International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 3 Mar. 2025, pp: 650-656 www.ijaem.net ISSN: 2395-5252

Ground Improvement by Stone Columns - A Brief Review and Routine Single Load Test on Stone Columns

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Abstract

A stone column is a ground improvement technique used in geotechnical engineering to enhance the load-bearing capacity and drainage properties of weak or soft soils. These columns are formed by inserting compacted crushed stone or gravel into the ground, creating vertical reinforcement elements. The application of sites containing low-strength soil deposits is of great concern concerning the rapid increase in urbanization and industrialization. To overcome such difficulties in construction, ground improvement techniques are frequently practiced. The provision of the stone column is one of the well-known approaches to improve the weak soil properties. Moreover, the application of reinforced stone columns is chosen over the conventional method of stone columns to enhance the strength and durability parameters of weak soils to a greater extent.

This paper presents a review about the Stone Column, their Construction Technique and Basic Design Aspects and discussion of Field Routine Single Column Test on a Stone Columns.

Keywords: Stone column, Ground improvement, Geosynthetics, Soft soils, Cohesionless Soil, Routine Single Column Test.

I. Introduction:

Stone columns are a widely used ground improvement technique that enhances the load-bearing capacity, stability, and drainage properties of weak soils. They are constructed by inserting crushed stone or gravel into the ground using vibro-replacement or vibro-displacement methods, creating stiff, vertically reinforced columns within the soil mass. Stone columns effectively reduce settlement, improve shear strength and accelerate consolidation by facilitating rapid drainage of excess pore water. Their applications span across various civil engineering projects, including foundation support for buildings, highways, and railway embankments, as well as liquefaction mitigation in earthquake-prone regions. Additionally, they are used in offshore and marine engineering to stabilize soft seabed soils for port infrastructure and wind farm foundations. The introduction of geosynthetic-encased stone columns has further expanded their use in extremely soft clays, ensuring greater lateral confinement and improved performance.

II. Application/Functions of Stone Columns:

a) **Soil Stabilization** – Improves weak soils like clay, silt and loose sand by providing additional strength.
b) **Load-Bearing Capacity** – Increases the foundation's ability to support heavy structures by reducing settlement.
c) **Drainage Enhancement** – Acts as a vertical drain, accelerating the consolidation of soft, water-saturated soils.
d) **Liquefaction Mitigation** – Reduces the risk of soil liquefaction in earthquake-prone areas by increasing soil density.
e) **Reduction of Differential Settlement** – Helps distribute loads more evenly, preventing uneven settlement of structures.
f) **Eco-Friendly Alternative** – Reduces the need for deep foundations like piles, making it a cost-effective and environmentally friendly solution.

III. Construction Techniques of Stone Column:

The construction methods for stone columns include the following. Each method is chosen based on soil conditions, project requirements and environmental factors.

3.1 Vibro-Replacement (Wet Method)

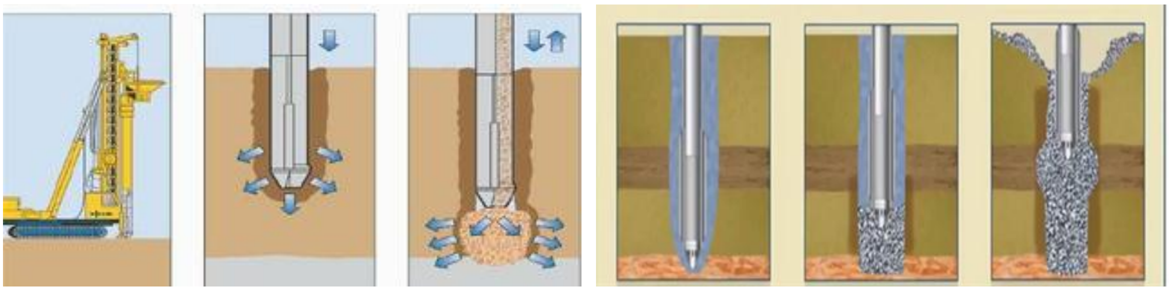
This method is used in soft, cohesive soils with high moisture content. A vibroflot (vibratory probe) is inserted into the ground using water jets. The soil is displaced and coarse aggregates (crushed stones or gravel) are fed into the cavity. The vibroflot compacts the stone column from bottom to top by vibrating and re-penetrating. Water helps in flushing out fine materials and assists in penetration. The top-feed method requires water for the installation, therefore, it is often referred to as a wet method.

3.2 Vibro-Displacement (Dry Method)

This method is suitable for granular soils or soils with low moisture content. In this method a vibroflot penetrates the soil without the use of water jets. Stones are added progressively and compacted using the vibroflot (Figure 1) This method avoids excess water usage and usually uses air instead of water therefore, it is often referred to as a dry method.

3.3 Rammed Stone Column (Dry Bottom Feed Method)

Rammed aggregate columns are installed by drilling a hole into the ground, backfilling it aggregates and ramming it. The method uses a displacement tool or mandrel to create a cavity in the ground. Crushed stone is fed through a bottom-feed system without the need for pre-excavation. The mandrel compacts the stone in layers as it is withdrawn. This method is suitable for low-strength and liquefiable soils (Figure 1).



Bottom Feed Process **Top feed process**

Figure 1: Construction Technique of Stone Column

IV. Basic Design Parameters of Stone Column:

The basic design parameters of stone columns depends upon the

a) **Soil Type**: Clay, silt, loose sand etc.

b) **Shear Strength (Cu):** Typically, stone columns are used in soils with Cu < 50 kPa.

c) **Groundwater Level:** Affects drainage and consolidation.

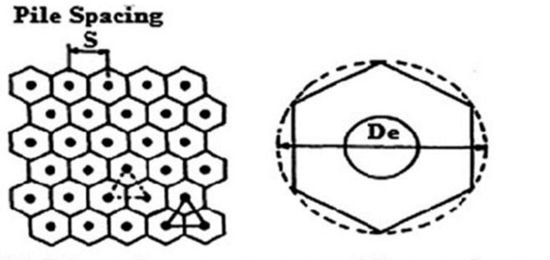
d) **Loading Conditions:** Structural loads, embankment loads etc.

4.1 Stone Column Diameter, D

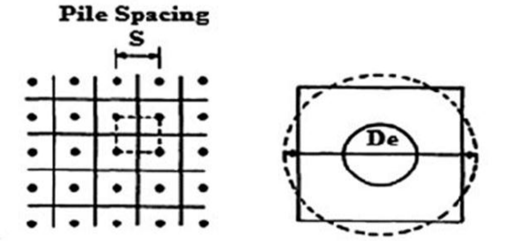
In vibro-flot method, the stone column diameter varies between 0.6 m in case of stiff clays to 1.1 m in very soft cohesive soils. The stone column diameter constructed by wet technique is bigger than that of a dry technique (1). Due to lateral displacement of stones during vibrations/ramming, the completed diameter of the hole is always greater than the initial diameter of the probe or the casing depending upon the soil type, its undrained shear strength, stone size, characteristics of the vibrating probe/rammer used and the construction method.

4.2 Pattern and Spacing

The square pattern or triangular pattern are possible installation patterns of stone column. But the most optimum and desirable installed shape is the triangular pattern since it gives the most dense and compacted packing of stone columns in a given area. The layouts of these two patterns are shown in Fig. 4.



(a) Triangular arrangement of Stone columns



(b) Square arrangement of Stone columns

Figure 2: Layouts of Stone Columns

4.3 Equivalent Diameter

The tributary area of the soil surrounding stone column forms regular hexagon around the column. It may be closely approximated by an equivalent circular area having the same total area (Figure 2). The equivalent circle has an effective diameter (De) which is given by following equation:

De = 1.05 S for an equilateral Triangular 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.

4.4 Replacement Ratio

The area of the stone column after compaction (As) to the total area within the unit cell (A) where D and De are diameter of stone and triangular pattern respectively (2) (Figure 2). is called as Replacement Ratio a_s. It quantify the volume of soil substituted by the stone column. The area replacement ratio ($a_{s)}$ is given by.

a_s = As / A
Where,
As = Area of Stone Column
A = Total area within cell

It is recommended that to improve bearing capacity of treated ground significantly by stone column, the area replacement ratio shall be more than 0.25 or greater (3).

V. Load Carrying Capacity of a Stone Column

The ultimate load capacity of single column is determined from load tests with reasonable accuracy. The settlement of a stone column obtained at safe/ working load from load test results on a single column should not be directly used in forecasting the settlement of the structure.

Method of Stone Column Load Test:

a) The load tests on stone column shall be performed at a trial test site to evaluate the load-settlerment behaviour of the soil-stone column system. The tests may be conducted either on a single column or on a group of minimum three columns.

b) For the load tests, a minimum of seven columns for a single column test and twelve columns for three column group test are constructed for triangular pattern as shown in Figure 3.

c) The diameter of the circular concrete footing or equivalent steel plate of adequate thickness and rigidity may be based centrally on the effective tributary soil area of stone column for a single column test and three times the effective area of single column for a three column group test.

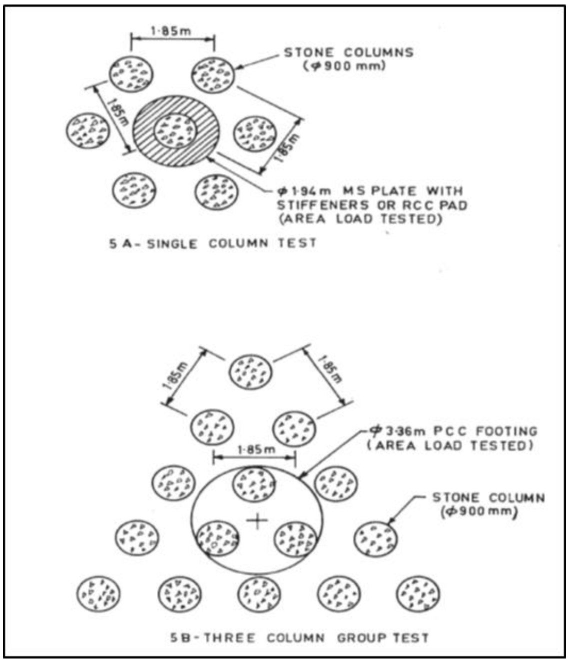


Figure 3: Arrangement of Columns for Load Test

VI. Case Study: Stone Column in Cohesionless soil to control the Settlement and Mitigate the Liquefaction Potential:

The present case study discuss the construction of stone columns at the foundation of a hydropower project. The foundation of the dam consists of the sand which have medium to dense compactness. Ground improvement was carried out using vibro stone column upto a depth of 10-17 m to mitigate liquefaction potential if any and to control settlements below the footprint of the dam.

The details of the vibro stone column scheme used for the ground improvement are given below.

Description	Parameter
Stone column diameter	900 mm
Pattern	Square
Spacing of Columns	2.0 m & 2.2 m c/c
Length of column from OGL	10-13 m & 17.0 m

Evaluation of Stone Column Performance

To evaluate the performance of the stone columns, the Routine Single Column Test was conducted.

Routine Single Column Test:

It was planned to test 10% the stone columns for the **Routine Single Load test** for a designed load intensity of 100 kPa. The test was carried out as per IS: 15284 (Part 1) – 2003. The test was deemed satisfactory if the settlement of the stone column was recorded less than 12 mm at 110 kPa load (1.1 times of design load).

The **Routine Single Column Load** test was conducted at existing Ground Level. First, the surface of testing platform was cleared to expose the top of the stone column. Then top of the column was levelled and lightly compacted to provide a firm horizontal-loading surface. A 60/40 mm thick square steel plate of size 2.2 m x 2.2 m was placed over the effective tributary soil area of stone column for testing. The stiffener plates were also used for the proper load distribution. A hydraulic jack of capacity 200 MT was placed over the centre of the plate for loading purpose. The settlements of the steel plate was recorded by four dial gauges of sensitivity equal to 0.01 mm fixed at diametrically opposite ends of the footing. The loading system and plan of Routine Single Column Load test is presented in Figure 4.

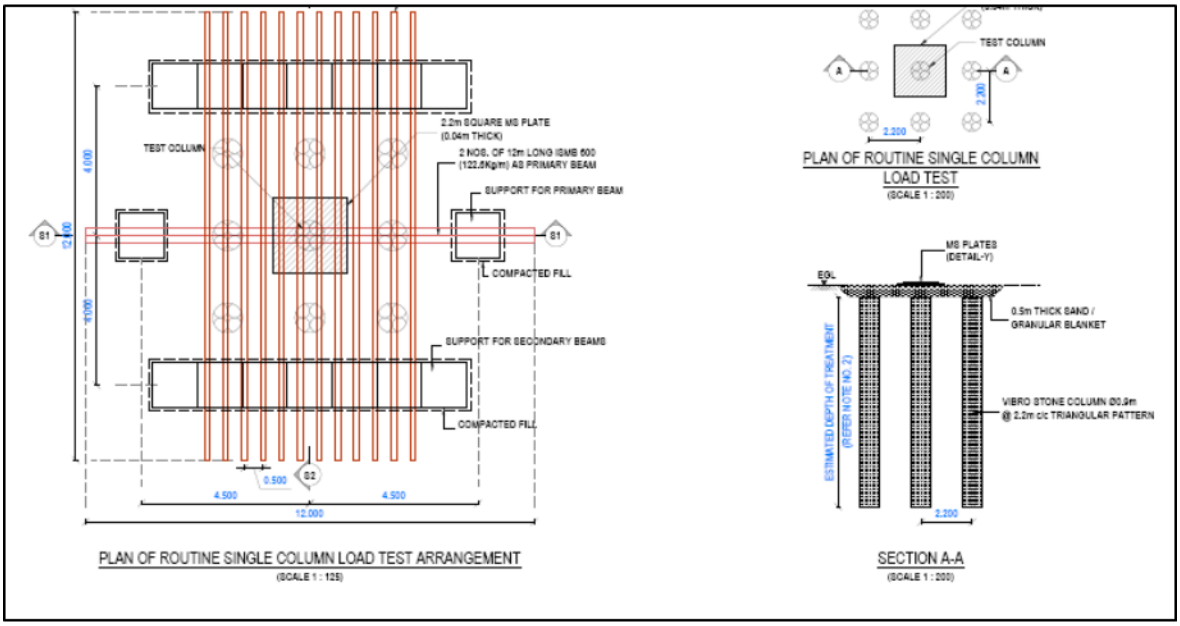
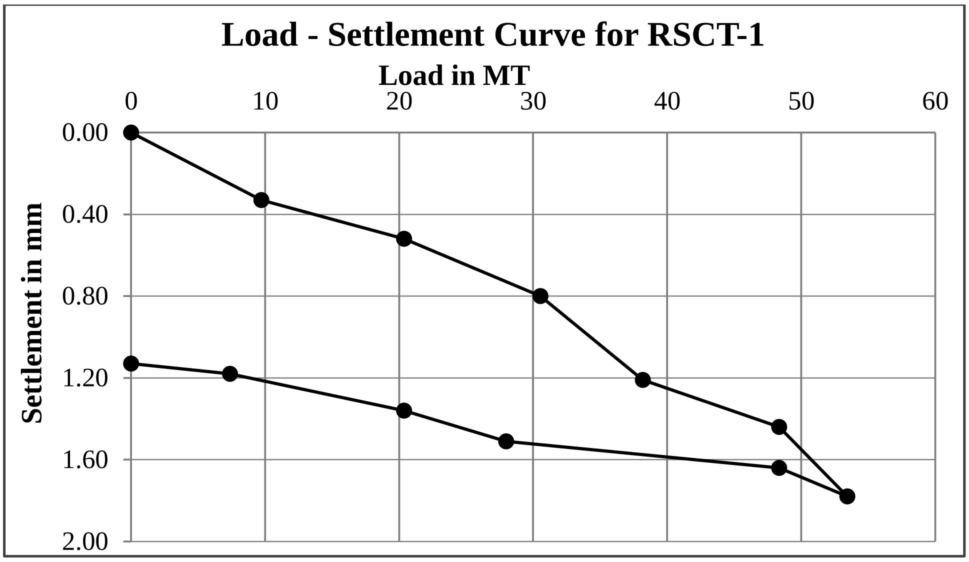


Figure 4: Typical plan and sectional view of Routine Single Column Load Test

The load was applied in five increments and each increment of load was maintained until the rate of settlement is less than 0.05 mm/h. The maximum test load 110 kPa (1.1 times of design load) was maintained for a period of 12 h after stabilization of the settlement as per IS:15284 (Part

1)-2003. The test plate was unloaded in five stages and in each stage, rebound of the plate is recorded after stabilizing the rebound. The four stone column were tested for the Routine Single Column Test and their Load vs. Settlement curve **for Single Column Routine Load Test** is presented in Figure 5 (a to d). The minimum and maximum settlement of the steel plate was recorded 1.73 mm and 2.08 mm respectively. The rebound of the steel plate was recorded 0.65 mm to 0.74 mm. The settlement recorded was less than the max permissible settlement of 12 mm as per as IS:15284 (Part 1)-2003 and found satisfactory.



(a)

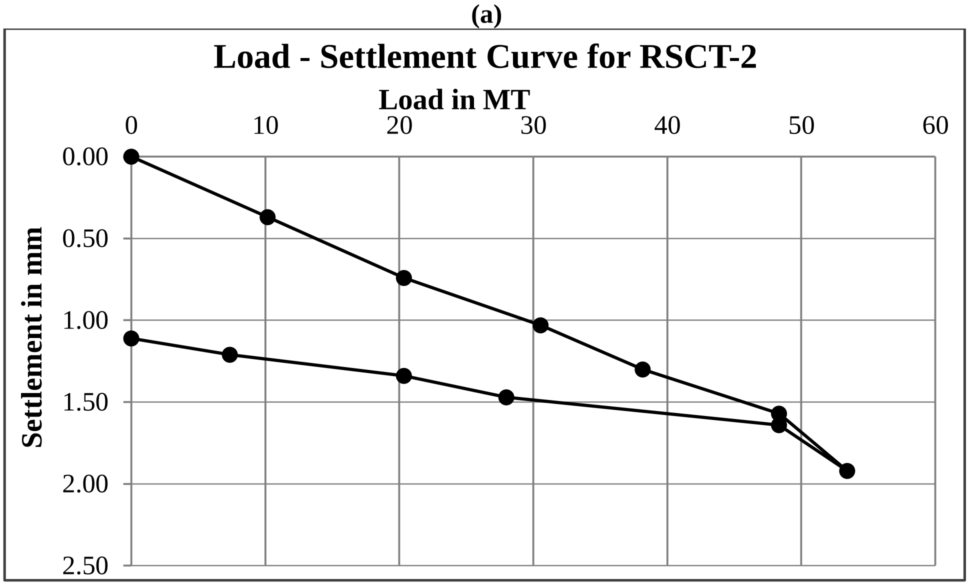
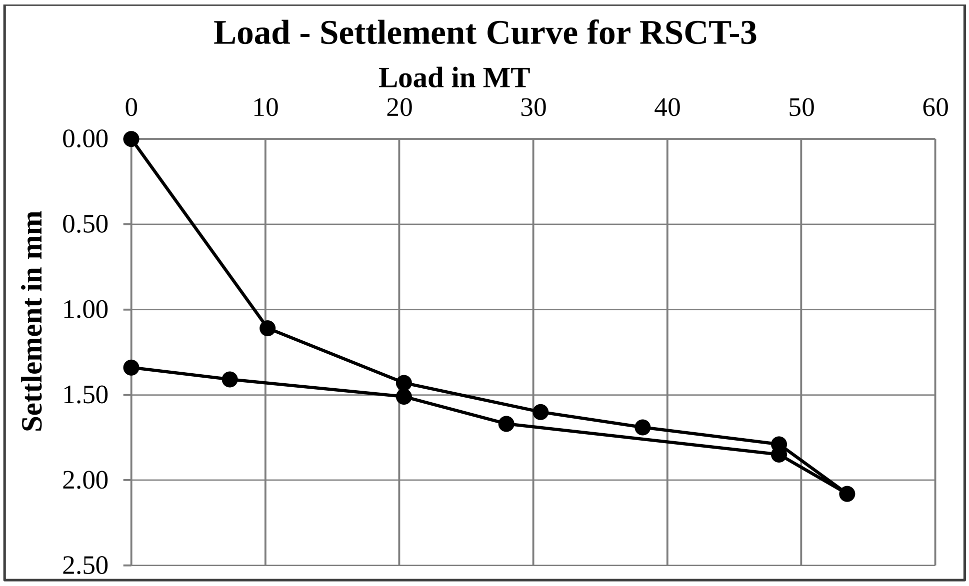
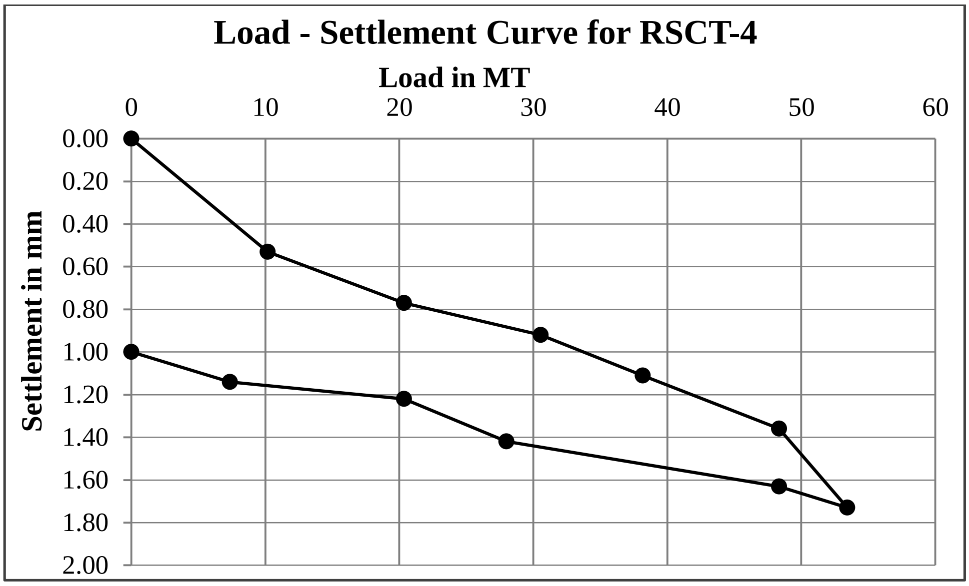


Figure 5 (b)



(c)



(d)

Figure 5: Load-Settlement Curve for Routine Single Load Tests

VII. Conclusions:

Stone columns are widely used for ground improvement in geotechnical engineering, particularly in weak or compressible soils. By installing compacted columns of crushed stone or gravel into the ground, they enhance soil strength, increase load-bearing capacity, and reduce settlement. These columns also improve drainage by facilitating water flow, which helps in mitigating liquefaction risks in seismic-prone areas. Based on the outcomes of past studies with physical modeling, mathematical analysis and full-scale testing, various parameters that influence overall performance of the stone column like column length, strength of the column material, area replacement ratio, column spacing, strength of the column material, and installation method have been discussed. Common applications of the stone columns include supporting embankments, roads, railways, and foundations for buildings and industrial structures. Their cost-effectiveness, efficiency, and eco-friendliness make them a preferred solution for stabilizing soft soils and ensuring long-term ground performance.

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