Research Article

A Study On Effects Of Length To Diameter Ratio On Settlement Behavior Of Floating Stone Column

Himmat Sarvaiya

Assistant Professor, Applied Mechanics Department, Lukhdhirji Engineering College, Morbi, Gujarat, India

Article History: Received: 10 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 16 April 2021

Abstract : This research aims to examine the effect of the length to diameter ratio of the floating stone column on settlement behavior. The load vs settlement labouratory tests are performed with the length to diameter ratio of floating stone column as 0, 2, 4, 5, and 6 of the stone column to find the corresponding settlement behavior. This research finding shows that the load-carrying capacity of the floating stone column increases with the increasing length to diameter ratio of the floating stone column up to a certain limit. Beyond that limit the load-carrying –capacity is not increased even by increasing the length of the stone column. This research is very helpful in the geotechnical engineering field where ground improvement work is required in the form of a stone column.

Keywords: Floating stone column, load vs settlement, load carrying –capacity, length to diameter ratio

INTRODUCTION

The stone column technique for ground improvement is widely used in India and all over the world. This technique is very effective to increase the bearing capacity of the soft soil compared to other field methods by considering the cost and its effectiveness Hughes J. M. O. (1974), Lee J. S. (1998), Pradip Das (2013). This research will directly impact the cost-effectiveness of this technique in the field of geotechnical engineering. To find the effect of the L/D ratio on the settlement behavior of the floating stone column, the diameter of the stone column is kept constant as 60 mm, and the L/D ratio changes to 0, 2, 4, 5, and 6. The zero L/D ratio means the loading is applied on the soil itself without any stone column inclusion. The test results are plotted as load vs settlement in the graphical form.

EXPERIMENTAL CONSIDERATIONS

A unit-cell idealization is used for the present study to simplify the actual phenomenon working behind the stone column method. The actual field stone column installation there to scale down to understand the exact behavior of the stone column in the laboratory as shown in figure 2. The laboratory unit-cell is modeled as a cylindrical steel tank having rigid and smooth inside boundary so that when a stone column is installed in the middle of a unit cell is represented as symmetry in all directions. The area influencing the stress due to the installation of the stone column is considered a unit-cell area. There is a no-stress beyond the boundary of the unit cell tank. This concept is used to predict the load settlement behavior of stone columns (Ali K. 2012, Ambily A. P 2007, Bora, Mukul C. 2010, Shivashankar R., (2011), IS 15284-part 1- 2003).

According to IS 15284 (part 1): 2003, the influence of load is within the equivalent diameter. The triangular pattern is considered to design the unit cell tank. A cylindrical unit-cell tank of 300 mm diameter and 600 mm height is used for load tests on a single stone column.

MODELING CONSIDERATION

The model test setup was designed similarly as done by Ambily AP 2007 and Gniel J. 2009. Important details related to boundaries, dimensions, materials, and loading conditions in the model are given due consideration as presented subsequently. A typical prototype stone column diameter varies from 0.6 to 1.0 m and length from 5-20 m. usually; the L/D ratio in the prototype stone column varies 5 to 20, in which L and D are the column length and diameter respectively. Based on this, the L/D ratio in the model test was adopted from 3 to 10. The model tank boundary for load tests was selected on the unit cell-based approach.

In the field, stone columns are formed at a typical diameter (d) range of 0.6 to 1 m, with a typical particle size (D) range of 25 to 50 mm, so that the ratio d/D typically lies between 12 to 40 (3). The column diameters used in the present model tests are 60 mm and the stone column aggregate of size passing from 10 mm and retained from 2 mm sieve size were used to prepare the stone column. The mean particle size (D_{50} = 1.5 mm) is used for the construction of the model stone column. The ratio d/D (column diameter/ mean particle size) in present model tests is 36.67 (corresponding to column diameter 60 mm).

MATERIALS PROPERTIES

The soil used is of CL type based on modified soli classification system and collected at a depth of 2 m, from SVNIT college campus, Surat, Gujarat, India. Collected clay was air-dried and pulverized. The pulverized clay was sieved through a 2 mm sieve for easy mixing and quicker hydration. The particle size distribution is shown in fig. 2. A series of undrained shear strength tests were carried out to determine the water content corresponding to undrained shear strength 30 kPa of clay. The resulting water content of the clay was found to be 30%. This amount of water content was kept the same in all tests. Other properties of clay soil are given in table 1.

Table 1: Properties of clay

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/m^3)	: 17
Optimum Moisture Content (%)	: 18
Undrained Shear Strength kPa	: 30
Bulk unit weight at 32% water content	: 18.5 kN/m^3

Crushed stones (aggregates) of size below 10 mm have been used to form a stone column. The aggregate size distribution is shown in Figure 1. The finer fraction passing through 2 mm was removed by sieving and used after air drying. Typical properties of aggregate used as stone column material are summarized in table 2.

Table 2: Properties of stone column material

The angle of internal friction (Deg.)	: 42°
Particle size mm	: 2-10 mm
Uniformity coefficient	: 2
Coefficient of curvature	: 1.125
Specific gravity	: 2.75
Dry unit weight kN/m^3	: 18.5
Unified classification system	: GP

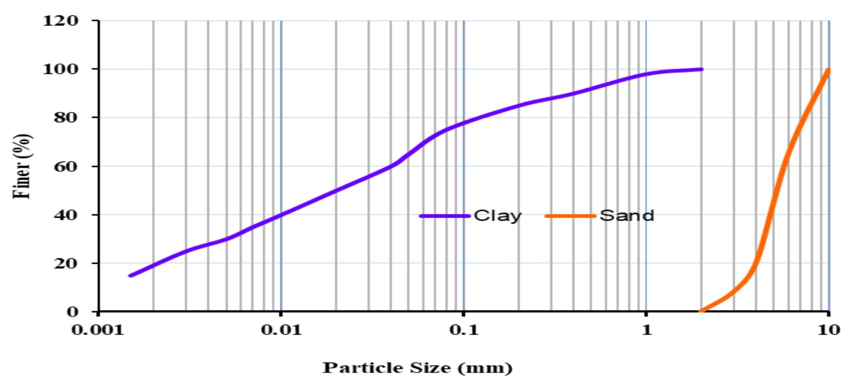

Figure 1: Grain size distribution of clay and stone aggregate for laboratory model test

PREPARATION OF CLAY BED

A series of unconfined compressive strength (UCS) tests are 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. The resulting water content of the clay is found to be 30%. This amount of water content is kept the same in all tests.

In all the tests, the identical technique is adopted to prepare the clay bed. To maintain similar properties throughout the tests, a clay bed is prepared at 30% water content. The bulk unit weight at 30% water content is found to be 18 kN/m3. Before filling the tank with clay, a thin coat of grease at the inner surface of the tank wall is applied to reduce the friction between the clay and the tank wall. The soil is filled in the tank in 5 layers with measured quantity by weight. Each layer was subjected to uniform compaction by hand to achieve 120 mm height and the corresponding unit weight. The stone column is constructed by the replacement method. Thin open-ended seamless steel pipes of 60 mm outer diameter and wall thickness 2.5 mm are used to construct the stone column. The outer surface of the pipe is lubricated by applying a thin layer of grease for easy penetration and withdrawal without any significant disturbance to the surrounding soil. For an ordinary stone column, a casing pipe is pushed into the soil along with a base plate having a circular groove to accommodate the casing pipe to prevent the soil from entering the pipe during the installation. When the casing pipe is pulled out, the base plate remains in the soil. Stones aggregates are charged into the hole in layers in measured quantities to achieve a compacted height of 120 mm. The pipe is 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 is done with a 2 kg circular steel bar with 10 blows of 100 mm drop to each layer. This light compaction effort is adopted to ensure that there is no significant lateral bulging of the column which creates a disturbance to the surrounding soft soil. The unit weight of stone columns is estimated with the quantity of aggregate consumed for the construction and the volume of the stone column. The corresponding unit weight of the stone column was found to be 18 kN/ m3. The procedure was repeated until the column was completed up to the full required height.

TEST PROCEDURE

A typical test arrangement for ordinary and reinforced stone column is shown in Fig. 3. All the experiments are conducted on floating stone columns in homogeneous clay beds in unit cell tanks. The load-settlement behaviour of stone column encased with and without using geosynthetics has been studied by applying the vertically load over it with the help of triaxial testing machine as shown in fig. 3. The vertical load was applied through a triaxial testing machine at constant displacement rate of 0.24 mm/min. the displacement rate chosen so as to avoid any possibility of squeezing out of soil particle from the clay bed and to avoid the generation of extra pore pressure in the clay bed. The approx. 5 mm seating load was applied before counting the actual settlement. The steel plate of 10mm thickness and diameter equals to the diameter of stone column was used to transfer the uniformly distributed load over stone column. The plate was directly rested over the stone column and the uniform loading was applied over the steel plate. The corresponding deformation is measured with the help of LVDT.

The stone column was constructed by a replacement method. After the soft soil bed was prepared, a casing pipe having an outer diameter equal to the diameter of the stone column was used to install the stone column. Thin open-ended seamless steel pipes of 60 mm outer diameter and 2 mm thick were used in the present study. The casing pipe pushed into the clay bed up to the required depth. In the case of the encased stone column, the encasement was provided around the casing pipe. The only static force was manually applied to push the casing pipe gently into the soil so as to minimize the disturbance in the clay soil that may change the properties of the clay after reinforcement.

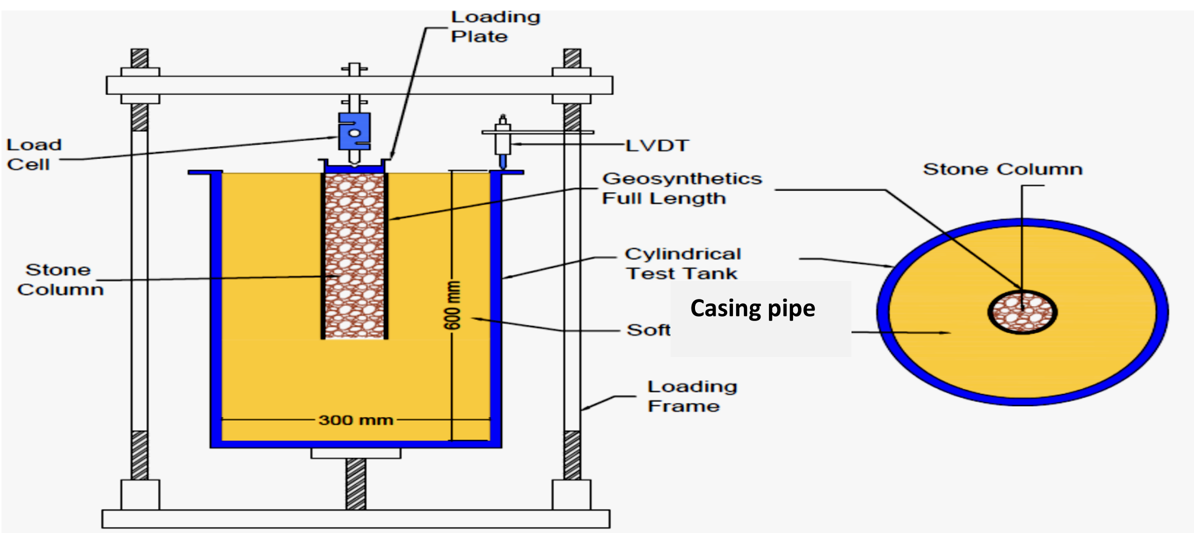

Figure 2: Schematic diagram for load test on single stone column in a unit cell

The outer surface of the pipe was lubricated by applying a thin layer of grease for easy withdrawal without any significant disturbance to the surrounding soil. The stone column aggregate material soaked for 24 hours before charging into the casing pipe in order to prevent it from absorbing the moisture from the surrounding clay soil. The stone column aggregate material was charged into the hole through casing pipe in layers in measured quantities so as to have each compacted fill layer of 50 mm thickness. A layer was compacted by a 2 kg circular steel tamper with 10 blows of a 100 mm drop to achieve uniform compacted density. This light compaction effort was adopted to ensure that there is no significant lateral bulging of the stone column which may create a disturbance to the surrounding soft clay. The corresponding unit weight was found to be 18.5 kN/m3. The casing pipe was then raised in stages ensuring a minimum of 5 mm penetration below the top level of the placed material. The procedure was repeated until the stone column was completed to the required depth as shown in figure 3.

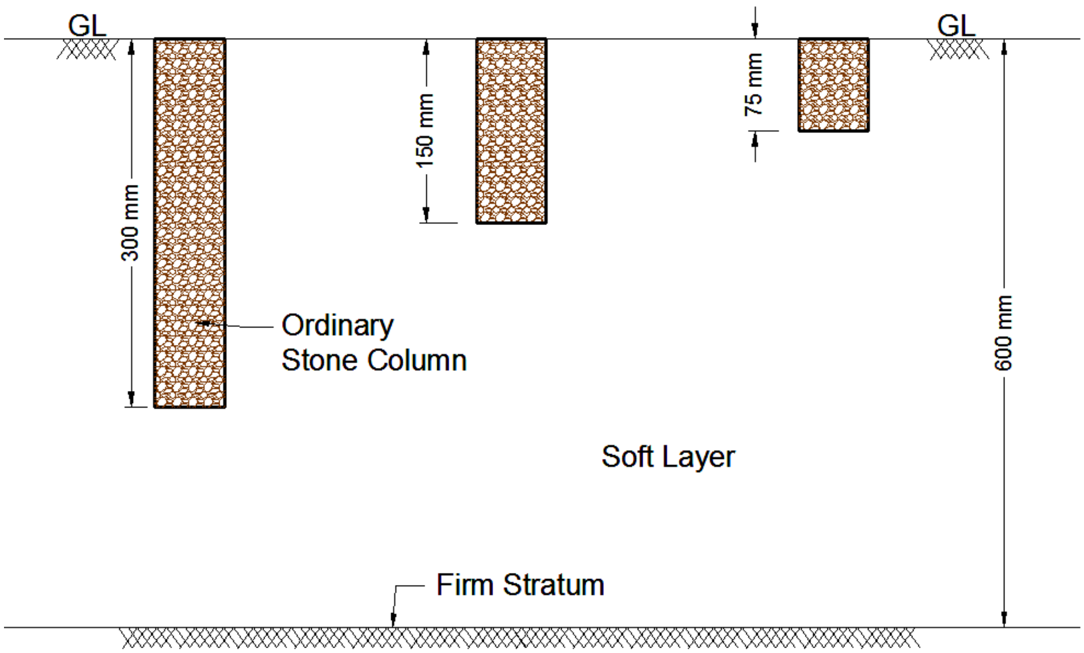

Figure 3: Laboratory model consideration for floating Stone column with different length consideration

EXPERIMENTAL PROGRAM

There are series of load tests performed to check the load settlement behavior of the floating stone column. Table 3 shows the list of an experiment performed to check the effects of length to diameter ratio of floating stone column on the load settlement behavior. To know the effect of the L/D ratio on the settlement behavior of floating stone column the diameter of the stone column is kept constant as 60 mm and the length of the floating stone column are changed as L/D ratio 0, 2, 4, 5, and 6 as listed in table 3.

Table 3. List of laboratory experiment to find the effects of L/d ratio on settlement behavior of floating stone column

Dia. of stone column	**L/D ratio of stone column**				
60 mm	0	2	4	5	6

RESULTS AND DISCUSSIONS

The laboratory experiments to find the effects of the L/D ratio on settlement behavior of floating stone column is shown in table 3 the diameter of floating stone columns is kept constant as 60 mm corresponding plate diameter is the same as the diameter of the floating stone column and the L/D ratio varying as 0, 2, 4, 5 and 6. The results show a significant improvement in load carrying capacity by inserting a floating stone column in a clay bed.

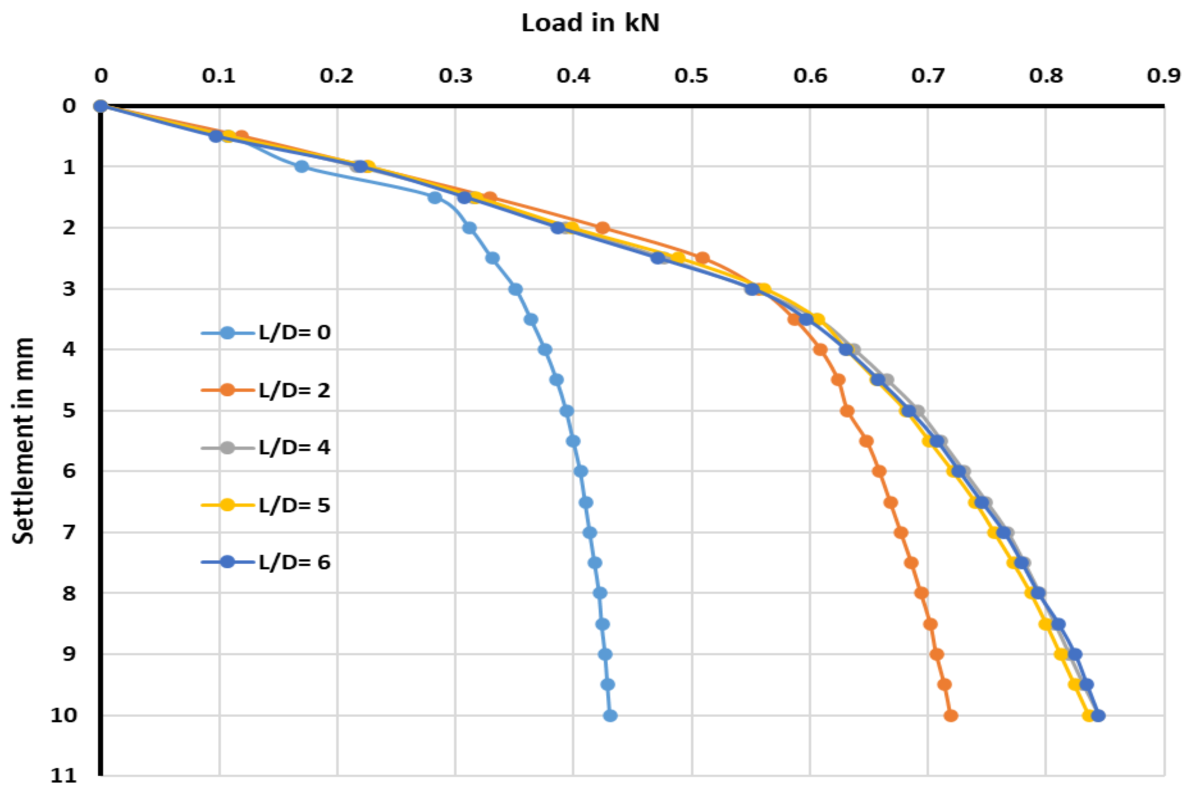

Figure 4: Load Vs Settlement for 60 mm Plate & Floating Stone Column at 10 mm prescribed settlement

For applying a load to the floating stone column, a loading plate corresponding to the column diameter is used for the same as the diameter of the stone column. The plate is exactly placed over the stone column at the center of the stone column and the load is applied for up to 40 mm settlement. The load is measured and compared at 10 mm prescribed settlement in each case of varying L/D ratio. Figure 4 shows the results obtained by performing a laboratory test to know the effects of the L/D ratio on the settlement behavior of the floating stone column.

CONCLUSION

The experimental results clearly show that by inserting the stone column the load-carrying capacity is increasing. The load-carrying capacity of the floating stone column for the L/D ratio 0, 2, 4, 5, and 6 at 10 mm prescribed settlement is observed as 0.43 kN, 0.72 kN, 0.84 kN, 0.84 kN, and 0.83 kN respectively as shown in figure 4. The results show that without inserting stone column the load-carrying capacity measured as 0.43 kN but when inserting stone column with varying length the load-carrying capacity is increasing. There is no further improvement observed beyond the L/D ratio 5. So it can be concluded that the effective L/D ratio for the stone column technique is 5. Further increasing the length of the stone column will unnecessarily increase the cost of the field project.

REFERENCES

1. Ali K., J. T. Shahu and K. G. Sharma (2012). *Model tests on geosynthetic-reinforced stone columns: a comparative study*, vol. 19, No. 4, (pp. 292–305). Geosynthetics International.
2. GABER, G. A. MECHANICAL PROPERTIES AND CORROSION BEHAVIOR OF REINFORCING STEEL IN DIFFERENT CEMENT WITH ADDITION OF NANO-SILICA ON BLENDED CEMENTIN TAP WATER.
3. Ambily A. P., Gandhi S. R. (2007). *Behavior of stone columns based on experimental and FEM analysis*, 133(4), (pp. 405–415). J. Geotech. Geoenvironmental Engineering ASCE.
4. HADDAD, J. S. EXPERIMENTAL STUDY OF THE EFFECT OF BALL DIAMETER, ROTATING MASS AND INPUT GRAIN SIZE OF SILICA SAND ON THE EFFICIENCY OF MILLING IN VERTICAL VIBRATING MILL.

5. Bora, Mukul C, Dash, Sujit Kumar (2010), *Load Deformation Behaviour of Floating Stone Columns in Soft Clay*, (pp. 251-254). IGS Mumbai Chapter & IIT Bombay.
6. AL-DEEN, D. H. J., HOBIHALEEM, A., & KHILFE, A. H. STUDYING THE PROPERTIES OF COCRMO (F75) DOPED Y USING (PM). *Carbon*, *99*(37.44), 0-35.
7. Gniel J, Bouazza A., (2009), *Improvement of soft soils using geogrid encased stone columns,* 27, (pp. 167–175). J Geotextiles Geomembrane.
8. Hughes J. M. O. and Withers N. J. (1974). *Reinforcing of Soft Cohesive Soils with Stone Columns,* Vol.7, No.3, (pp. 42-49).Ground Engineering,
9. RENU, S. L., & BHARDWAJ, S. TO STUDY THE GENETIC VARIABILITY IN C. CORONARIUM AND ITS DIFFERENT MUTANTS.
10. IS 15284-part 1 (2003), *Design and construction for ground improvement — guidelines for stone column.*
11. Lee J. S., Pande G. N., (1998). *Analysis of stone-column reinforced foundations*. 12, (pp. 1001-1020). International Journal for Numerical and Analytical Methods in Geomechanics.
12. Khan, S. A., Aabid, A., & Baig, M. A. A. (2018). CFD analysis of CD nozzle and effect of nozzle pressure ratio on pressure and velocity for suddenly expanded flows. *International Journal of Mechanical and Production Engineering Research and Development*, *8*, 1147-1158.
13. Pradip Das, Sujit Kumar Pal (2013). A *Study of the Behavior of Stone Column in Local Soft and Loose Layered Soil,* Vol. 18: (pp. 1777-1786). Electronic Journal of Geotechnical Engineering.
14. Shivashankar R., Dheerendra Babu M. R., Sitaram Nayak, V. Rajathkumar (2011). *Experimental Studies on Behavior of Stone Columns in Layered Soils*. vol:29, (pp. 749–757). Geotechnical and Geological Engineering
15. Szoka, A. N. N. A., Gajowiec, G. R. Z. E. G. O. R. Z., Serbinski, W. A. L. D. E. M. A. R., & Zielinski, A. N. D. R. Z. E. J. (2016). Effect of surface state and stress on an oxidation of the zircaloy-2 alloy. *Intl J Manag Inform Techn Eng*, *4*, 55-64.