar ali et al.[7] studied the behavior of stone columns with and without geo-synthetics to find out the effect of reinforcement and l/d ratio on the bearing capacity of the composite soil. K.G Sharma et al. [8] in their experimental study studied the behavior of stone columns with and without reinforcements to evaluate relative improvement in the failure stress of the composite ground due to different configurations of the reinforcement. Kumar Rakesh et al. [9] studied soft ground improvement with fiber reinforced granular pile. J. A. Black et al. [10] 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. Ruben Aza-Gnandji et al. [11] investigated the behavior of single rammed stone columns. K.V.S.B. Raju et al. [12] investigated that the behavior of stone columns subjected to cyclic loading to improve the characteristics of black cotton soil. It is also seen that the load carrying capacity of the stone column depends on the fill material. The inclusion of stone as fill material proves to be better than using sand and gravel when considering load carrying capacity and drainage (Girish M.S et al. [13]). Though the Silica-Manganese slag is a waste material, it can be used as a column fill material. In the present study, the placing of geo-textile circular discs within the stone columns in lateral direction is investigated through laboratory strain controlled load test. The effect of the parameters such as, the depth of geo-textile reinforcement from ground level, spacing of geo-textiles reinforcement were analyzed.

II. Materials

The materials used in this study are Marine clay, Silica-Manganese slag, Geo-textile circular discs, Sand. The source and the properties of these materials are described below.

Marine clay is collected from Visakhapatnam port trust at EQ-3 berth near Gnanapuram road area. The soil is highly compressible inorganic clay. Silica-Manganese slag is used as a stone material in this study. Table.1 shows the index and engineering properties of marine clay. Marine clay is shown in Figure.1 (a).

Table 1. Index and engineering properties of marine clay

Properties	Values
Liquid limit (%)	72.9
Plastic limit (%)	25.6
Plasticity Index	47.2
Specific Gravity	2.48
Optimum Moisture Content (%)	26.4
Maximum Dry Density (kN/m^3)	14.6
Classification (IS : 1498-1972)	CH
Unconfined compressive strength(in kPa) at 35% water content	30

The Silica-Manganese slag produced during the primary stage of steel production is referred to as submerge arc furnace. This slag is obtained from smelting process in ferro-alloy industry. This slag is collected from Sri Mahalaxmi Smelters (Pvt.) Limited near Garbam (vill), Garividi, Vijayanagaram (Dt) and the aggregates of sizes between 4.75 mm and 10 mm have been taken for the present study. Major constituents of Silica-Manganese slag are SiO_2 and CaO for about 24% and 45% respectively. Table.2 shows the physical properties of Silica- Manganese slag. Silica-Manganese slag is shown in Figure.1 (b).

Table 2. Physical Properties of Silica-Manganese slag

Properties	Values
Specific Gravity (Gs)	2.79
Water absorption	0.69%
Unit weight	1.88g/cm^3

The geo-textile sheet used in this study is non woven geo textile which is collected from Ayyappa Geo-textile installers, Lankelapalem, Vishakhapatnam. Mass of the geotextile is 100g/m^2 and Tensile strength is 4.5kN/m. Geo-textile circular discs are shown in Figure.1(c).

The sand used as a blanket is clean river sand collected from Nagavali River, Sankili, Regidi Amadalavalasa (mandal), Srikakulam (Dt). The sand used as a blanket is sieved through 4.75mm sieve and is classified as well graded sand.




Figure 1(a).Marine clay Figure 1(b).Silica-Manganese slag Figure 1(c). Geo-textile circular discs Figure 1(d). Sand

III. Experimental program

Experimental program carried out includes the construction and testing procedures of clay bed, ordinary floating stone column and reinforced stone columns and are discussed below.

3.1. Preparation of 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 depth. 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 300mm 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 covered with wet gunny cloth and then left for 24 hours for moisture equalization. Figure. 2 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 200mm diameter and 300mm height. Figure.5 (b) shows the Schematic view of stone column foundation for test.

Figure 2. Clay bed

3.2. Construction of ordinary floating stone column

After the clay bed was prepared for a depth of 10cm, a perspex pipe having its outer diameter 50mm (diameter of the stone column) and 1mm thick was placed at properly marked centre of the clay bed in the tank. 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. Silica-Manganese slag is used as the course 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 course 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 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.

Figure 3. Ordinary floating Stone Column

3.3. Construction of reinforced stone columns with circular geo-textiles discs

After the clay bed was prepared for a depth of 10cm, a perspex pipe having its outer diameter 50mm (diameter of the stone column) and 1mm thick was placed at properly marked centre of the clay bed in the tank. 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 reinforced column portion is constructed after constructing the plain stone column portion to its required depth ("L" minus reinforcement depth). This reinforced stone column was casted in steps by reinforcing with geotextile with 5cm spacing for desired depths (0.25L, 0.5L, 0.75L and L) and compacting the each layer. During this process the casing pipe is withdrawn 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 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. The same procedure was followed in the case of 2.5cm spacing (D/2) of geo-textile, but the blows were given after every 5cm spacing.

Figure 4. Placing of geo-textile circular discs

3.4. Testing of clay bed/ Stone columns

After construction of plain clay bed/ Stone columns, load was applied through the12 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 Figure. 5(a) and schematic diagram of stone column foundation is shown in Figure. 5(b).

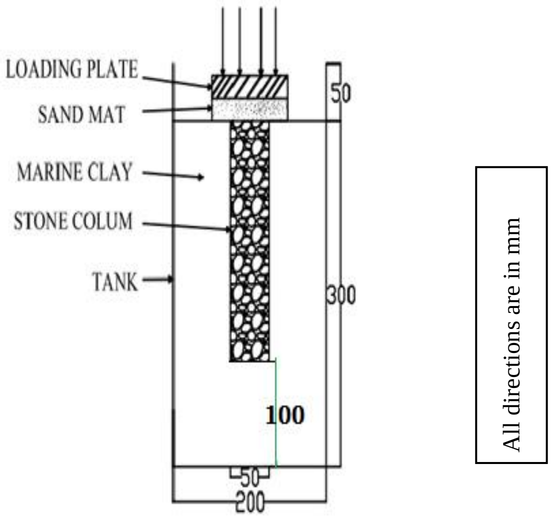


Figure 5(a). Test set up for loading

Figure 5(b). Schematic diagram of loading

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 Discussion

After the completion of experimental program on clay bed, ordinary floating column and reinforced stone column, the load-settlement response is studied from the results obtained from the experimental program.

4.1. Load settlement response of plain clay bed and ordinary floating stone column

Figure.6 shows the load-settlement response of plain clay bed and ordinary floating stone column. The load carrying capacity of Silica-Manganese slag stone columns got better results than the plain clay bed. This is because of the densification of the bed by stiffer Silica-Manganese slag stones inclusion. The ultimate load carrying capacity of plain clay bed is 34kg and corresponding settlement is 7.5mm. The ultimate load carrying capacity with stone column is 43kg. The column inclusion increased the load carrying capacity by 26% to that of clay bed alone. The settlement at the ultimate load has also been reduced to 7.1 mm.

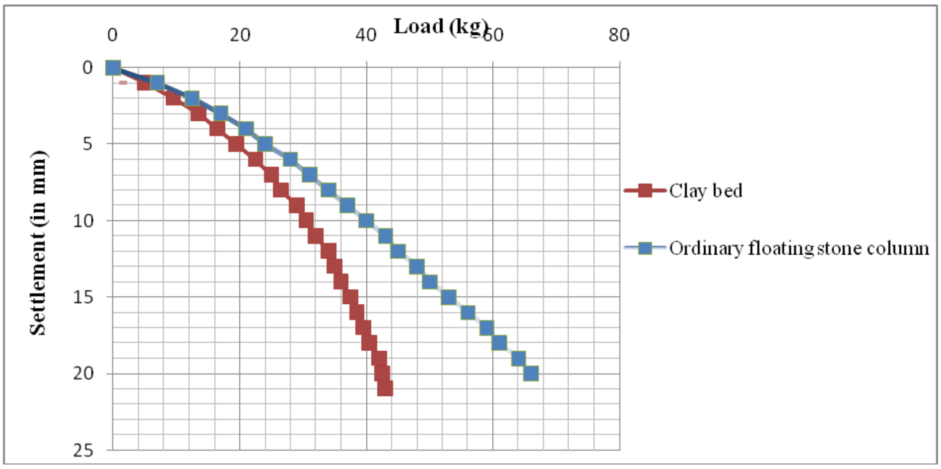


Figure 6. Load settlement curves of clay bed and ordinary floating column

4.2. Load settlement responses of reinforced stone columns with varying reinforcement depths (0.25L, 0.5L, 0.75, L) at a spacing of D (5cm)

Further the stone column is reinforced with circular discs of geo-textiles placed horizontally at spacing equal to the diameter of the stone column (5cm). The load-settlement response is observed with varying reinforcement depths (0.25L, 0.5L, 0.75, L). The ultimate load carrying capacities of reinforced stone column with reinforcement depths of 0.25L, 0.5L, 0.75L and L are 53.5kg, 60kg, 69kg and 81kg respectively and the corresponding settlements are 5.8mm, 5mm, 4.3mm and 4mm. This indicates the improvement in load carrying capacities when compared to the ordinary floating column were 24%, 40 %, 60% and 88% respectively. The increases in load carrying capacities with reinforcement are 1.6, 1.8, 2.0 and 2.4 times respectively for reinforcement lengths of 0.25L, 0.5L, 0.75L and L when compared to clay bed alone.

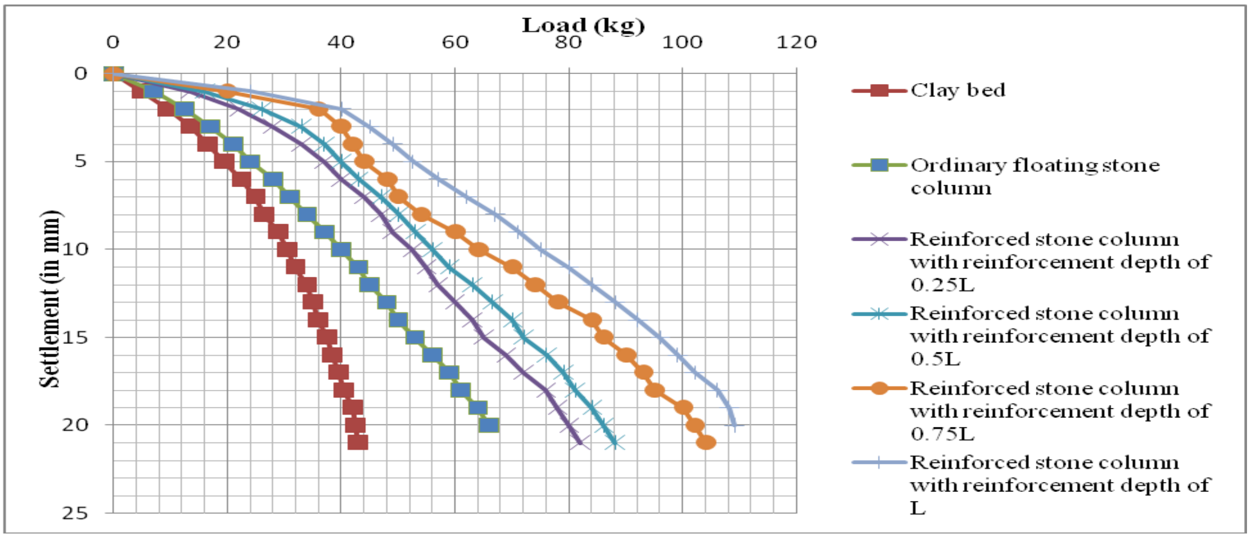
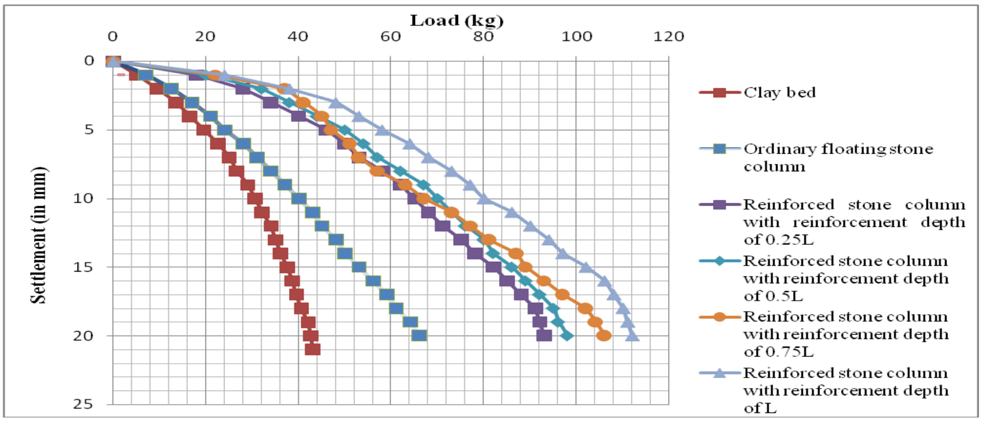


Figure 7. Load Settlement curves of reinforced stone columns with varying reinforcement depths at a spacing of D (5cm)

4.3. Load settlement responses of reinforced stone columns with varying reinforcement depths (0.25L, 0.5L, 0.75, L) at a spacing of D/2 (2.5cm)

Geo-textile circular discs were placed horizontally at spacing equal to half of the diameter of the stone column (2.5cm). The load settlement response is observed with varying reinforcement depths (0.25L, 0.5L, 0.75, L). The ultimate load carrying capacities of reinforced stone column with reinforcement depths of 0.25L, 0.5L, 0.75L and L are 64kg, 66kg, 73.5kg and 85kg respectively and the corresponding settlements are 5mm, 4.8mm, 3.9mm and 3.4mm. This indicates improvement in load carrying capacity when compared to the ordinary floating column were 49%, 54%, 71% and 98% respectively. The increases in load carrying capacities with reinforcement are 1.8, 1.9, 2.1 and 2.5 times respectively for reinforcement length of 0.25L, 0.5L, 0.75L and L when compared to clay bed alone.



Figire 8. Load Settlement curves of reinforced stone columns with varying reinforcement depths at a spacing of D/2 (2.5cm)

4.4 Ultimate load vs settlement values at different test conditions

Table.3 shows the ultimate load vs settlement values of different test conditions (plain clay bed, ordinary floating column and reinforced stone columns) with varying reinforcement depths at spacing of 5cm and 2.5cm.

Table 3. Ultimate load Vs Settlement values at different test conditions

Test condition	5cm spacing		2.5cm spacing	
	Load(kg)	Settlement (mm)	Load(kg)	Settlement (mm)
Plain clay bed	34	7.5	34	7.5
Ordinary floating column	43	7.1	43	7.1
Reinforced column with reinforcement depth of 0.25L	53.5	5.8	64	5
Reinforced column with reinforcement depth of 0.5L	60	5	66	4.8
Reinforced column with reinforcement depth of 0.75L	69	4.3	73.5	3.9
Reinforced column with reinforcement depth of L	81	4	85	3.4

V. Analysis of bulging

Bulging of reinforced stone columns with varying reinforcement depths at a spacing of 5cm and 2.5cm were studied and analyzed bellow.

5.1. Bulging of reinforced stone columns with varying reinforcement depths at a spacing of 5cm

Figure.9 shows the bulging curves of floating stone columns with varying reinforcement depths at 5cm spacing. The horizontal deformations of the columns are measured at the outer face of each column for every 2.5cm interval. A graph is plotted between the depths of column vs bulging of the column. The maximum bulging observed was 1.3cm, 1cm, 0.9 cm, 0.8cm and 0.6cm for ordinary stone column, stone column reinforced with length of 0.25L, 0.5L, 0.75L, L respectively.

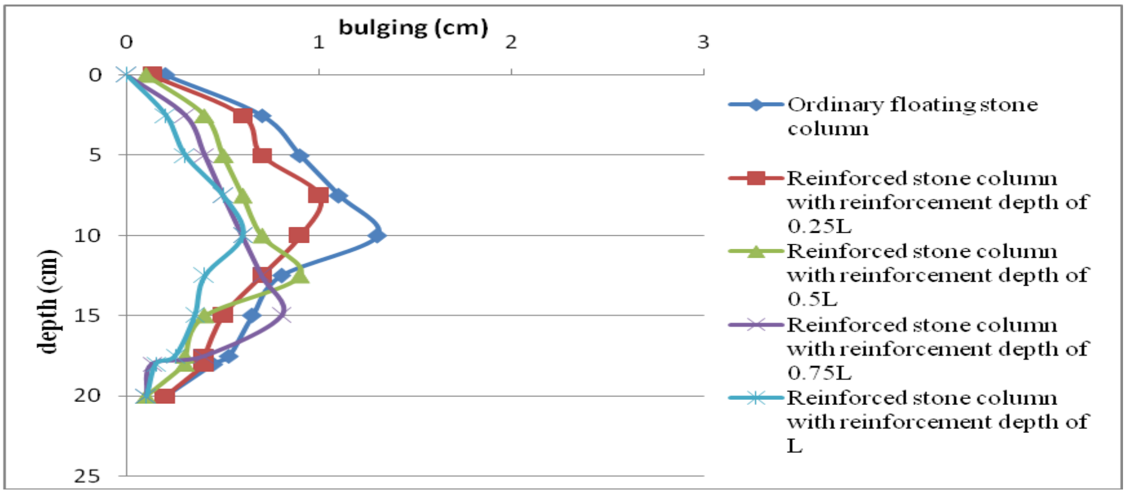


Figure 9.Bulging curves of reinforced stone columns reinforced with varying depths at a spacing of 5cm

5.2. Bulging of reinforced stone columns with varying reinforcement depths at a spacing of 2.5cm

Figure.10 shows the bulging curves of floating stone columns with varying reinforcement depths at 5cm spacing. The horizontal deformations of the columns are measured at the outer face of each column for every 2.5cm interval. A graph is plotted between the depths of column vs bulging of the column. The maximum bulging observed was 1.3cm, 0.8cm, 0.7cm, 0.6cm and 0.4 cm for ordinary stone column, stone column reinforced with length of 0.25L, 0.5L, 0.75L, L respectively.

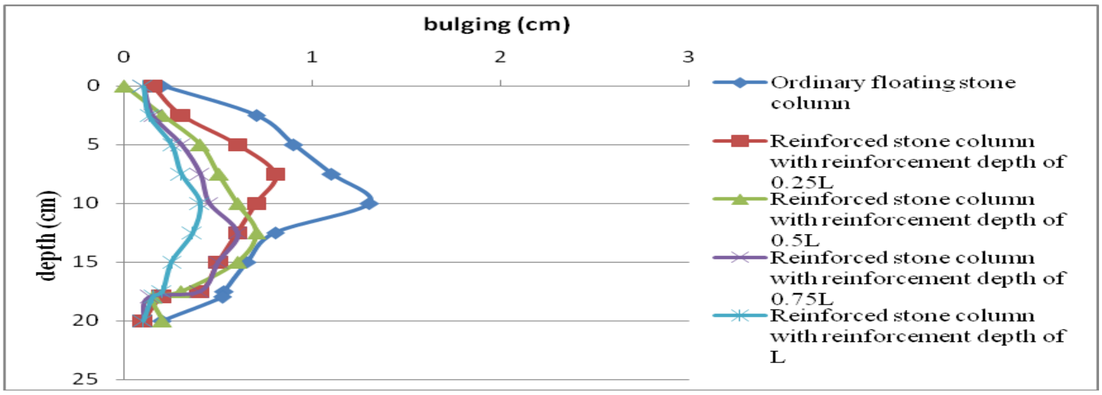


Figure 10. Bulging curves of reinforced stone columns reinforced with varying depths at a spacing of 2.5cm

V. Conclusions

The conclusions derived from the present study are listed below.

1. Inclusion of ordinary floating stone column increased the load carrying capacity of plain clay bed by about 26%.
2. The load carrying capacity and stiffness of the floating stone column are increased by lateral reinforcement of column using geo-textile circular discs.
3. The improvement in load carrying capacity of reinforced column also depends on the reinforcement depth. Load carrying capacity of the stone column reinforced for full length with D (5cm) and D/2 (2.5cm) spacings shows 51 % and 33% better performance respectively than that of columns reinforced to top quarter depth.
4. Load carrying capacities of the stone columns reinforced with circular discs placed at D/2 (2.5cm) spacing shows better performance than D (5cm) spacing, where as the increment is reduced by increasing the depth of column. This increment is very less when reinforced with a reinforcement depth of 0.75L and L.
5. The settlement is decreased when the stone column is reinforced with geotextile. The decrement in settlement of reinforced stone column for full length with D (5cm) and D/2 (2.5cm) spacing shows 78% and 109% respectively when compared to the ordinary floating stone column.
6. 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.

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