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Experimental Study on Sindhudurg Soft Soil Improvement with Stone Column and Granular Blanket

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Abstract— ***stabilizing the soft soil by stone column reinforcement is one of the most accepted methods of ground improvement techniques. The characteristics of soft soil, such as low shear strength and permeability with high water content and compressibility, pose a significant challenge for constructing structures and embankments. Structures built over the soft soil experience a huge settlement, which may become the main cause of failure. Thus, for any construction, improvement of the soft soil properties is necessary. Stone columns are frequently used to improve the soft soil nowadays. Stone columns speed up the rate of consolidation of the soft soil and thereby increase the load-carrying capacity and lower the settlement value. Stone column is one of the soil stabilizing methods that is used to increase bearing capacity and decrease the settlement of soft soils. Also unreinforced granular blankets are now being utilized to overcome the problems of soft soils. In this research, the bearing capacity of stone columns, granular blanket, and a combination of both methods in unreinforced modes were studied using scaled physical models with l/d ratio 6. Results show that using granular blanket, stone column, and combination of both improves bearing capacity of soft soil.***

Index Terms — Consolidation, granular blanket, ground improvement, l/d ratio, settlement, soft soil Nomenclature.

Nomenclature— SB - Sand Bed, FSC - Floating End Stone Column, ESC - End Bearing Stone Column, GB - Granular Blanket.

I. INTRODUCTION

In simple words-ground improvement can be defined as "the process of enhancing the quality of soil." The ground improvement techniques applied are tools used by the geotechnical engineer for "fixing" the problems of poor ground, when a poor ground exists at the project site (Ghanti & Kashliwal, 2008). Soft clay deposits are extensively located in many coastal areas and they exhibit poor strength and compressibility. Stone column that consist of granular material compacted in long cylindrical holes is used as a technique for improving the strength and consolidation characteristics of soft clays.

Load carrying capacity of a stone column is attributed to frictional properties of the stone mass, cohesion and frictional properties of soils surrounding the column, flexibility or rigidity characteristics of the foundation transmitting stresses to the improved ground and the magnitude of lateral pressure developed in the surrounding soil mass and acting on the sides of the stone column due to interaction between various elements in the system. The stone column derives its axial capacity from the passive earth pressure developed due to the bulging effect of the column and increased resistance to lateral deformation under superimposed surcharge load. The theory of load transfer, estimation of ultimate bearing capacity and prediction of settlement of stone columns was first proposed by several researchers (Malarvizhi, 2004). As per IS 15284: Part 1 (2003), failure mechanisms of single granular pile loaded over its area depends upon the length of the pile and its critical length is four times the pile diameter irrespective of whether it is end bearing or floating. Basack et al. (2018) carried out laboratory tests and numerical analysis to study lateral deformation behaviour and clogging characteristics of soft clay stabilized using stone columns.

Yoo and Abbas (2019) performed laboratory investigation about the performance of geosynthetic-encased stone column-improved soft clay under vertical cyclic loading. Table 1. Properties of Soft Soil Used in the Present Study. The study revealed that the benefit of stone aggregate and granular material increases bearing capacity of soft soil .Superstructure load is shared by soil, stone column and granular blanket in the ratio of their stiffness. Since the stiffness of stone column is much greater than that of unreinforced soil and granular blanket the load carrying capacity of the reinforced soil increases. Stone aggregates are usually employed as stone column fill. Water can easily permeate through the stone aggregates into granular pile and helps in dissipation of excess pore water pressure and accelerates the rate of consolidation.

The present study is aimed to investigate the influence of stone columns on strength of red soft soil from experimental investigations. This study aims to analyse settlements observed against each load and time as well as strength parametrs of granular piles at time of failure. This study also gives comparative investigation between full model length end bearing stone column and having l/d ratio 6 of floating end stone column increamental load verses settlement behaviour of these two different conditions.

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II. MATERIALS

A. Soft Soil

The samples were collected from an uncultivated agricultural land near Bhadgoan Budruk, Tehsil Kudal, in District Sindhudurg. The soil properties are tabulated in Table 1 and the particle size distribution curve is shown in Fig. 1.

B. Aggregates

To study the effect of stone column installed in Sostone aggregates and sand were used. The particle of the aggregate curve.

C. Sand

Sand was obtained from river bed in Maharashtra state in India. It is used as granular Blanket on the unit cell area.it is beneficial for vertical and lateral drainage within the whole unit cell area. The particle size distribution curve of river sand is illustrated in fig.1.

III. METHODOLOGY

A series of tests were performed incorporating various combinations of variables. Fig. 2 shows the flow chart depicting the entire methodology of the current study. Since the aim is to find the influence of stone column geometry and end conditions on strength and consolidation characteristics in soft soil, variations are planned in three broad categories.

1. Stone column of diameters (d) 50, 63 and 75 mm were used.
2. Ratio of l/d for floating end stone column is 6.
3. Boundary conditions of stone column were varied between end bearing stone column and floating end stone column.

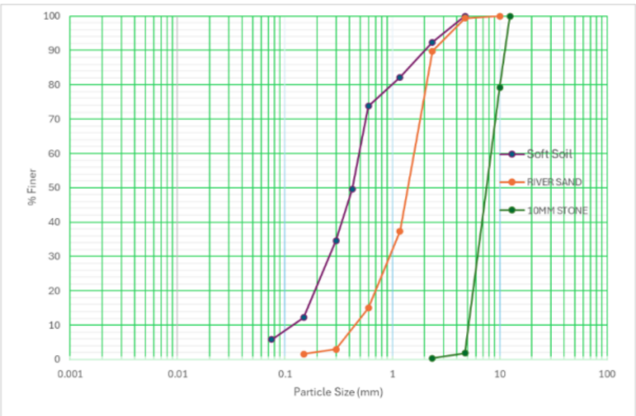

Fig. 1 Grain Size Distribution Curve of Soft Soil, River Sand and Aggregate

Table 1. Properties of Soft Soil Used in the Present Study

Properties	Value
Specific gravity (G)	2.33
Optimum moisture content (OMC)	23.5%
Maximum dry density	1.68 g/cm³
Liquid limit (LL)	43.5%
Plastic limit (PL)	30.55%
Plasticity index (PI)	12.95 %
Cohesion (c)	0.0815Kg/cm²
Soil friction angle (Φ)	25.7º
Classification CI-CH	(Silty & Clays of Medium Compressibility)
	(Silty& Clays of High Compressibility)

Experimental Arrangements

For performing tests, a circular casing pipe was used to install granular pile. Circular PVC pipes of 224 mm diameter and 603 mm height and one pipe cap for pipe was used as test tank. Schematic diagram of test tank is shown in Fig. 3 for floating end stone column of d = 63 mm and l/d = 6. Fig.4 depicts schematic diagram for end bearing stone column of d = 75 mm. A 20 mm sand layer was placed over the surface of pipe only on floating end stone column.

Soft soil of Bhadgoan, Tehsil-Kudal, District-Sindhudurg in India was prepared by mixing soil grains thoroughly with water at water content equal to optimum moisture content (OMC) and was lightly compacted by the 50mm diameter and 1.962kg cylindrical hammer in the test tank. Stone column was installed by drilling a hole with the help of PVC pipe of 50mm, 63 mm, 75mm diameter In the experiment, after every 5cm of soil bed hight and light compaction these pipes were lifted upward, by keeping the pipe 1cm under the soil. Thereafter, a plate of 200 mm diameter was placed over the clay bed for uniform distribution of load over the reinforced clay. For floating end stone column 20mm granular blanket was spread over the clay bed surface. Loading was applied in increments of 20 kg (i.e., 20 kg, 40 kg and 60 kg). Two LVDTs was attached to the loading plate which gave the settlement in the plate, That settlement of the plate is actually the settlement of there inforced soil.

Preparation of Clay Bed

Soft soil was oven dried and powdered with the help of hammers so that it passes through 4.75 mm sieve. Then water equal to OMC was thoroughly mixed with soft soil. Before filling the clay in tank, the pipe cap (diameter slightly more than pipe diameter) is attached at the bottom of the pipe. Then some oil was applied on the inner surface of pipe so that removal of clay bed from tank after completion of test is

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easily accomplished. The mixture of soft soil and water was then filled in the tank in five layers to ensure uniform density throughout the depth of tank .Each test was performed over period of 3 days time. On daily basis, after each load increment, LVDT readings were noted against specific time.

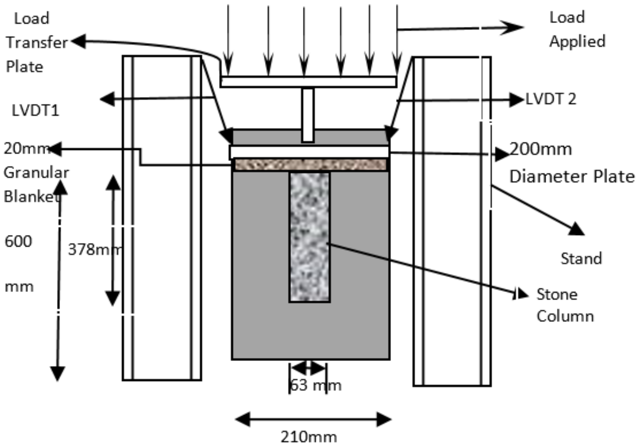

Fig. 3. Schematic Skech of Experimental Setup for Floating End Stone Column Having d=63mm, l/d

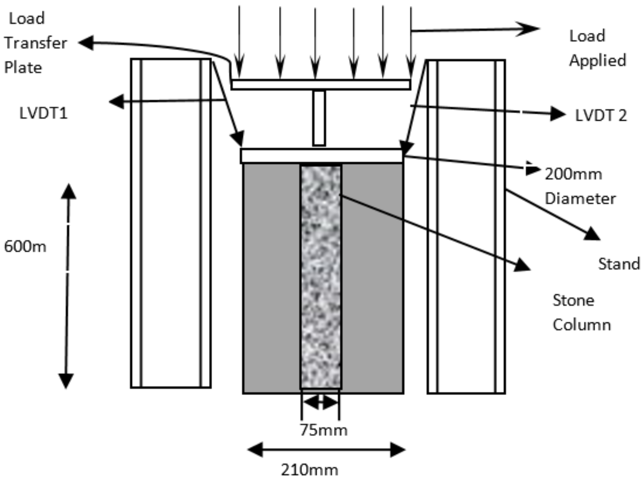

Fig. 4. Schematic Skech of Experimental Setup for End Bearing Stone Column Having d=75mm

Table. II. Summary of the experimental test

No	test name	test description
1	sb	Only Soil Bed
2	esc, d=50mm	End Bearing Stone Column Of 50 mm Diameter
3	esc, d=63mm	End Bearing Stone Column Of 63 Mm Diameter
4	esc, d=75mm	End Bearing Stone Column Of 75 Mm Diameter
5	fsc,d=50, gb=20mm	Floating End Stone Column L/D =6 Of 50 Mm Diameter With 20mm Granular Blanket
6	fsc,d=63,gb=20mm	Floating End Stone Column L/D =6 Of 63 Mm Diameter With 20mm Granular Blanket
7	fsc,d=75,gb=20mm	Floating End Stone Column L/D =6 Of 75 Mm Diameter With 20mm Granular Blanket

Installation of Stone Column

Hole of required diameter was prepared by the PVC pipes inserted in the first layer of the clay bed by rotating it manually at the center of the tank. Care was taken so that the surrounding soil of the bore hole is disturbed as less as possible. And remove the inserted soil in the hole of PVC pipe. 10mm stone aggregates was inserted within the PVC pipe. Light compacted end bearing pile, the hole was bored till the bottom of clay bed and for floating pile the hole was bored up to desired length from the top (according to l/d ratio). After first layer of clay bed and stone aggregate light compaction, PVC pipe was lifted upward slowly keeping some portion of pipe within the soil bed. Further layer of clay bed was prepared and light compaction cell tank were conducted as per the table 2. Fig. 5 shows the entire test setup and soil sample. Load increment of equal sets of 20 kg was applied to soil under testing at intervals of 24 hours. Soft soil was compacted by the steel hammer of 50mm diameter of steel hammer of 1.96kg.

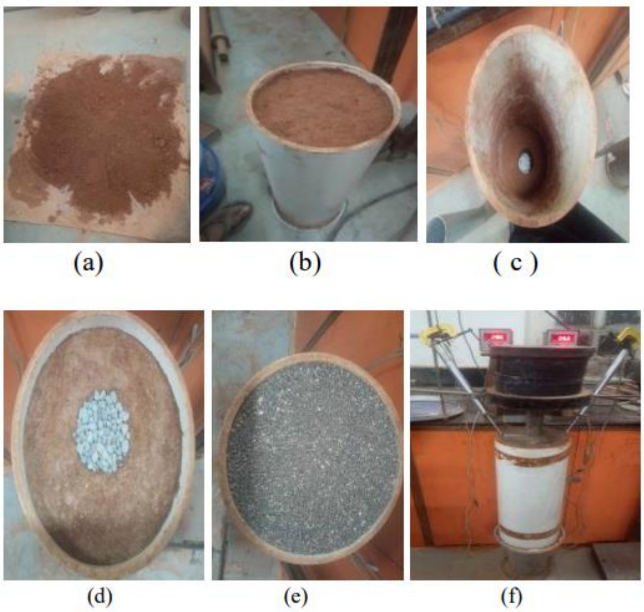

Fig. 5 Sample Preparation: (a) Soft Soil Sample, (b) Only Soil bed (c) Sample with Hole in Test Tank (d) Sample with Stone Column Installed in End Bearing Stone Column (e) Sample of Floating End Stone Column with Granular Blanket (f) Test Setup

IV. RESULTS AND DISCUSSIONS

The load-settlement behavior of each test was observed and the load carrying capacity of reinforced soft soil with change in geometry of stone column was noted. The influence of geometry (diameter and l/d ratio) also evaluated.

A. Soft Soil Reinforced with End Bearing Stone Column

1. Load-Settlement Behavior

The values of settlement for each loading condition are recorded for all cases of end bearing stone columns and depicted in Figs. 6 and 7. Figs. 6(a), 6(b) and 6(c) indicate that increase in diameter values of stone Colum result in significant increase of both strength and stiffness as compared to unreinforced soft soil. For stone columns with d = 50 mm, failure is assumed to take place at a settlement of 5 mm (d/10). This gives the load carrying capacity of unreinforced soil as 160 N and for d=50mm was 520N. Thus, the percentage improvement in load carrying capacity for d =50mm , is 225%. Similarly, in case of d = 63 mm, failure occurs at settlement of 6.3 mm. Fig. 6(b) indicates the load carrying capacity of unreinforced soil as 195 N and for d = 63, it was found to be 720N . Therefore, percentage improvement in load carrying capacity for d=63mm is 269.23% . The percentage improvement in load carrying capacity of unreinforced soil as 230N and for d = 75 mm stone column it was found to be 855N.Therefore, the percentage improvement in load carrying capacity for d =75mm is 271.74%.

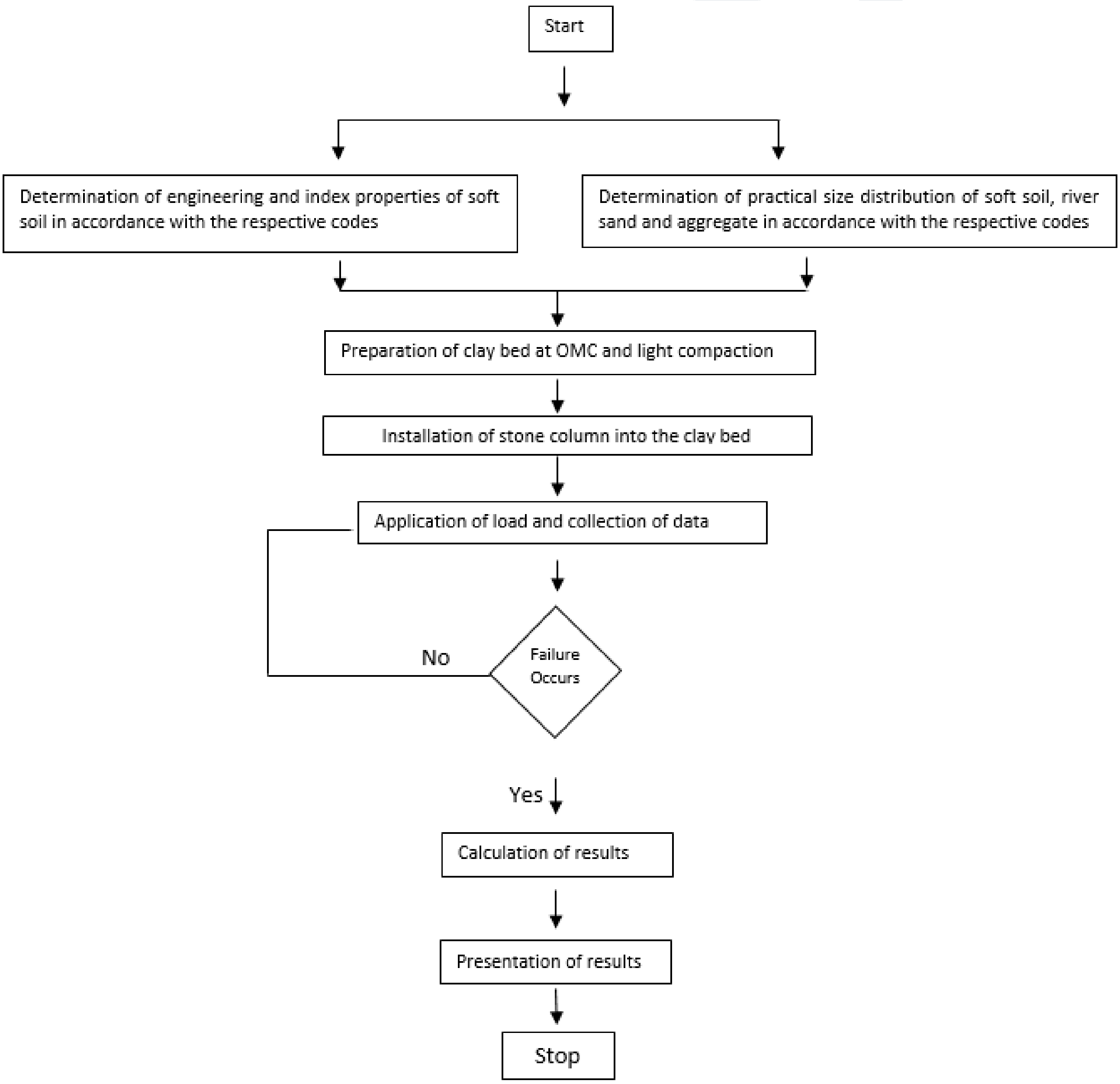

Fig. 2. Flow Chart Depicting the Methodology of the Present Study

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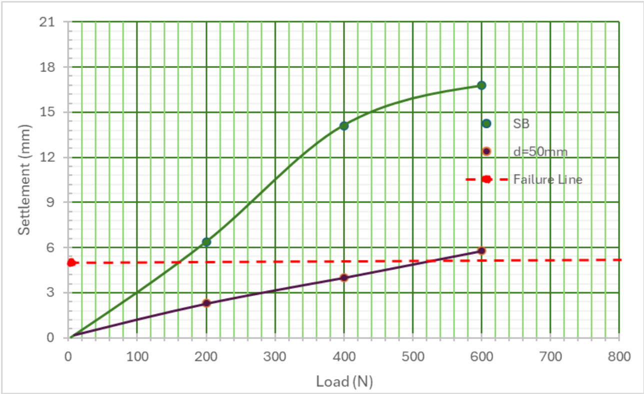
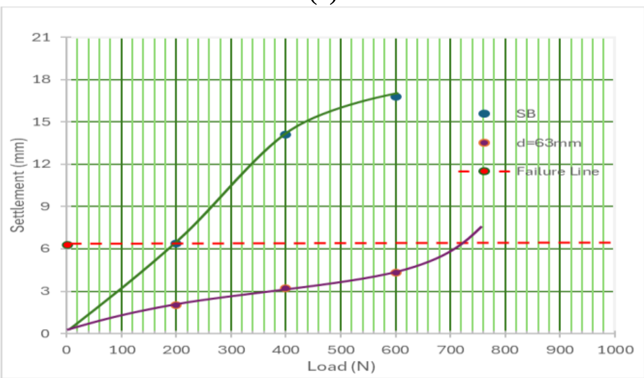


(a)



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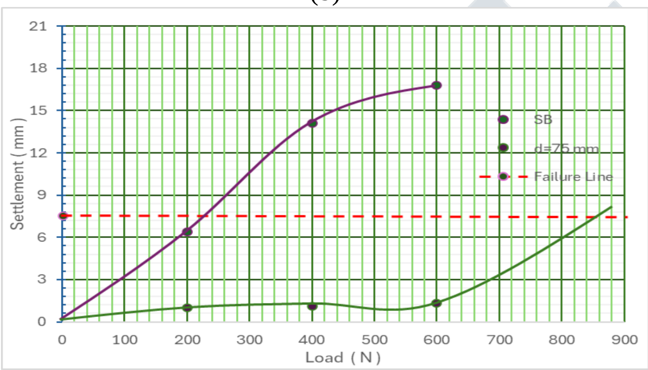


(c)

Fig. 6. Load Settlement Behaviour for End Bearing Stone Column for DifferenT Diameter When (a) d=50mm (b)d=63mm (c) d=75mm

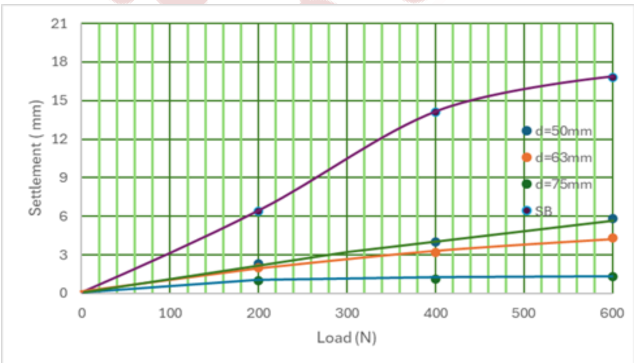


Fig.7 Load Settlement Behavior For End Bearing Stone Column Having Different Diameters

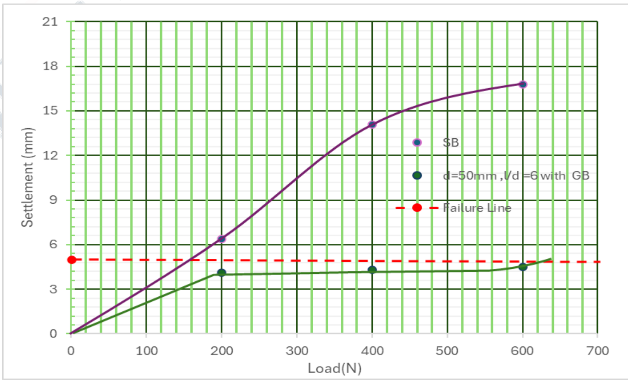
Fig.7 indicates that increase in diameter for diffstone column results in increase in load carrying capacity as well. The percentage increase in load carrying capacity when diameter increases from d = 50 mm to d =63mm was found to be 38.46% and from d = 63 mm to d = 75 mm, it was18.8 %. This behavior is quite justified as the increase in diameter leads to increase in volume of stone columns which have much higher stiffness compared to soil mass. So, higher the volume of stone column, higher would be the fraction of load carried by it and hence, the load carrying capacity of stone column reinforced soil bed increased for larger dimensions of stone columns.

B. Soft Soil Reinforced with Floating End Stone Column

In the tests involving floating type of stone column with granular blanket, tests were conducted for same geometries of stone column as of end bearing stone column. Only l/d ratio of 6 used for floating end bearing stone column with granular blanket of 20mm on the surface of the unit cell area as per the Fig.4.

1. Load-Settlement Behaviour

Figs. 8 (a), (b) and (c) indicate that increase India meter for constant l/d ratio of 6 stone column results in increase in load carrying value. Figures 8 and 9 depict the load-settlement behavior for floating end stone columns. It is seen that the percentage improvement in load carrying capacity for l/d = 6 and 20mm granular blanket is 287.5% for 50 mm diameter stone columns with respect to unreinforced soil. Similarly, in case of d = 63 mm with l/d=6 and granular blanket of 20mm the percentage improvement was 242.5%. And in case of 75mm stone column with l/d=6 and 20mm granular blanket the percentage improvement was 247.73%.



(a)

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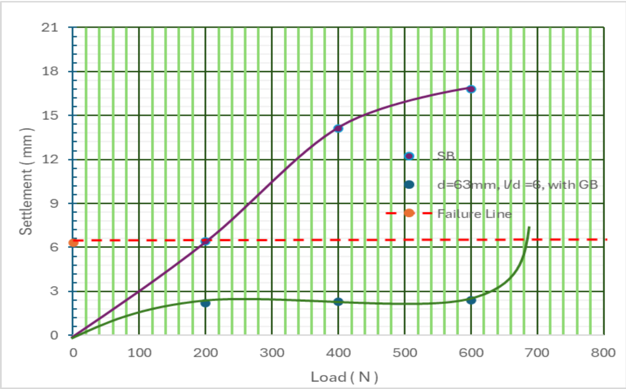

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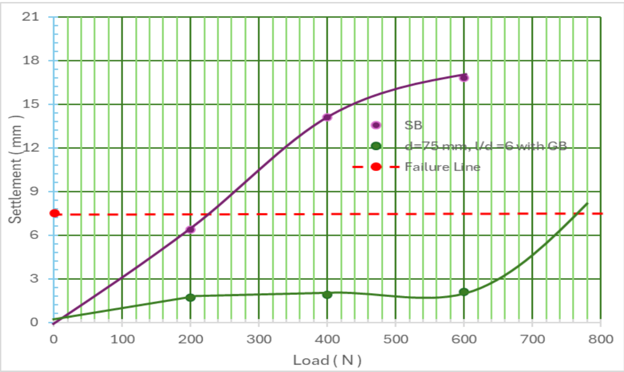


(c)

Fig. 8. Load Settlement Behavior for Floating End Stone Column Having Constant l/d Ratio of 6 And 20 mm Granular Blanket When (a)d= 50mm, (b)d=63mm and (c) d=75mm.

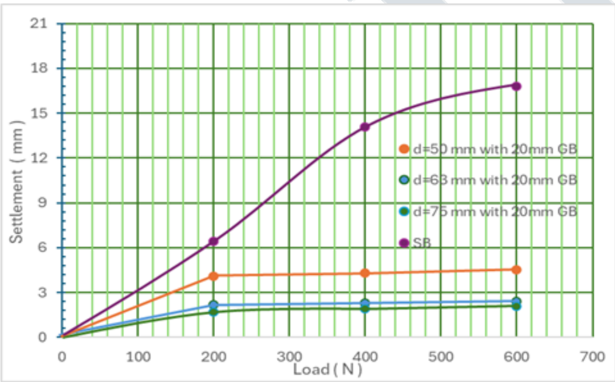


Fig.9. Load Settlement Behavior for Floating End Stone Column Having Different Diameters when l/d = 6

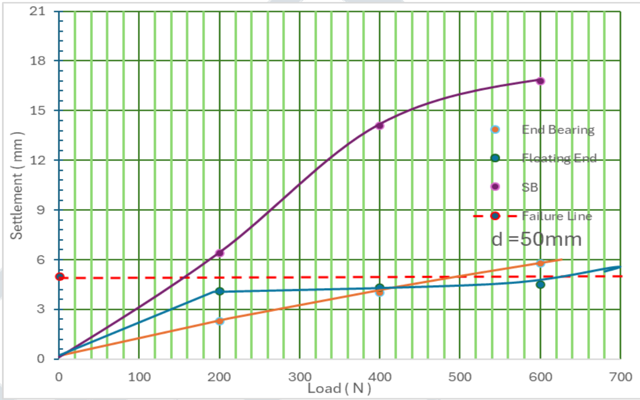
Fig.9 indicate that increase in diameter for l/d =6 ratio of stone column results in increase in load carrying value as well. For l/d = 6 with granular 20mm blanket the percentage increase in load carrying capacity when diameter increases from d = 50 mm to d = 63 mm was found to be 10.48% and from d=63mm to d=75 mm, it was found to be 11.68.

C. Comparison of Boundary Conditions

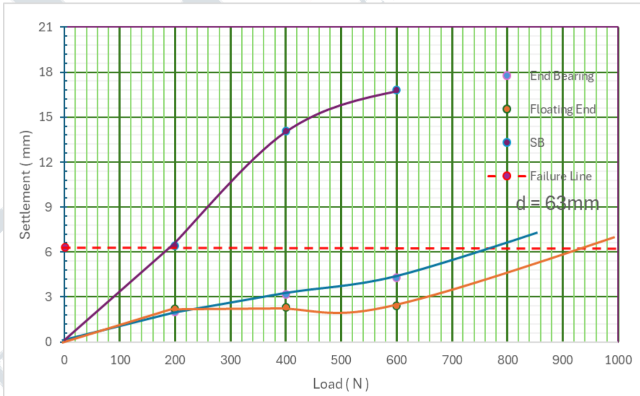
Comparing the results obtained in end bearing stone column with floating end case, the following observations are noticed.

1. *Load-Settlement Behaviour*

Each case of same diameter is compared with each other in the subsequent graphs shown in Fig. 10. Sample exhibits comparable pattern in all three cases of constant diameter. At d = 50 mm Soft soil fails at 160 N, end bearing stone column reinforced soil fails at 480 N and floating end reinforced soil with granular blanket at 620 N. So, load carrying capacity for floating end condition higher than end bearing stone column condition of same geometry. Higher geometries also follow similar trends.



(a)



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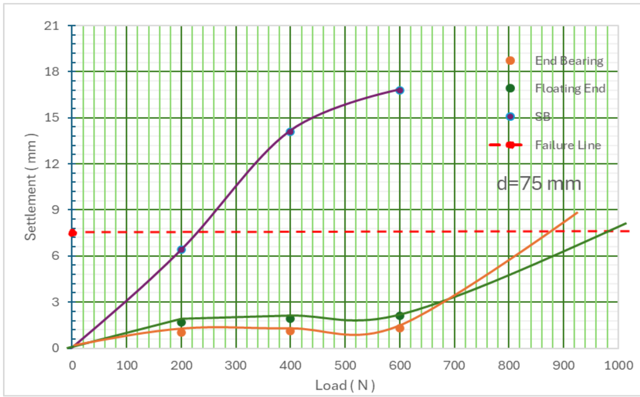

(c)

Fig.10 Load Settlement Behavior for End Bearing and Floating End Stone Columns when: (a) d = 50 mm (b) d =63 mm (c) d=75mm

V. CONCLUSION

After analyzing test results, following conclusions have been drawn.

1. Reinforcing Soft soil of Sindhudurg with stone columns is an easy and economic technique for its improvement as it improves strength, consolidation characteristics.
2. Stone columns considerably enhance the load carrying capacity of soft soil. Increasing the diameter of stone columns improves strength in both end bearing and floating end stone columns. However, increasing the diameter of stone columns improves the soil more in terms of consolidation characteristics.
3. Ultimate settlement occurs much faster in case of stone column reinforced soil as compared to unreinforced soft soil. This is because of the granular flow media which allows flow of water much more readily. Floating end stone columns with granular blanket is more favorable than end bearing stone columns considering rate of consolidation. And also economical view point. So, load carrying capacity for floating end Condition higher than end bearing stone column condition of same geometry.
4. Total ultimate settlement decreases upon reinforcing soil with stone column. It further decreases with increase in diameter of stone column because of increased stiffness of the reinforced soil. However, increase in diameter has higher sensitivity in reducing the total settlement.
5. As the diameter of stone columns increases, rate of consolidation also increases because of the faster ejection of pore water. Floating end stone columns give higher rate of consolidation because only radial flow occurs through clay media in this case and entire vertical flow of pore water takes place through the granular material of blanket which are over the surface of the unit cell area which improves the rate of consolidation.
6. Overall floating end stone column with 20 mm granular blanket enhance the load carrying capacity of the soft soil because of the two combinations of the coarser material which gives more stiffness to the Sindhudurg soil as compare to whole reinforcement of end bearing stone column.

The current study gives the delightful different experience of combination of end bearing and floating end bearing stone column

With granular blanket. So that it gives extremely different result as floating end stone column with granular blanket gives increased load bearing capacity as compared with end bearing stone column. That is the extremely break up the mindset prepared by the reviewed papers. Results of experimental tests on reinforced and unreinforced soil have been presented in graphical as well as tabular form. These results will act as guiding tool for the selection of suitable geometry of stone columns in different field conditions (end bearing and floating). The results also indicate how sensitive the output parameters are with increase of any input parameter which will help choose whether to increase the diameter of stone Column or its length in order to achieve the desired strength and consolidation properties. The current study can be extended in the future to take into account the effects of increased length of granular blanket on the both type of stone columns.

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