AN EXPERIMENTAL STUDY ON LOAD CAPACITY OF FLOATING STONE COLUMN IN SOFT SOIL

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ABSTRACT

This paper is an attempt to investigate the improvement of load carrying capacity of stone column through laboratory model tests. The tests are conducted on single stone column. The stone columns are installed in clayed bed prepared in controlled condition in small testing tank call unit cell tank. The load tests were performed on single stone column. Tests were performed with different diameter and different length to diameter ratio of stone column, with a stone column area alone loading condition. The length to diameter ratio of 0, 2, 4, 5, and 6 were used. The diameter of casing pipe and the loading plate of 45mm, 50mm, 55mm, 60mm, 65mm, 70mm, 75mm and 80mm were used to form the stone column. The loading was applied through triaxial testing machine over the rigid steel plate of diameter similar as the diameter of the stone column. The results from the load tests indicated a clear improvement in the load carrying capacity of clay. The increase in the load carrying capacity also increases as the diameter of the granular pile increases.

KEYWORDS: *Stone Column, Unit Cell, Ordinary and Reinforced Stone column. Improvement ratio.*

I. INTRODUCTION

There are various methods employed in the field to stabilize weak soil deposits are; stone columns [2, 4, 7, 8, 18] vacuum pre-consolidation [10], lots of numerical analysis work have been done regarding soil improvement using stone column [15, 17, 19, 23]. The ground improvement in case of very soft soil whose unconfined compressive strength is very low should be treated with some encasement [1, 2, 5, 6, 13, 14, 16, , 20, 21, 22, 24, 25]. Among all these methods, the stone column technique is preferred because it gives better reduction in settlements, increase the load carrying capacity of modified ground and most importantly it accelerates the consolidated settlements. Another major advantage with this technique is the simplicity of its construction method [22], the stone column derives its load carrying 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 stone column length should be such that it can withstand the load coming from superstructure. However the length increases the limiting length may not influence the carrying capacity of stone column. So for the economic purpose the length should be terminate at depth 4 to 5 times the diameter of the stone column whether it is end bearing or floating stone column [3]. Many research work have been done on stone column rested over firm strata [1, 2, 6, 16]. However it is not necessary to have firm strata available even after a greater depth. In such condition it is required to leave stone column in suspended condition in soft soil. This paper presents an experimental study on effects of length and effects of diameter on load carrying capacity of stone column in soft soil. In this paper it is found that the length of stone column is effective up to 4 to 5 times the diameter of stone column. If further increases in the length of the stone column length, there was no influence in load carrying capacity. The improvement factor ratio with respect to untreated soil was found out [12].

The presence of the stone column in natural ground creates a composite material, which is comparatively stiffer and stronger than the original soil. This technique was first adopted in European countries in the early 1960s and there after it has been used successfully in many parts of the world. The granular stone column fails generally in compressive loads in different modes, such as bulging [8] general shear failure, and sliding. A long granular pile having a length greater than its critical length, i.e., about 4 times the diameter of the column fails by bulging irrespective of whether it is end bearing or floating [9]. In this research work the effects of length to diameter ratio on the load bearing capacity have been studied. the research work organisation includes the Laboratory Experimental studies, Properties of clay, Properties of Stones column aggregate, Preparation of clay bed, Stone column Preparation method, Experimental setup and considerations, Results of experimental studies and concluding remarks at the end of the paper.

II. LABORATORY EXPERIMENTAL STUDIES

The laboratory model tests conducted on single stone column installed in a clay bed prepared in controlled conditions in small testing tankscalled unit cell tank. The load tests were performed on a single stone column. Tests were performed with different diameter and different length to diameter ratio of a stone column, with a stone column area alone loading condition. The length to diameter ratio of 0, 2, 4, 5, and 6 were used. The diameter of casing pipe and the loading plate of 45mm, 50mm, 55mm, 60mm, 65mm, 70mm, 75mm and 80mm were used to form the stone column. The loading was applied through triaxial testing machine over the rigid steel plate of diameter same as the diameter of the stone column.

2.1. Properties of clay

The clay used is natural clay from SVNIT Surat campus, Gujarat, India from the depth two meters below the ground level. Properties of clay used are given in table1:

Table1. Properties of Soil

Classification (IS: 1498-1970)	: CL
Specific Gravity	: 2.6
Liquid Limit (%)	: 45
Plastic Limit (%)	: 20
Plasticity Index (%)	: 25(Medium Plastic)
Clay Content (%)	: 35
Silt Content (%)	: 60
Max. Dry Density (kN/m3)	: 17
Optimum Moisture Content (%)	: 18
Undrained Shear Strength	: 30 kPa
Bulk unit weight at 27% water content	: 18.5 kN/m^3

2.2. Properties of Stones column aggregate

Crushed stones (aggregates) of size below 10mm have been used to form stone column [11]. The finer fraction passing through 2mm was removed by sieving and used after air drying. Typical properties of aggregate used as stone column material are summarized in table2.

Table2. Property of stone column material

Angle of internal friction	: 42°
Particle size	: 2-10 mm
Uniformity coefficient	: 2
Coefficient of curvature	: 1.125
Specific gravity	: 2.75
Dry unit weight kN/m3	: 18.5
Unified classification system	: GP

2.3. Preparation of clay bed

A series of unconfined compressive strength (UCS) tests were carried out on cylindrical specimens with a diameter of 38 mm and height of 76 mm to determine the moisture content corresponding to clay undrained shear strength of 30 kPa. Figure 1 depicts the variation of the undrained shear strength with water content. The resulting water content of the clay was found to be 27% and this amount of moisture content was kept the same in all tests.

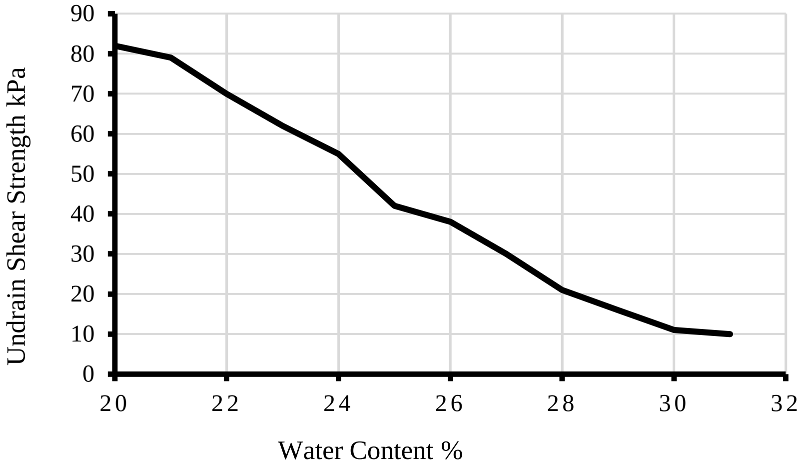
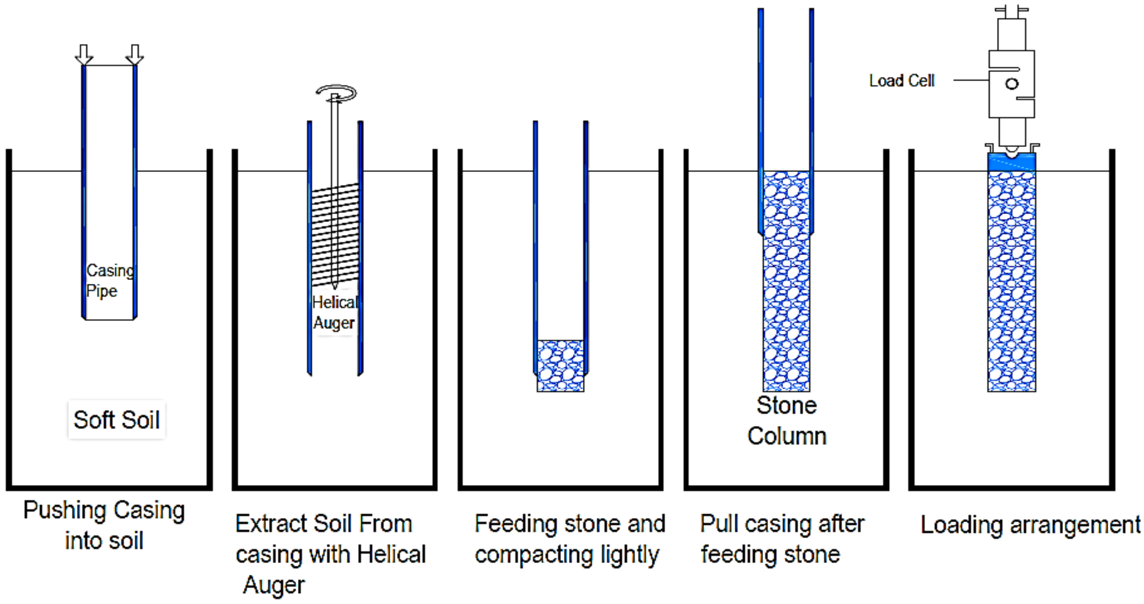


Figure 1. Undrained Shear strength vs. Water content

An identical technique was adopted to prepare the clay bed in all the tests [22]. To maintain similar properties throughout the tests, clay bed was prepared at 27% water content in all the cases. The bulk unit weight at 27% water content was found as 18 kN/m3. Before filling the tank with clay, a thin coat of grease at the inner surface of tank wall was applied to reduce the friction between clay and the tank wall [1, 22]. Soil was filled in the tank in 5 layers with measured quantity by weight. Each layer was subjected to uniform compaction with a tamper to achieve 120 mm height and the corresponding unit weight. Stone column was constructed by replacement method. Thin open-ended seamless steel pipes of 45 and 75 mm outer diameter and wall thickness 2.5 mm were used to construct the stone column. The outer surface of the pipe was lubricated by applying a thin layer of grease for easy penetration and withdrawal without any significant disturbance to the surrounding soil. Stones were charged into the hole in layers in measured quantities to achieve a compacted height of 120 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. This light compaction effort was adopted to ensure that there is no significant lateral bulging of the column, which creates disturbance to the surrounding soft soil. Unit weight of stone columns was estimated with the quantity of aggregate consumed in the construction and the volume of the stone column. The corresponding unit weight of stone column was found to be 18 kN/m3. The procedure was repeated until the column was completed to the full height.

2.4. Stone column Preparation method

The center of the cylindrical tank was properly marked after preparing the soil bed, a casing pipe of the required diameter inserted forcefully into the soil bed up to the required depth. The inner portion of the casing is removed by an auger. The required amount of stone column aggregate material charged into the casing and compacted by using 12 mm diameter rod to achieve the required density. At the end of compaction of each layer, the casing tube is withdrawn to a certain level and stone is charged and compacted. This procedure is repeated until the full length of the column is formed. In this study the vibro replacement floating stone column technique is used as shown in Figure 2.



Pushing Casing into soil

Extract Soil From casing with Helical Auger

Feeding stone and compacting lightly

Pull casing after feeding stone

Loading arrangement

Figure 2. Vibro replacement stone column technique

2.5. Experimental setup and considerations

A typical test arrangement is shown in Figure4. All the experiments were conducted on floating stone columns in homogeneous clay beds in unit cell tanks so that L/D ratio (length of the column/diameter of the column) is ranging from 0mm, 2mm 4mm, 5mm and 6mm. [1, 17, 22]. The load was applied through a triaxial testing machine with a constant displacement rate 0.60mm/min. This rate of displacement is chosen to avoid any possible squeezing out of soil from the annular space between the inside of unit cell cylindrical tank and the loading plate and also to prevent build-up of excess pore water pressures. The load was applied through a 12 mm thick mild steel plate. The resulting displacement measured with LVDT as shown in figure5.

Following are the series of experiments were carried out in the labouratory. The stone column diameter vary from 45mm to 80mm with respective length to diameter ratio of 0, 2, 4, 5 and 6.

Table: 3 A list of experiment conducted in labouratory

L/d ratio	Diameter of stone column							
Only Clay	45mm	50mm	55mm	60mm	65mm	70mm	75mm	80mm
2								
4								
5								
6								

The Triangular arrangement of stone columns and Equivalent pattern was used for the present study. The unit cell modelling was prepared based on the equivalent diameter as suggested by an Indian standard code of practice for stone column [IS 15284 (part 1): 2003]. The equivalent diameter indicates the area of influence. The diameter of the unit cell tank is same as the equivalent diameter. The stresses due to the loading are within the inside boundary of unit cell. The stresses not intersect the periphery of the tank.

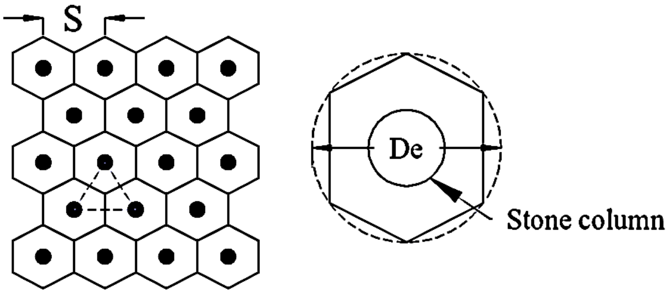


Figure 4. Triangular arrangement of stone columns and Equivalent pattern [IS 15284 (part 1): 2003]

The equivalent circle has an effective diameter (De) which is given by following equation:

D_e = 1.05 S for an equilateral pattern, and

= 1.13 S for a square pattern

Where

S = spacing of the stone columns.

The resulting equivalent cylinder of composite ground with diameter De enclosing the tributary soil and one stone column is known as the unit cell.

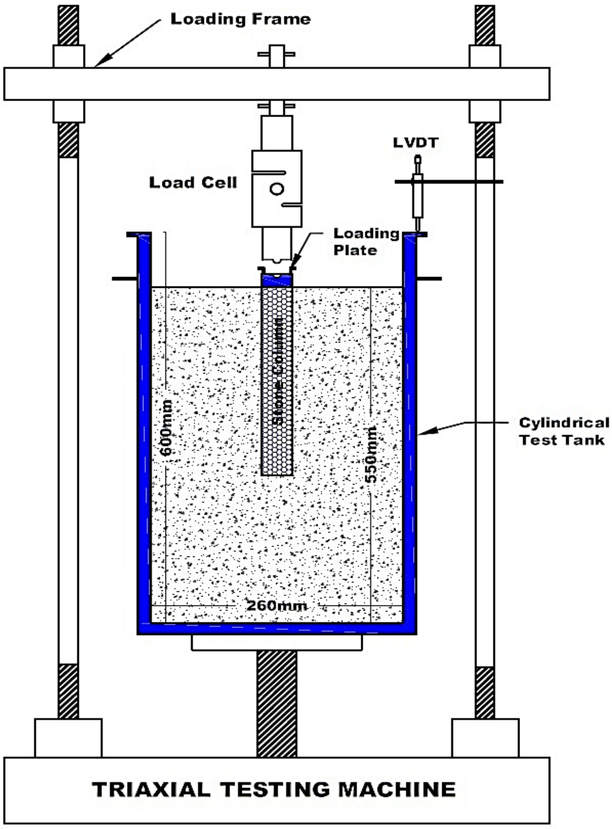


Figure 5. Loading arrangement and displacement measurement using triaxial testing machine

2.6 Results of experimental studies

The results summarized as in the tabulated form as well as in graphical form. All the test results measures the load carrying capacity at 10mm prescribed displacement.

The load deformation test results are compared with untreated soil. Figure 5 shows the load carrying capacity of 45mm diameter stone column at 10mm settlment. The settlement with corresponding load is measured with the LVDT. The capacity of 45 mm diameter stone column at 10 mm settlement with L/D ratio 0, 2, 4, 5 and 6 is 0.3, 0.52, 0.53, 0.65 and 0.70 kN respectively as shown in figure 6. The load carrying capacity of stone column compared to untreated soil with different L/D ratio 2, 4, 5, and 6 is increases 1.73, 1.77, 2.17 and 2.33 times respectively. The trends obtained from results shows that by increasing the length of stone column, the load carrying capacity of stone column increases.

Figure 6, 7, 8, 9, 10, 11, and 12 shows the load carrying capacity of 50, 55, 60, 65, 70, 75 and 80mm diameter stone column at 10mm settlement respectively. The settlement with corresponding load is measured with the LVDT. The capacity of stone column at 10 mm settlement with different L/D ratio is of different stone column diameter is measured as shown in figures respectively. The load carrying capacity at 10 mm settlement is tabulated as shown in table 4.

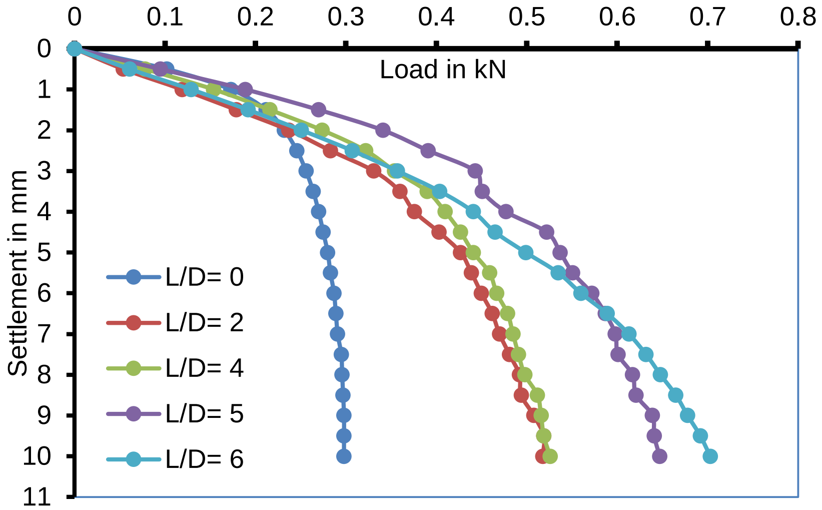


Figure 6. Load Vs Settlement for 45 mm diameter stone column with fifferent L/D ratio

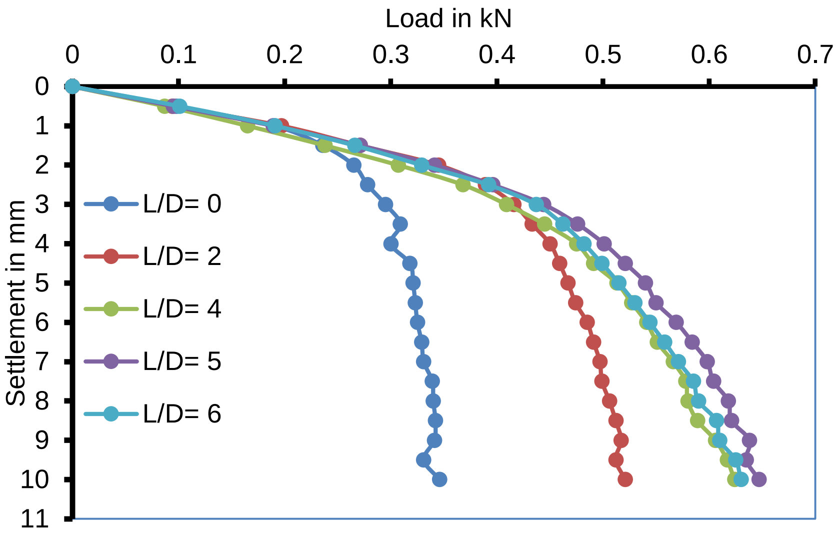


Figure 7: Load Vs Settlement for 50 mm Plate & Stone Column at 10mm prescribed settlement

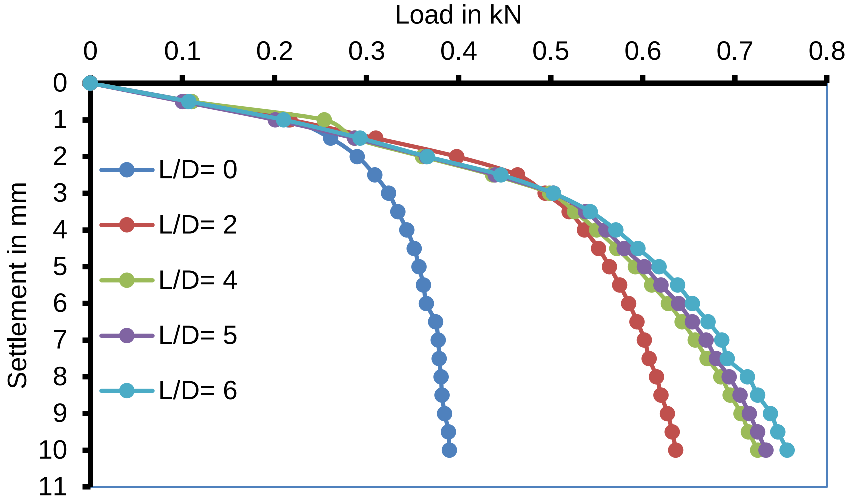


Figure 8: Load Vs Settlement for 55 mm Plate & Stone Column at 10mm prescribed settlement

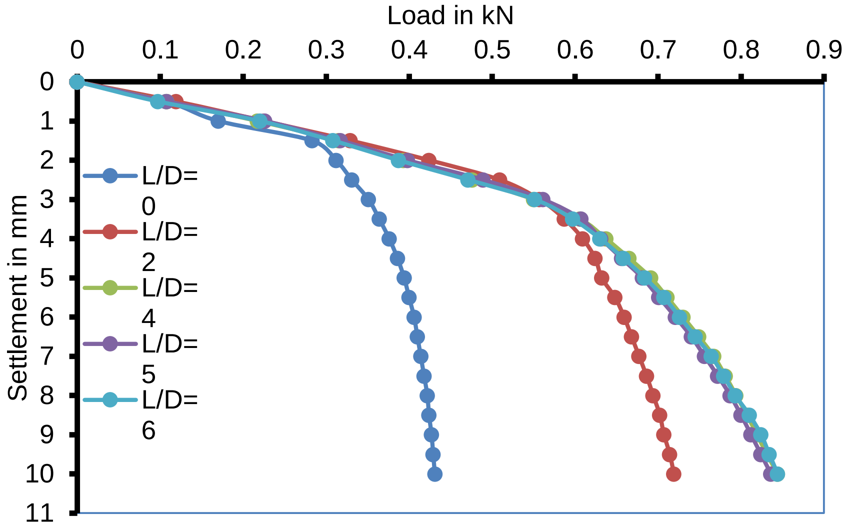


Figure 9: Load Vs Settlement for 60 mm Plate & Stone Column at 10mm prescribed settlement

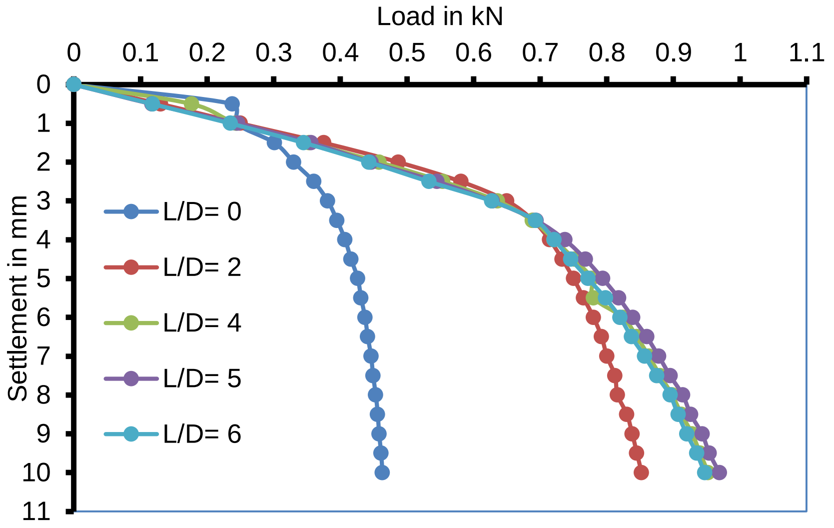


Figure 10: Load Vs Settlement for 65 mm Plate & Stone Column at 10mm prescribed settlement

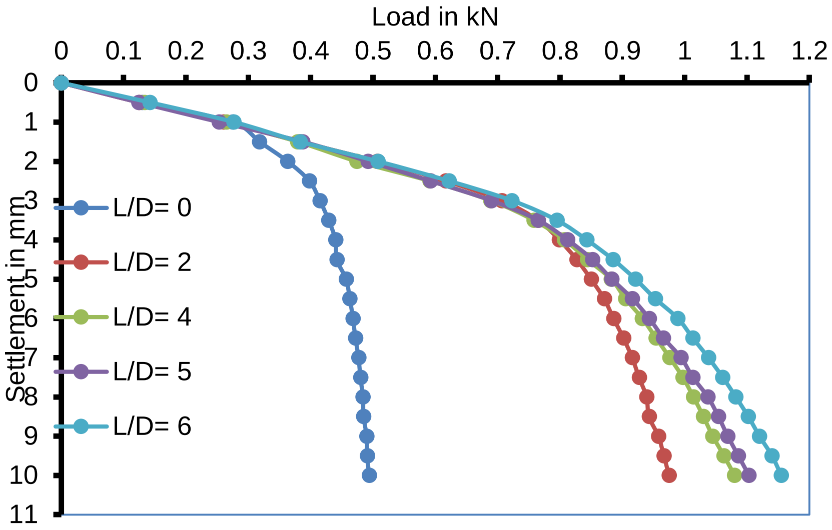


Figure: 11 Load Vs Settlement for 70 mm Plate & Stone Column at 10mm prescribed settlement

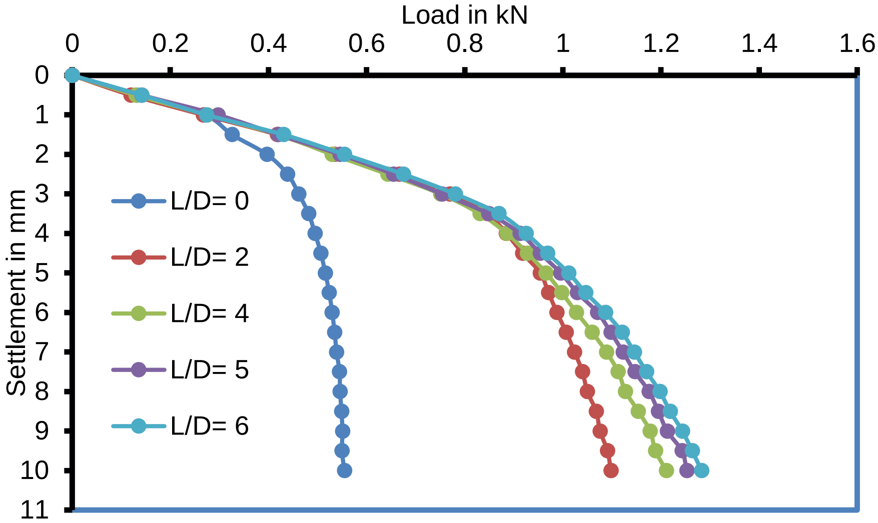


Figure: 12 Load Vs Settlement for 75 mm Plate & Stone Column at 10mm prescribed settlement

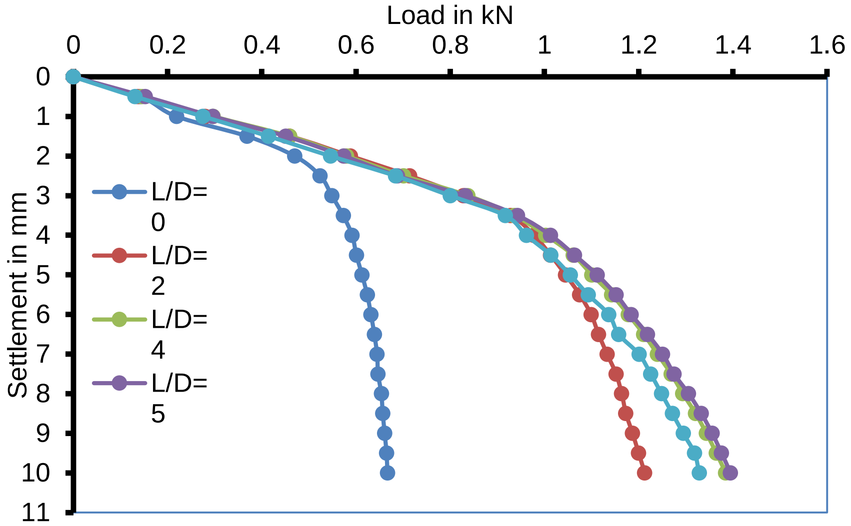


Figure 13: Load Vs Settlement for 80 mm Plate & Stone Column at 10mm prescribed settlement

Table: 4 Load carrying capacity of stone column with different diameter and with different L/D ratio

L/d	45 mm diameter		50 mm diameter		55 mm diameter		60 mm diameter	
	Load in kN	Improvment ratio	Load in kN	Improvement ratio	Load in kN	Improvement ratio	Load in kN	Improvement ratio
0	0.298	1	0.346	1	0.390	1.000	0.430	1.000
2	0.517	1.73	0.525	1.52	0.636	1.631	0.719	1.672
4	0.525	1.02	0.623	1.19	0.725	1.859	0.844	1.963
5	0.647	1.23	0.647	1.04	0.720	1.846	0.836	1.944
6	0.703	1.09	0.629	0.97	0.757	1.941	0.844	1.963

L/d	65 mm diameter		70 mm diameter		75 mm diameter		80 mm diameter	
	Load (kN)	Improvement ratio	Load (kN)	Improvement ratio	Load (kN)	Improvement ratio	Load (kN)	Improvement ratio
0	0.463	1.00	0.494	1.00	0.555	1.00	0.667	1.000
2	0.852	1.84	0.975	1.97	1.098	1.98	1.213	1.819
4	0.952	1.12	1.080	2.19	1.211	2.18	1.385	2.076
5	0.969	1.02	1.103	1.13	1.253	2.258	1.395	2.091
6	0.947	0.98	1.155	1.07	1.222	2.202	1.329	1.993

The graph and tabulated values indicate the load settlement behaviour at 10mm prescribed displacement. There may be no ultimate failure limit occurs. The load vs. displacement response was measured with different L/d ratio as 0 (only clay bed loaded), 2, 4, 5, and 6.

III. FUTURE SCOPE

One of the major problem occurs when treating soft soil with ordinary stone column is that the stone column aggregate dispers in to the surrounding soil while applying vertical loading. This may results in to failure of ordinary stone column. Further research needed to improve such soft soil to control the dispertion of stone column aggregate into surrounding soil so that the load capacity of stone column can be increase.

IV. CONCLUSIONS

The major conclusions that can be drawn from the present study are as follows:

1. Inclusion of granular stone column material considerably improves the load-settlement characteristics of soft clay. The load carrying capacity of clay bed reinforced with stone column is increased about 2 times the load capacity of untreated claybed measured at 10 mm displacement.
2. As increasing the L/d ratio of the stone columns, the load carry response increases. But the response effective up to the depth of L/d ratio ranging from 4 to 5, beyond increasing the L/d ratio will not improve the settlement characteristics.
3. With increase the diameter of stone column the load carry response increases.

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