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Improvement of Soft Clays Using Stone Columns With And Without Encasement

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Abstract. Engineering structures constructed on thick deposits of soft clay have problems of low bearing capacity, excessive total and differential settlement etc. To mitigate such problems, stone column technique seems to be very suitable and favorable ground improvement technique for deep soft soil improvement. Further to prevent excessive bulging, squeezing of stone into soft soil, stone column can be encased with suitable geo-synthetics. Another advantage of encasement is having high load carrying capacity and lesser settlement of composite foundation. This paper presents an experimental study of single granular piles with and without encasement in improving the bearing capacity and reducing the settlements. The main objectives are (a) to identify key considerations for the general use of encased stone columns and columns without encasement, (b) provide insights for design and construction.
Laboratory experiments have been carried out with granular piles of size, 6 cm. In laboratory setup, hydraulic pressure was used to apply the load to the soil granular pile system and the dial gauges was used to measure the settlements. To obtain the stiffness of the pile, a test were carried on piles with and without encasement, by loading only the pile material neglecting the confining effect of the surrounding soil as the soil is soft in nature. Study of the bearing capacity ratio which is defined as ratio of the bearing capacity of treated soil with granular pile to the bearing capacity of untreated soil for a given settlement for the foundation was made. Granular piles made of stone and sand, and encasement of piles with leno netted material. To cast the piles, casing pipes of the required diameter 6cm was used.

Keywords: Stiffness, Modulus of elasticity, Stone column, Encased, Bearing capacity

1 Introduction

The main advantage of the stone column is its ability to adjust itself to the applied load and redistribute the applied load when stress is concentrated on it. This is due to the increase in deformation associated with bulging when the critical vertical stress level is exceeded. This response is different from load sharing response of a pile in soft clay where in the pile can offer the resistance mainly by bearing, hence pile of longer length than stone column is required.

Advantages of encased stone columns over stone columns include: (i) the column is confined in such a way that it does not intrude into the soft soil; (ii) a consistent diameter is maintained by the encased material; and (iii) improved shear capacity to the column is provided by the tensile strength of the encased material and increased confinement of the sand or gravel.

2 Literature Review

Studied on the consolidation and deformation around end bearing columns under distributed loads and compared the laboratory results with analytical solution and numerical simulation (Castro (2012). Studied on the behavior of stone column in layered soil consisting of weak soil in the top layer under a series of plate load tests (Shivashankar(2011).Presented the behaviour of remolded kaolin clay reinforced by stone column. It is found that Young's modulus of kaolin clay increases as the cavity expansion ratio and consolidation stress increases and the undrained shear strength is more at lower at consolidation stress. It is also noted that the ratio of undrained Young's modulus to undrained shear stress increases when the consolidation stress decreases (Frikha (2013).

3. Materials Used

3.1. Clay

The clay was collected from a field in Patancheru area of Medak district. The properties of clay obtained from various laboratory tests are presented in Table 1.

Table 1. Properties of soft soil

S NO.	Type of test on clay	Results
1	Grain size Distribution	
	Gravel (%)	0.5
	Coarse Sand (%)	1.5
	Medium Sand (%)	6
	Fine Sand (%)	9
	Silt & Clay (%)	83
2	Atterberg Limits	
	Liquid Limit (%)	67
	Plastic Limit (%)	32
3	Standard Proctor Compaction Test	
	Maximum Dry Density (kN/m^3)	14.71
	Optimum Moisture Content (%)	23.50
4	Modified Proctor Compaction Test	
	Maximum Dry Density (kN/m^3)	17.06
	Optimum Moisture Content (%)	15.60

3.1.1 Ascertainment of unconfined compressive strength at different moisture contents

Unconfined compressive strength tests were conducted at different moisture contents (30 to 47%, approximately) to obtain the required consistency (soft) for the clay soil. The UCS values are decreasing with an increase in moisture content. Moisture content around 46.2 % is used for the preparation of the clay bed for all the load tests.

Table 2. Variation of UCS with moisture content

S. No.	Moisture Content (%)	Bulk Density (kN/m^3)	UCS (kN/m^2)
1	30.50	13.802	144.28
2	35.10	12.959	83.39
3	39.62	11.968	25.66
4	45.92	11.212	22.56
5	46.35	11.026	19.52

3.2 Gravel

Aggregate having particle size, 12.5 mm to 4.75 mm was used for the preparation of the stone column. The gravel for stone columns is classified as uniformly graded using the grain size distribution curve.

3.3 Sand

Medium to fine sand was used in the preparation of stone columns in the proportion of 70% of gravel and 30% of sand to fill in the gaps between the aggregate particles.

3.3.1 Angle of internal friction (ϕ) of gravel-sand mix

The angle of internal friction of the stone column material was obtained by conducting the direct shear test at different normal stresses on gravel mixed with sand in the proportion of 70% to 30% respectively. Fig. 1 depicts the stress-strain curves for gravel-sand mixture.

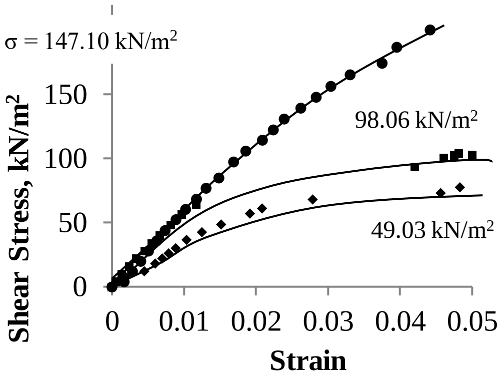

Fig.1. Stress-Strain curves for gravel sand mix at different Normal stresses

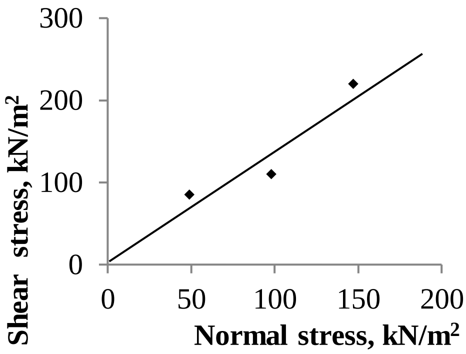

Fig.2. Normal stress vs. Shear stress of gravel sand mix

Fig.2. Shows the curve of normal stress vs. shear stress (strength envelope) at failure. Angle of internal friction for the mixed proportion of gravel and sand was 52.76º.

3.4 Leno Netted Bag

The Leno netted bag was used as encased material to the stone columns. The thickness of the leno netted bag is 0.47 mm.

Fig.3. Leno netted bag

4 Test Program

In order to achieve the objectives of the project, load tests were conducted on unreinforced soft clay and soft clay reinforced with stone columns (granular columns). To examine the effect of stiffness on load carrying capacity stone columns of diameter 6 cm was used for single column load tests. The clay bed is prepared by varying density to a thickness of 47 cm.

The properties of the clay and stone column are as follows.

Clay bed: moisture content 46 to 47%, dry density 10.14 to 10.25 kN/m3, thickness of clay bed - approximately 47 cm.

Stone columns: d=6.5cm & 7cm, L of column = 37cm, and dry density of column = 18.82 kN/m3.

Tests were conducted with two sizes of the plates. One exactly equal to the diameter of column and the other 23.5 cm which is more than 3 times the diameter of the column covering both the column as well as the soft soil adjacent to the column.

All the tests were conducted in a cylindrical tank (see Fig.4) of height 50cm and diameter 40cm.

Fig.4. Cylindrical tank

4.1 Load test on unreinforced clay bed

Test procedure for load test on the unreinforced clay bed as follows.

The clay bed was prepared by compacting in four layers to a total thickness of 47 cm in cylindrical tank using 47% moisture content. A loading plate of diameter 6 cm was placed on the top of the clay bed in the center of plate coinciding with the center of the tank. Two dial gauges were placed on the loading plate to measure the average settlements under load (see Fig. 5).The load was applied gradually on the loading plate using hydraulic jack. The settlements were noted, according to applied load. The application of the load was ceased when there are negligible settlements. The load was used till the loading plate penetrated completely into the clay bed. The test results were presented in Table 5. The stress-settlement curve for this test is shown in Fig.6

Fig.5. Dial gauges on loading plate

Table 3. Load test results for unreinforced clay bed

Stress (kN/m^2)	Average settlement (mm)
0	0
0.82	0.8
1.58	1.2
2.322	2.1
3.896	3.53
5.44	4.96
6.81	6.62
7.18	7.78
9.055	9.95
9.792	11.61

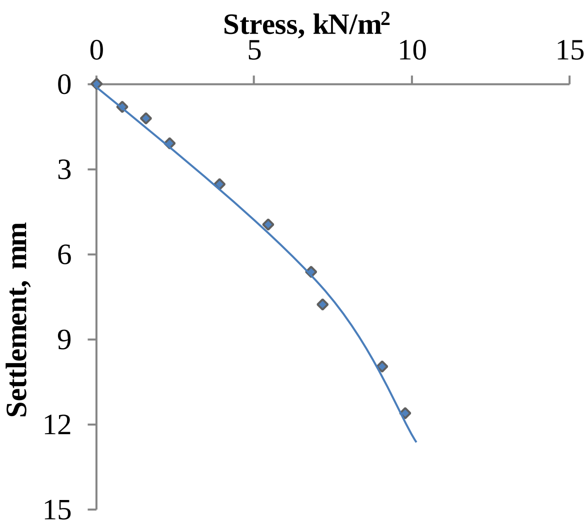

Fig.6. Stress-Settlement curve of unreinforced clay bed using a loading plate diameter 10 cm

4.2 Load tests on Stone Column

Load tests were conducted, on a single stone column of diameter 7 cm using a loading plate of diameter 6 cm and 23.5 cm.

(A) Stone column of diameter 7 cm using a loading plate of diameter 6 cm

The test procedure for load test on a stone column of diameter 7 cm using a loading plate of diameter 6cm placed on the top of the stone column is as follows. Oven dried clay was mixed thoroughly with a water content of 46.20% taken in the cylindrical tank compacted in four layers to a total thickness of 47 cm. To prepare the stone column, a casing pipe of 6 cm diameter was inserted into the clay bed without disturbing the soil mass as the center of the tank coincides with the center of the pipe. After inserting the casing pipe, the soil sample present in the pipe was removed and replaced with gravel and sand mix at proportions of 70% and 30% respectively through the pipe was pulled out gently without disturbing the surrounding soil. The mix proportion was properly compacted with the help of 6 mm diameter rod to maintain the uniform density. After establishment of stone column, the diameter of stone column changed to a diameter of 7 cm due to removal of pipe. The loading plate placed on the stone column area was shown in Fig.7(2). Two dial gauges arranged on the loading plate to measure the settlements of stone column was shown in Fig.7 (3). The load was applied gradually to the plate using hydraulic jack. The settlement of stone column corresponding to applied load was measured. The load was increased after the settlement of stone column has stopped or is negligible. The load was applied up to the loading plate was sunk into the soil. After the test, three samples of testing soil were taken to obtain the moisture content of the soil.

The test setup for this was shown in Fig.7, The test results were presented in Table 3 and Fig.8

(1)

(2)

(3)

Fig.7. (1) Preparation of a stone column, (2) Loading plate placed on the stone column area, (3) Dial gauges was arranged on loading plate

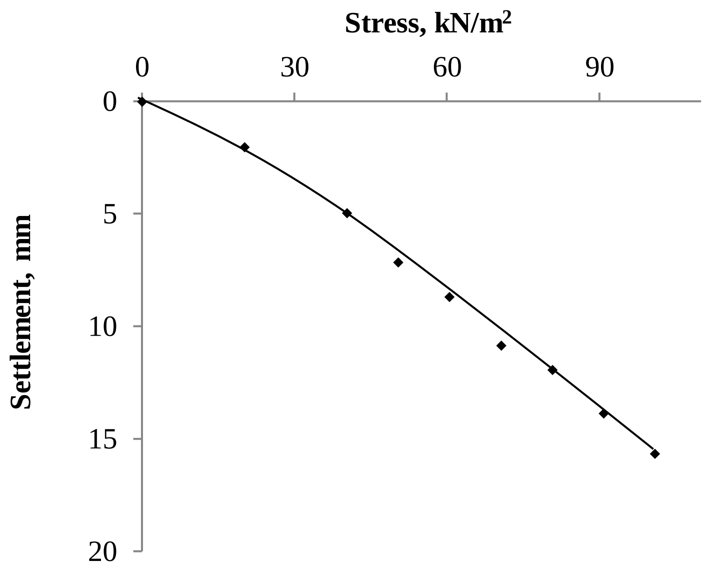

Fig.8. Stress-Settlement curve for stone column of diameter 7 cm using a loading plate diameter 6 cm

Table 4. Load test results for stone column of diameter 7 cm using a loading plate diameter 6 cm

Stress (kN/m^2)	Average settlement (mm)
0	0
20.169	2.04
40.339	4.95
50.424	7.16
60.509	8.68
70.594	10.85
80.679	11.93
90.764	13.85
100.849	15.65

(B) Stone column of diameter 7 cm using a loading plate of diameter 23.5 cm

The test procedure for load test on a stone column of diameter 7 cm using a loading plate of diameter 23.5 cm placed on the top of the stone column same as that of Stone column of diameter 7 cm using a loading plate of diameter 6 cm.

Table 5. Load test results for stone column of diameter 7 cm using a loading plate diameter 23.5 cm

Stress (kN/m^2)	Average settlement (mm)
0	0
3.944	0.84
7.889	1.34
11.833	1.83
15.778	2.84
19.722	3.40
23.667	4.52
27.611	5.23
31.556	6.10
35.500	6.91
39.445	8.17
42.075	8.98
44.704	9.88
47.334	11.00
49.964	11.84
52.593	12.90

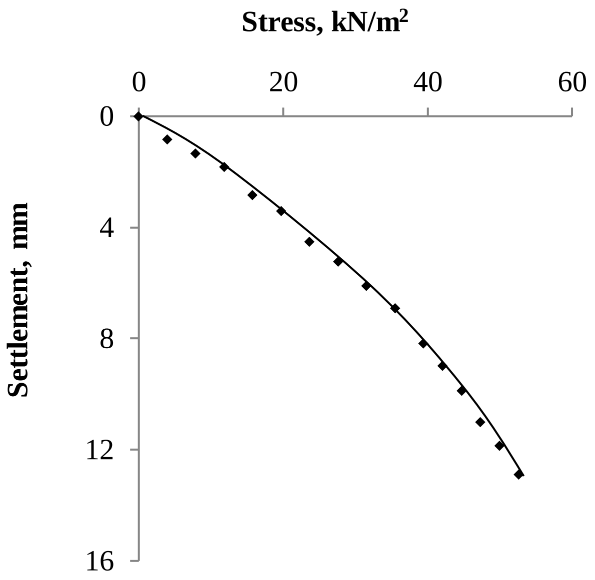

Fig. 9. Stress-Settlement curve for stone column of diameter 7 cm using a loading plate diameter 23.5 cm

4.3 Load tests on Encased Stone Column

The Leno netted bag was used as encased material. The load tests were conducted on single encased stone columns of diameter 7 cm and 6.5 cm using a loading plate of diameter 6 cm and 23.5 cm.

(A) Encased stone column of diameter 7 cm using a loading plate of diameter 6 cm

The test procedure for load test on an encased stone column of diameter 7 cm using a loading plate of diameter 6 cm placed on the top of the stone column as follows.

The clay was taken in the cylindrical tank compacted in four layers to a total thickness of 47 cm, mixed thoroughly with a water content of 46.20%. The stone column was prepared by using a casing pipe of 6 cm diameter through inserting into the clay bed without disturbing the soil mass as the center of the tank coincides with the center of the pipe. After inserting the casing pipe, the soil sample present in the pipe was removed and placed with an empty leno netted bag. After that the leno netted bag was filled with gravel and sand mixture at proportions of 70% and 30% respectively. The casing pipe was pulled out gently without disturbing the surrounding soil. The mix proportion was properly compacted with the help of 10 mm diameter rod to maintain the uniform density. After installation, the diameter of the encased stone column expanded to 7 cm (Fig.10 (1)). The loading plate was placed only on the encased stone column area.

To measure the settlements of the stone column two dial gauges were arranged on the loading plate. The load was applied gradually to the plate using hydraulic jack. Corresponding to applied load the settlements of stone column was noted. The load was increased after the settlement of stone column has stopped or is negligible. The load was applied until the loading plate was sunk into the soil. After the test, three samples of testing soil were taken to obtain the moisture content of the soil. The test setup for this was shown in Fig. 10.

(1) (2)

Fig.10. (1) Preparation of the encased stone column, (2) Stone column after completion of the test

Table 6. Load test results for an encased stone column of diameter 7 cm using a loading plate diameter 6 cm

Stress (kN/m^2)	Average settlement (mm)
0	0
30.25	0.77
50.42	2.20
90.76	5.99
121.01	8.50
151.27	10.97
181.52	13.62
201.69	14.58

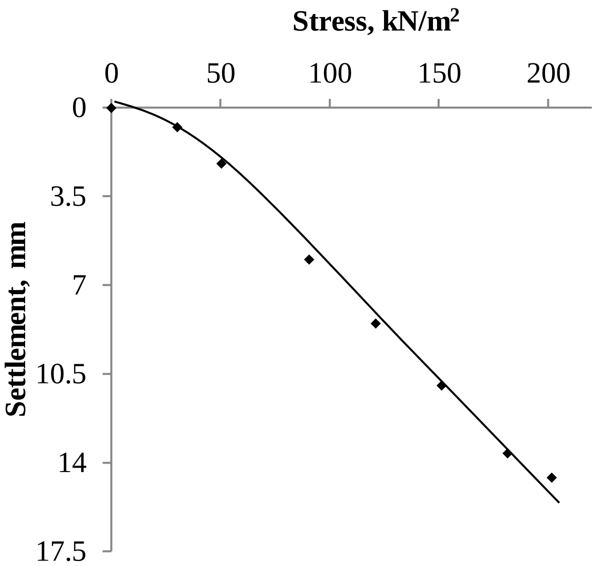

Fig.11. Stress-Settlement curve for stone column of diameter 7 cm using a loading plate diameter 6 cm

(B) Encased stone column of diameter 6.5 cm using a loading plate of diameter 23.5 cm.

The same test procedure was conducted for encased stone columns of diameter 7 cm and 6.5 cm using a loading plate of diameter 6 cm and 23.5 cm.

Table 7. Load test results for an encased stone column of diameter 6.5 cm using a loading plate diameter 23.5 cm

Stress (kN/m^2)	Average settlement (mm)
0	0
6.57	0.52
13.14	1.12
19.72	2.47
26.29	3.79
32.87	5.11
39.44	6.61
46.01	7.85
52.59	9.55
59.16	11.65
65.74	13.84

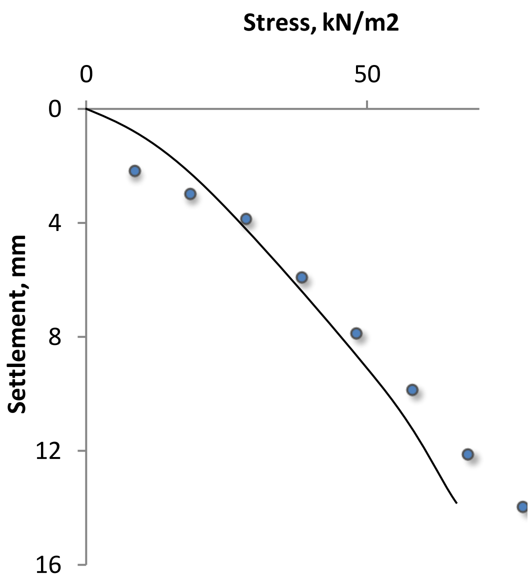

Fig. 12. Stress-Settlement curve for stone column of diameter 6.5 cm using a loading plate diameter 23.5 cm

5 Analysis and Discussion

This chapter presents the comparison of the load-distortation characteristics of reinforced soft clay by introducing the stone columns. The main focus of this chapter was the comparison of the stiffness and stress settlement behaviour of the stone columns with and without encasement installed in soft clay beds. The stiffness and the load carrying capacity of an encased single stone column is expected to be increased compared to without encasement.

5.1. Modulus of elasticity of clay from UCS test

Stiffness of clay were obtained by conducting UCS tests, at different moisture contents. The results of UCS tests were presented in Table 8. It is observed that with increase in moisture content, the stiffness of clay decreased.

Table 8. E values for clay at different moisture content

Moisture content (%)	30.50	35.10	39.62	45.92	46.35
E (kN/m^2)	4000	3200	850	800	347

The stress- settlement reactions saw from load tests on single stone columns of different diameters are shown in below tables and figures. From load test on clay bed at 47% moisture content the stiffness of clay was E = 1250kN/m^2.

5.2 Single stone columns of diameter 6 cm and 7 cm

(A) Using a large diameter of loading plates (23.5 cm)

The stress-settlement responses were studied for load tests on a stone column of diameter 7 cm and 6.5 cm using a loading plate of 23.5 cm diameter. Table.12. Shows the comparison of properties of the stone columns. It was observed that the bulk density of clay and dry density of stone column were almost equal in both test conditions and the stiffness of the stone column increased with an increase in diameter.

Table 9. Comparison of stone columns of diameter 7 cm and 6.5 cm using a loading plate diameter 23.5 cm

S.NO.	Property	7 cm diameter	6.5 cm diameter
1	Bulk density of clay (kN/m^3)	14.98	14.98
2	Maximum dry density of stone aggregates (kN/m^3)	18.82	17.70
3	Stiffness, E (kN/m^2)	2150.53	3000

Fig.11. shows the comparison of stress-settlement curves. The settlement of the stone column increases with an increase in stress. For particular stress with increase in diameter the settlements decreases.

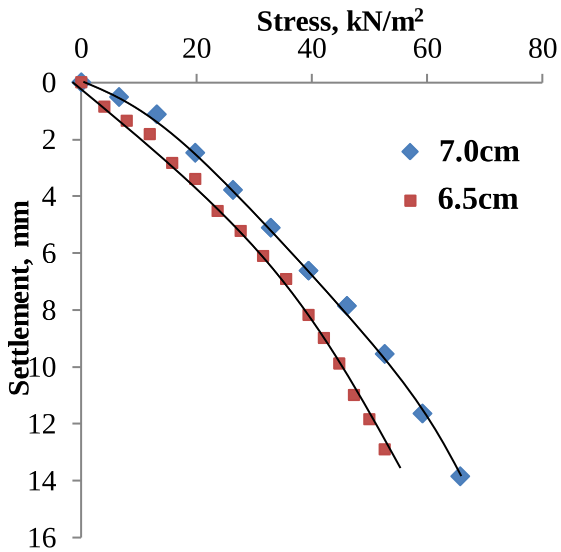

Fig. 13. Stress-settlement responses to the stone column of diameter 7 cm and 6.5cm using a loading plate diameter 23.5 cm

5.3. Single stone column of 7 cm diameter using a loading plate of diameter 6 cm

The load tests results of a stone column and an encased stone column of diameter 7 cm was presented in Table.9. It was observed that the stiffness of an encased stone column increased.

Table.10. Comparison of a stone column with encased stone column of 7 cm diameter

S.NO.	Property	Stone column	Encased stone column
1	Bulk density of clay (kN/m^3)	14.83	14.83
2	Maximum dry density of stone aggregates (kN/m^3)	17.70	18.97
3	Modulus of Elasticity, E (kN/m^2)	3333.3	7888.89

Fig.14.shows the comparison of stress-settlement curves. By applying Leno netted bag as encased material, the settlement of a stone column is decreased.

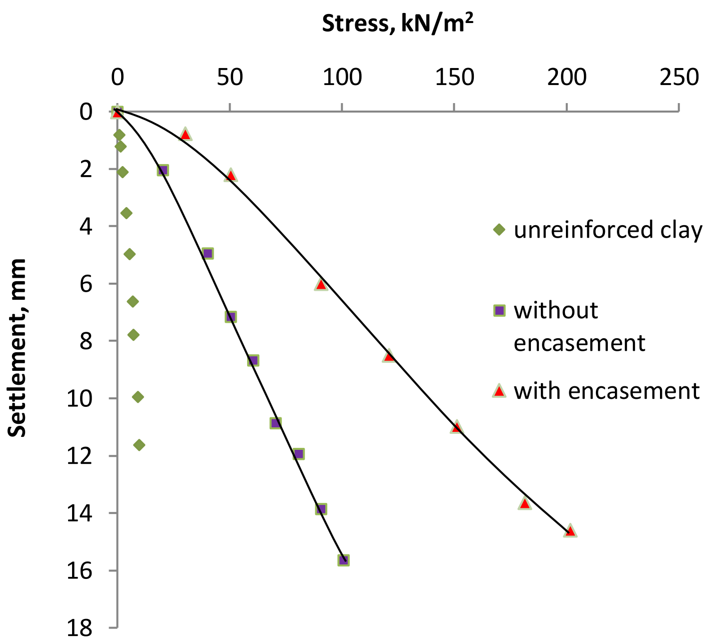

Fig. 14. Comparison of Stress-settlement responses of unreinforced clay bed and stone column of 7cm diameter

6 Conclusions

1. A small diameter pile with an encasement can give preferable execution over an uncased pile.
2. The stiffness of an encased stone column increased by 2.37 times when compared with the stiffness of an uncased stone column.
3. If the diameter of loading plate decreases then stiffness of the stone column increases, vice-versa.
4. The stiffness of Uncased stone column increased by 2.6 times and the stiffness of Encased stone column increased by 6.3 times when compared to the stiffness of Unreinforced clay bed.

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