Settlement Characteristics of Stone Column on Saturated Soil

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Abstract – *Construction of structures in soft soils are difficult due to change in properties of overlying soil. These may include change in water content, shear strength, and void ratio. Construction of road, railways embankments over a soft soil needs special consideration due to the change in the overlying soil characteristics which may led to settlement of the structure. Soft clays are characterized by low shear strength, high compressibility and low bearing capacity. Consolidation is one of the problems in soil engineering. During consolidation of soft clays under loading, large ground settlements take place over long periods of time owing to low permeability of clays. So, it is necessary to avoid such damages by providing suitable vertical drains before construction.*

This paper presents the results obtained from the settlement characteristics of saturated bentonite clay using stone column as a vertical drain. The main objective of the study is to find the settlement character, discharge capacity and shear strength of bentonite clay with stone columns under different patterns. The study was carried out by changing the diameter of stone column and spacing of stone columns and patterns of column. Shear strength characteristics of clay was determined at different depths adjacent to the stone columns. Results shows that using stone column in saturated soil, settlement increases with 12% with increase in diameter, at decreased spacing. Decreased spacing accelerates the consolidation effects by improving the drainage path for pore water dissipation. Straight pattern has more effect on the settlement characteristics of stone column. Shear strength of the saturated soil increase to 4.7 % with the provision of stone column.

Keywords— Consolidation, Ground Improvement, Settlement, Shear Strength, Stone Column

1. INTRODUCTION

Construction of any structure on the ground requires a proper investigation about the site to be built. It mainly includes investigation about soil; its types type, and shear strength characteristics. Based on these results, if the soil is having suitable shear strength construction will proceed. Whereas if the soil is poor suitable ground modifications are made. When structures are constructed over highly compressible soil such as clay, settlement will occur after a long time. This may due to the consolidation character of the soil. Consolidation is the expulsion of pore water from clay under the application of steady static load. This results in reduction in volume causing settlement. Imposition of load from structures generates excess pore water pressure in soft layer. The load from the structure is initially taken up by the water molecules existing within the soft layer. As a result, a hydraulic gradient develops and slowly the water will ooze out of pore space depending upon permeability of soil. With the passage of time excess pore water pressure decreases and correspondingly the effective stresses in the layer increases.

As a result, consolidation process continues and soil gets compressed due the load transferring to the soil grains. Foundation of the structure would settle until the complete consolidation takes place. Irreparable damages will occur to structure under consolidation process. Because of low permeability and poor drainage characteristics of soft soil, it becomes essential to drain out pore water before construction begins otherwise, the added weight of new structure will cause water to squeeze out for a long period of time. Thus, settlement can be reduced before the newly construction over these soft soils. So, it would be better if major portion of this consolidation settlement takes place before/during construction phase itself.

The stone columns are constructed by making holes in the deposit and filling these holes with gravel (or small stones) of size 6 to 100 mm. Stone columns act as vertical drains, increasing rate of consolidation. They reinforce the soft soil deposit because it is replaced by strong stone columns at discrete points. The stiffness of the stone columns is very large as compared to that of the soft soil. A large portion of the superimposed load is carried by stone columns. Thus, the bearing capacity of the clay deposit is increased and the settlements are reduced.

This study involves use of stone column as a vertical drain in saturated soft soil. They are placed at a particular spacing. It is used as a technique for improving the shear strength and consolidation characteristics of soft clays. By providing stone column in saturated soil discharge capacity increase and it leads to settlement of surrounding soil. Also shear strength of the soil can be increased. Besides working as drains it also acts as a reinforcement to the soil because soft clays replace by these columns at discrete point.

2. OBJECTIVES AND SCOPE OF THE STUDY

Construction of structures over compressible soil is difficult due to the settlement problems. Damages are mainly due to long term consolidation settlement. So, it is better to avoid settlement after construction by providing suitable drains. By providing vertical drains along horizontal and vertical position settlement can be reduced at a faster rate. Consolidation can be achieved at a faster rate and settlement can be reduced before a newly construction at the site. The scope of this research was to investigate the settlement and discharge capacity of compressible soil with and without vertical drains and also to determine the change in shear characteristics of the soil. Also, to increase the bearing capacity of the compressible soil.

The aim of the study includes the following

- To determine the settlement characteristics of stone column in compressible soil
- To compare the settlement and discharge capacity of compressible soil along straight and zig-zag pattern.
- To find the shear strength variation of compressible soil near stone column.

3. MATERIALS

The materials required for the experiment includes bentonite clay, gravel, model tank, and footing. The details regarding the materials are given below.

3.1 Bentonite Clay

Foundation soil used for this study is bentonite clay of high plasticity. The bentonite was collected from Perumbavoor, Kerala. Clay has a fine texture. The grain size distribution was found using IS: 2720-part 4.

Table-1: Basic Properties of Bentonite Clay

Properties	Values
Specific gravity	2.22
Liquid Limit	190%
Plastic limit	52.6%
Plasticity index	137.4%
Soil type	CH
Dry unit Weight (g/cc)	1.16 g/cc
Optimum moisture content	48.9 %
Unconfined compressive Strength	66.22 kN/m^2

3.2 Gravel

Gravel of size 12mm is used for the study for the purpose of providing a vertical gravel column and for a horizontal drainage layer. The gravel was air dried before conducting all the laboratory tests.Gravel was collected from Thrissur.

Table -2: Basic Properties of Gravel

Properties	Values
Specific gravity	2.6
Aggregate crushing value	24%
Aggregate Impact value	15.75%
Water absorption	2.41%
Coefficient of curvature (Cc)	4.75
Uniformity coefficient (Cu)	2.43
Hardness Value	31.44%

3.3 Footing Plate

Footing plate used for plate load testing has a dimension of 15cm×15cm×1.6cm.

3.4 Tank

A square rigid test tank was fabricated using plain galvanized steel sheet of thickness 5mm .The tank is of size 500mm x 500mm x 750mm respectively. Stiffeners were provided on the outer sides and bottom of test tank to make it rigid. Outlets are provided at the bottom of the tank for the provision of discharge of water from the tank during the test. A container is used to collect the water drain out from the tank to find the discharge capacity. Model tests were conducted under axial conditions.

4. METHODOLOGY

Tests were carried out in two series. Physical and mechanical properties of materials in which the index properties such as specific gravity, grain size distribution and the consistency indices tests were carried out in first series. In the second series test was conducted to evaluate the effects of stone column. Experimental programme was conducted to study the settlement character of stone column under saturated condition of clay. This was achieved by conducting plate load test. Load –settlement response of stone column was determined by plate load test. The dimensions of the test tank for model testing are fixed based on boundary conditions. Shear strength variation over the depth of foundation soil near stone column was determined by conducting unconfined compressive strength test.

4.1 Filling of Test Tank

The selected soil for the study is bentonite clay which is highly compressible and it provides as a foundation soil. The clay bed for the tests was prepared in a large test tank of plan dimensions 0.5 m×0.5m and 0.75m in depth. The tank was first filled with a layer of gravel of 12mm diameter up to a thickness of 5cm. Then clay was weighed corresponding to maximum dry density. The test tank was marked 3 equal layers. The quantity of clay was calculated for each layer corresponding to the required dry density. Then filled this predetermined quantity of clay in each layer with a water content twice the value of optimum moisture content, then it is compacted and placed. Slurry in the test tank was allowed to consolidate for 3 days. Then vertical drains are installed along on the compressible soil with different materials.

4.2 Installation of Drains

The plan area of the tank is so selected that the loading on the stone column would not be affected by the tank boundaries. The vertical drains were installed by displacement method, and were extended down to the bottom of the tank. For this study various drains used are PVD, stone column, geomat encased stone column. These drains are installed along vertical direction and horizontal direction in order to determine the settlement effects, discharge capacity and shear characteristics of soil. Drains used were of length 0.4 m. A casing pipe having an outer diameter equal to the diameter of the drains was used to install the columns. The casing pipe was pushed into the soil till the bottom of the tank. Installation of encased column was done using two casing pipes.

The casing pipe along with the geosynthetic encasement was slowly pushed in to the clay bed vertically at the specified location in the clay surface in the tank until it reaches the bottom of the tank. The quantity of the stone aggregate required to form the stone column was premeasured and placed after removing the casing. The stone aggregate was moistened before charging into the casing pipe in order to prevent it from absorbing the moisture from the surrounding clay soil. After placing the column, clay bed was leveled and steel plate was placed at the top of bed. The loading plate used in the tests is of square plate with a dimension 20 x 20cm, so that the stone column along with contributory soil area of stone column is loaded the test tank was marked to equal layers. The quantity of sand was calculated for each layer corresponding to the required relative density. Then filled this predetermined quantity of sand in each layer with compaction using rammer. The sand was filled in layers up to the level where the tip of the piles was rest. Then pile was kept in correct embedment depth and position. Then filling of sand was continued till it reaches 2cm below pile cap bottom. The gap is provided for avoiding frictional resistance of bottom face of footing during loading. Then the top surface of sand bed was levelled.

4.3 Setting Load Measurement

After preparing the test tank, the hydraulic jack was clamped to the reaction frame and its hose was connected to the lever system. The load was applied to the loading plate by using rigid reaction frame through the hydraulic jack and proving ring. A calibrated proving ring of 100 KN and dial gauge of 25 mm capacity with sensitivity of 0.01 mm is used for measuring loads and settlement respectively. The proving ring and dial gauge are set to zero before the testing was started. Settlement corresponding to each load increment was observed. After conducting the plate load test samples from 3 layers were collected to determine the variation in shear strength. Also discharge capacity during each installation of drains were observed. The proving ring and dial gauge are set to zero before the testing was started. The test was started by applying load using hand operated hydraulic jack. The pile was loaded at a constant loading rate until an ultimate bearing state was reached. The behavior of piled raft was obtained by plotting the graph between vertical displacement and axial load. Final load at which the piled raft stops taking further load is taken as the ultimate axial load capacity of the footing.

Fig -1: Loading setup

5. RESULTS

Study was conducted by using plate load test .For this stone columns were arranged in different patterns and at different spacing with varying diameter. The test results of axial load test on stone columns are given below. Also test were conducted to determine shear strength variation of the soil near the stone column by collecting sample from the test tank.

5.1 Load –Settlement Graphs for Spacing

Chart 1 shows the load settlement characteristics of compressible soil with 2cm dia. stone column installed along straight pattern with spacing of 10 cm and 20 cm.

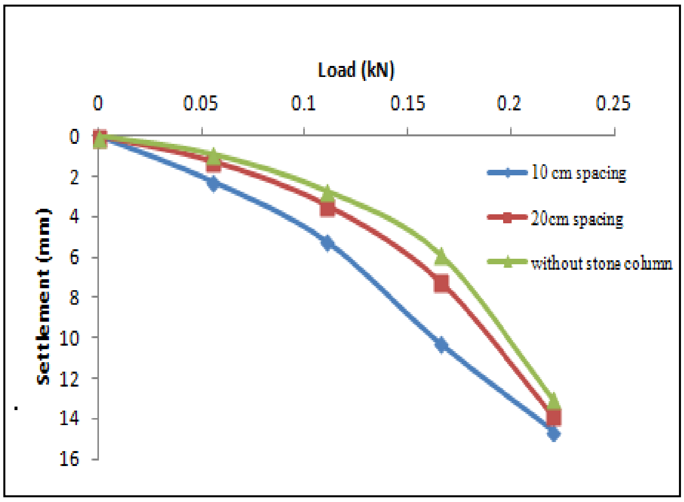


Chart -1: Load Settlement curve for 2cm dia. column

From the chart 1, it is observed settlement increases with decreasing spacing. The initial settlement of clay bed at a particular axial loading was found to be 13.4mm. When stone column of 2cm diameter was provided at a spacing of 10cm and 20cm, settlement was found to be 14.6mm and 13.9mm. Under application of load, discharge takes place which leads to settlement of soil

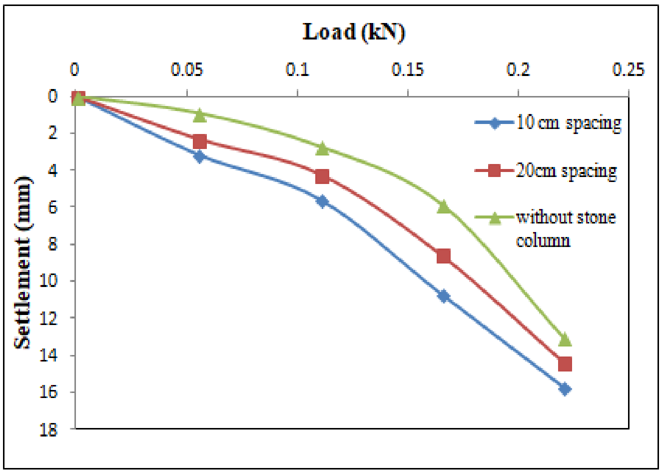
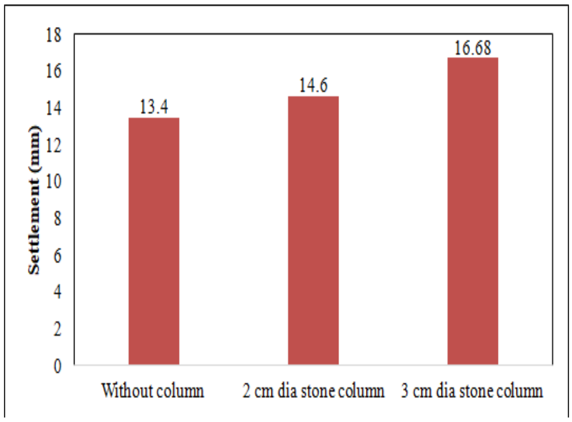


Chart -2: Load Settlement curve for 3cm dia. column

It is clear from chart 2, with increase in spacing settlement was found to be decreased for 3cm dia. Settlement increases with increase in diameter and decreases with spacing. The discharge capacity is found to be increased with diameter.

Variation of maximum settlement for 2cm and 3cm diameter stone column is shown in chart 3.



5.2 Load –Settlement Graph for Patterns

Columns were installed at straight and zig-zag patterns for 2cm diameter column. Load settlement curve for 2cm diameter column along straight and zig-zag pattern is shown in chart 1 and chart 4.

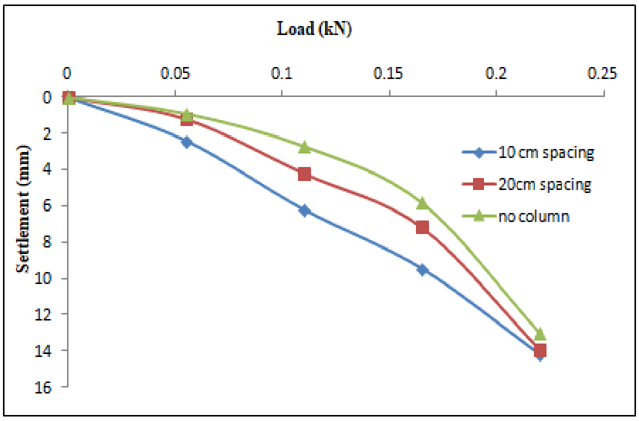


Chart- 4 : Load settlement curve for 2cm dia. column zig-zag pattern

Settlement of column at 10cm spacing for straight and zig- zag pattern was found to be 14.6 mm and 14.2mm. For 20cm spacing settlement was found to be 13.8mm and 13.6mm for straight and zig-zag pattern. Also discharge capacity is found to be more in case of straight pattern due more number of stone columns. From the above graph it can be observed that straight pattern is more effective than zig-zag pattern for 2cm diameter stone column.

Variation of settlement of 2cm diameter column along straight and zig-zag pattern is shown in chart 4.

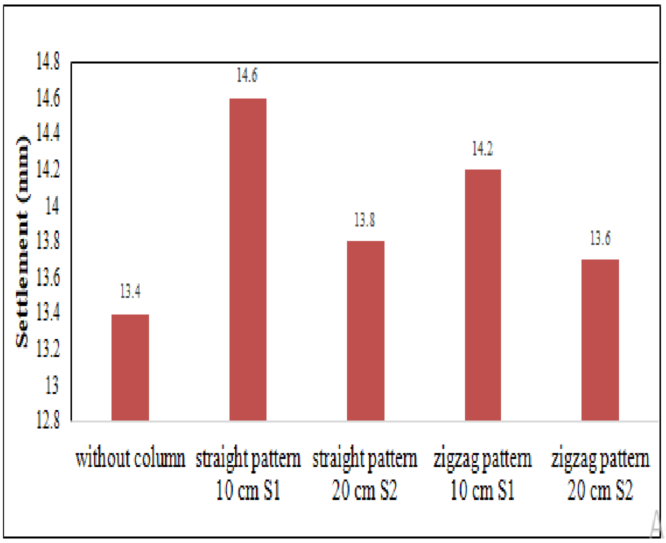


Chart-5 : Settlement characteristics of 2cm dia. stone column

The chart 5 shows settlement behaviour of compressible soil with and without column. There is a decrease in settlement rate with increase in spacing for both patterns. Also, settlement rate increased with installation of column. From the above graph it can be observed that straight pattern is more effective than zig-zag pattern.

5.3 Shear Strength Behavior of Compressible Soil

Chart 6 shows the shear strength character of saturated clay with and without stone columns. Shear strength of the saturated clay was found to be 61.22kN/m^2.

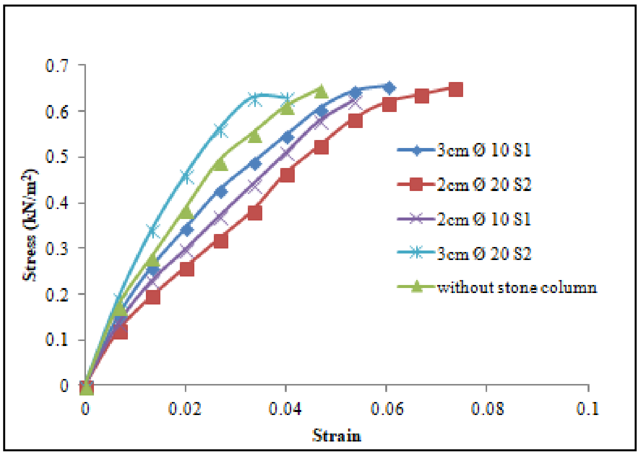


Chart -6: Stress Vs strain

Shear strength of saturated clay increase upto 3% when stone column of 2cm diameter was placed at a spacing of 10 cm and 2.7% for 20cm spacing. For 3cm diameter stone column shear strength was found to be 4.7% at 10cm spacing and 3%for 20cm spacing. Variation of shear strength characteristics of compressible soil with and without stone column for different diameter is shown in chart 7.

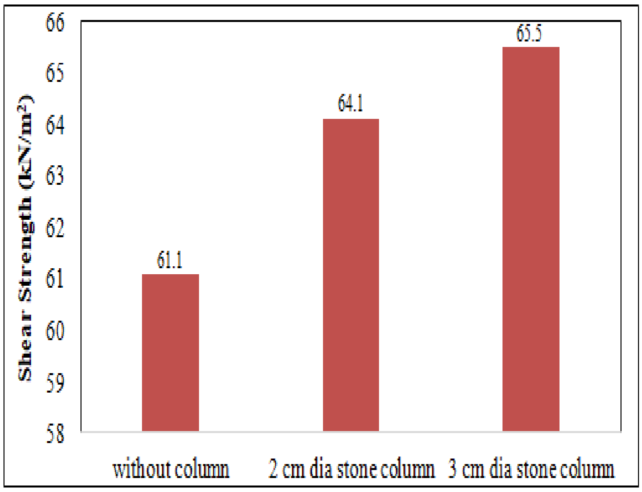


Chart -7: Variation of shear characteristics of compressible soil

Shear strength is maximum for 2cm and 3cm diameter column at a spacing of 10cm.the strength was found to be

64.1 kN/m^2 and 65.5 kN/m^2. Thus there is an increase of strength of saturated soil to 65.5 kN/m^2

6. CONCLUSIONS

Following conclusions are derived from the study of stone columns on compressible soil.

- With inclusion of stone column settlement of the compressible soil has found to be increased.
- With increase in diameter the settlement of the column was found to be 7%.
- With decrease in spacing the settlement rate was found to be 8.6%.
- Discharge capacity of the column increases with increase in diameter
- Straight pattern has 3% more settlement rate than zig-zag pattern for 3cm diameter stone column and 1.4% for 2 cm diameter column.
- Shear strength of soil increase up to 2.7% for 2 cm dia stone column and 4.7% for 3 cm dia stone column.
- Shear strength of the saturated soil increases to 12% with the provision of stone column. Straight pattern is found to be very effective.

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