# Ground Improvement Using Stone Columns

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**Abstract** - ***This paper presents a comprehensive study on the improvement of soft soils using the stone column technique. Through a combination of experimental testing and literature analysis, the behavior of black cotton and red soils under various loading and moisture conditions is analyzed. The research demonstrates a significant increase in the bearing capacity of soils treated with stone columns. Notably, black cotton soil exhibited an enhancement of up to 7.8 times under dry conditions and 2.7 times under soaked conditions. The study further evaluates the impact of h/d ratios and explores the comparative performance between black cotton and red soils. The findings support the application of stone columns as an effective and economical ground improvement method in geotechnical engineering.***

***Key Words***: **Black cotton soil, Ground improvement, Stone column, Load bearing capacity, h/d ratio**

## 1.INTRODUCTION

In civil engineering projects, the performance of foundations is critically influenced by the underlying soil properties. Soft soils such as black cotton soil, marine clays, and silty sands often exhibit poor shear strength, high compressibility, and excessive settlement under loading, making them unsuitable for direct foundation placement. Traditional solutions like soil replacement or deep foundations are often time-consuming and uneconomical for widespread applications.

Among various ground improvement techniques, stone columns (also referred to as granular piles) have emerged as a widely adopted and effective solution for reinforcing weak soil strata. The technique involves the installation of compacted crushed stone or gravel in vertical columns within the soil mass. These columns enhance the load-carrying capacity of the soil, reduce settlement, and accelerate the rate of consolidation by functioning as vertical drainage paths.

The installation methods include vibro-replacement (wet process) and vibro-displacement (dry process), which are chosen based on groundwater conditions and soil characteristics. The behavior of stone columns depends on various parameters such as column diameter, spacing, depth, h/d ratio (height-to-diameter), encasement type, and loading condition.

In the Indian context, where expansive soils like black cotton soil are prevalent, the use of stone columns offers a reliable and economical alternative for foundation improvement. The current study aims to evaluate the performance of stone columns in both black cotton and red soils under varying conditions including soaked and un-soaked states, as well as to analyze the influence of h/d ratios on load-bearing capacity.

## 2. LITERATURE REVIEW

Numerous studies support the effectiveness of stone columns. A.P. Ambily and S.R. Gandhi (2004) found bulging as a typical failure mode and reported linear load-settlement behavior under total area loading. Ali et al. (2010) observed that smaller diameter columns encased with geosynthetics provided higher bearing capacity. Ismail et al. (2011) concluded that sand columns improve consolidation rates. Other researchers including Sudheer et al. (2011), Kalantari (2012), and Pradip Das (2013) emphasized the advantages of geosynthetic encasement and the importance of diameter and length ratios in column behavior.

## 2. OBJECTIVES

a. To determine the engineering properties of black cotton and red soil.
b. To analyze the load-bearing capacity of untreated and stone column-treated soils.
c. To study the impact of h/d ratio on bearing performance.

d. To evaluate soil response under soaked conditions.
e. To compare black cotton and red soils for stone column efficiency.

## 3. METHODOLOGY

Soil samples were collected and tested for properties like Atterberg limits, grain size, compaction, and unconfined compressive strength. Stone columns were installed in compacted soil molds using PVC pipes, and tests were conducted for varying h/d ratios and under soaked/dry conditions using a compression testing machine.

### 3.1 MATERIALS USED

- Black Cotton Soil: Collected from Hosapet, air-dried, and sieved.
- Red Soil: Used as the bed layer due to its relative hardness.
- Sand: Natural river sand used for surface levelling before load application.
- Stone Chips: 10 mm downsize aggregates used for stone column formation.

## 4.0 RESULTS AND DISCUSSIONS

### 4.1 GEOTECHNICAL TEST RESULTS

#### 4.1.1 Grain Size Distribution

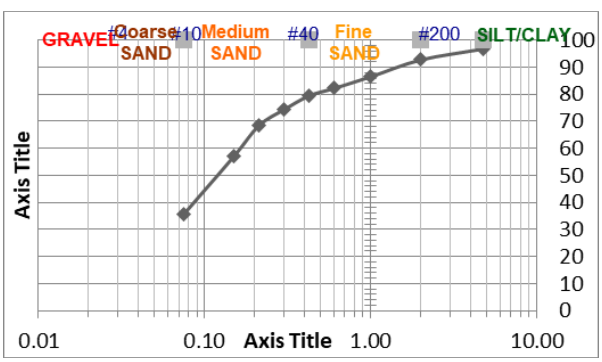


Fig 1: Graph for Grain Size Distribution.

The soils were classified based on particle size, indicating a dominance of fine sand and silt fractions, which influence permeability and compaction behavior.

#### 4.1.2 Specific Gravity of Soil

Table 1: Specific Gravity of Red Soil

| SI. No | Particulars | Trail-1 | Trail-2 |
|---|---|---|---|
| 1 | Weight of Pycnometer | 0.646 | 0.646 |
| 2 | Weight of bottle + 1/3rd | 1.100 | 1.042 |
| 3 | Weight of bottle + soil + | 1.810 | 1.766 |
| 4 | Weight of bottle + water | 1.504 | 1.504 |
| 5 | Specific Gravity, G | 3.05 | 2.955 |

Average specific gravity of Red soil = 3.00

Table 2: Specific Gravity of Black Cotton Soil

| SI. No | Particulars | Trail-1 | Trail-2 |
|---|---|---|---|
| 1 | Weight of Pycnometer bottle (W1), g | 32 | 32 |
| 2 | Weight of bottle + 1/3rd dry soil (W2), g | 55 | 54 |
| 3 | Weight of bottle + soil + water (W3), g | 97 | 96 |
| 4 | Weight of bottle + water (W4), g | 82 | 82 |
| 5 | Specific Gravity, G | 2.87 | 2.75 |

Average specific gravity of Black Cotton soil = 2.69.

Specific gravity values of 2.69 for black cotton soil and 3.00 for red soil indicate higher mineral density in red soil, contributing to its better load distribution.

#### 4.1.3 Standard Proctor Compaction:

Table 3: Maximum Dry Density and Optimum Moisture Content for Red Soil

| Water content (%) | Bulk density $\rho b = \frac{M}{V}$ g/cc | Dry density $\rho d = \frac{\rho b}{1+w}$ g/cc |
|---|---|---|
| 6 | 1.90 | 1.76 |
| 8 | 1.92 | 1.78 |
| 10 | 1.90 | 1.72 |
| 12 | 1.88 | 1.67 |

Table 4: Maximum Dry Density and Optimum Moisture Content for Red Soil.

| Water content (%) | Bulk density $\rho b = \frac{M}{V}$ g/cc | Dry density $\rho d = \frac{\rho b}{1+w}$ g/cc |
|---|---|---|
| 15 | 1.35 | 1.17 |
| 18 | 1.41 | 1.19 |
| 21 | 1.46 | 1.20 |
| 24 | 1.48 | 1.19 |
| 27 | 1.46 | 1.18 |

The Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) were determined as 1.20 g/cc at 21% for BC soil and 1.78 g/cc at 8% for red soil, revealing higher compaction efficiency for red soil.

#### 4.1.4 Liquid Limit:

Table 5: Liquid limit of Red soil

| Water Content (%) | No of Blows |
|---|---|
| 24 | 50 |
| 27 | 40 |
| 28 | 10 |
| 30 | 7 |

Table 6: Liquid limit of Black Cotton soil

| Water Content (%) | No of Blows |
|---|---|
| 65 | 54 |
| 70 | 40 |
| 75 | 27 |
| 80 | 19 |

BC soil showed a liquid limit of 80%, indicating high plasticity and expansive behavior, whereas red soil exhibited a moderate liquid limit of 30%.

4.1.5 Plastic Limit:

Table 7: Plastic limit for Red soil

| Container No. | R1 |
|---|---|
| $W_1$ (g) Wet Weight | 18 |
| $W_2$ (g) Dry Weight | 16 |
| $W_3$ (g) (W1-W2) | 2 |
| Water Content (%) | 12.5 |

Table 8: Plastic limit for Black Cotton soil

| Container No. | R1 |
|---|---|
| $W_1$ (g) Wet Weight | 32 |
| $W_2$ (g) Dry Weight | 31 |
| $W_3$ (g) (W1-W2) | 1 |
| Water Content (%) | 20 |

The plastic limit of black cotton soil was found to be 23%, significantly higher than red soil (12.5%), confirming its expansive nature and lower workability.

4.2 TESTING AND ANALYSIS

4.2.1 Compression Test on Red Soil With & Without Stone Columns

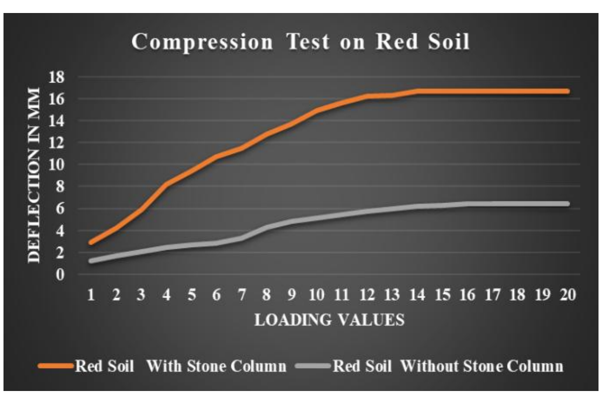


Fig 2: Compression Test on Red Soil with and without Stone Columns.

4.2.2 Compression Test on Black Cotton Soil With & Without Stone Columns

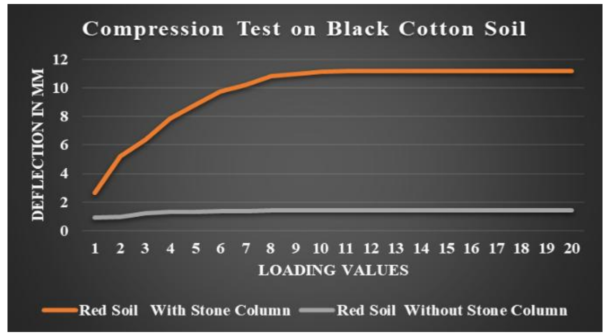


Fig 3: Compression Test on Red Soil with and without Stone Columns.

The deflection behavior of soil under increasing load is a key parameter in assessing its stability and deformation characteristics. In untreated conditions, both black cotton and red soils exhibited higher deflection for a given load, indicating poor resistance to deformation.

Upon introduction of stone columns:

- Red Soil showed reduced deflection from 19.8 mm to 6.43 mm at a maximum load of 2000 kN, reflecting a 67% decrease in settlement, thereby improving stiffness and load dispersion.
- Black Cotton Soil showed an even more significant reduction in deflection from 20 mm to 3.31 mm, recording an 83.4% decrease, which highlights the high efficiency of stone columns in expansive and compressible soils.

4.2.3 Compression Test on Black Cotton Soil with Varying Hight Ratios of Stone Columns

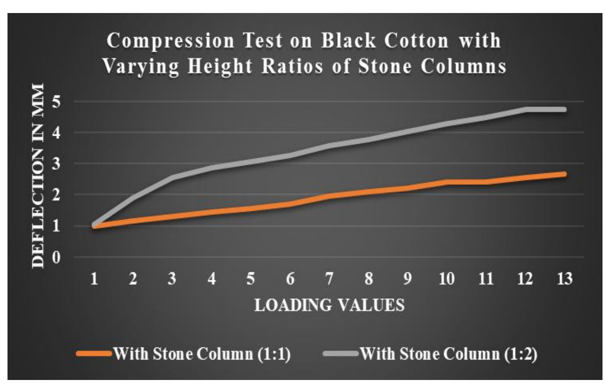

Fig 4: Compression Test on Black Cotton Soil with Varying Hight Ratios of Stone Columns (1:1 v/s 1:2)

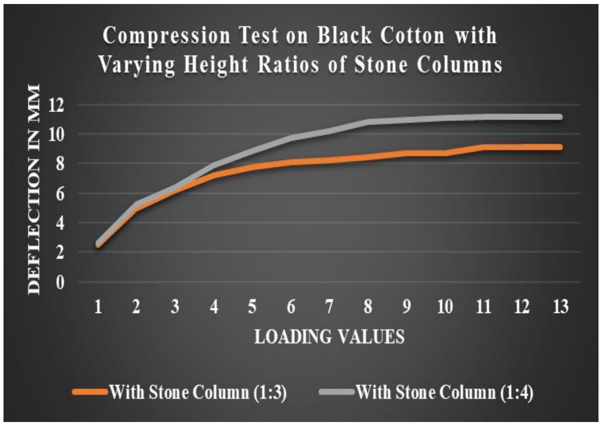


Fig 5: Compression Test on Black Cotton Soil with Varying Hight Ratios of Stone Columns (1:1 v/s 1:2)

For varying h/d ratios in black cotton soil, deflection decreased progressively from 6.17 mm (1:2) to 3.31 mm (1:4), suggesting that longer stone columns contribute to greater confinement and settlement control.

4.2.4 Compression Test on Black Cotton Soil in Soaked Condition With & Without Stone Columns

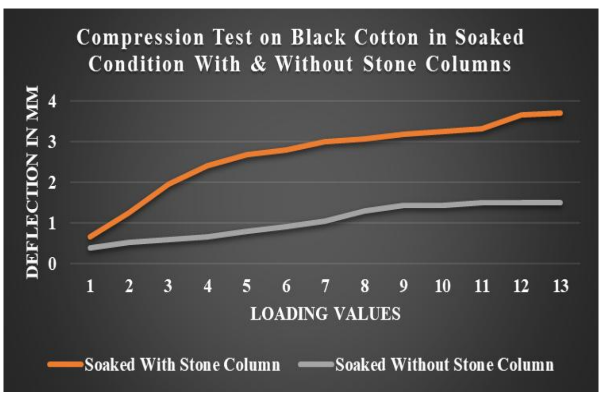


Fig 6: Compression Test on Black Cotton Soil in Soaked Condition With & Without Stone Columns

Under soaked conditions, the untreated BC soil reached 20 mm deflection, while the stone column-reinforced sample deflected only 4.03 mm, indicating a fivefold improvement in deformation resistance even in wet conditions.

4.2.5 Performance Comparison of Stone Column-Reinforced Red and Black Cotton Soils Under Compression

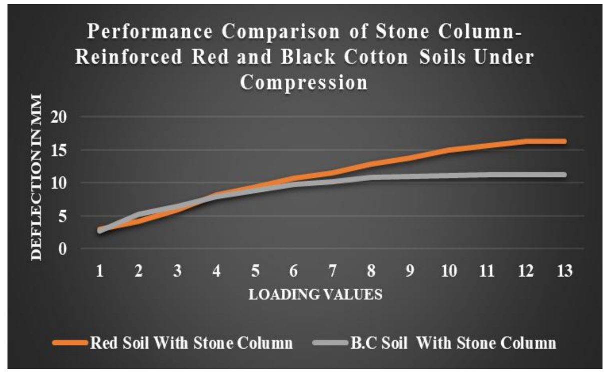


Fig 7: Performance Comparison of Stone Column-Reinforced Red and Black Cotton Soils Under Compression

The graph compares the deflection behavior of red soil and black cotton soil (B.C soil), both reinforced with stone columns, under increasing compressive loads. It is observed that while deflection increases with load for both soils, red soil exhibits consistently higher deflection values than B.C soil. This indicates that B.C soil, when treated with stone columns, offers greater stiffness and better resistance to settlement compared to red soil. The relatively flatter curve of B.C soil suggests that stone columns are more effective in improving its compressive performance. Overall, the results highlight the suitability of stone column reinforcement particularly in expansive soils like black cotton soil.

## 5.0 CONCLUSIONS

a. Stone columns significantly enhance the bearing capacity of soft soils, especially black cotton soil.
b. Performance improves with increasing h/d ratio, with 1:4 giving optimum results.
c. The method is effective even under soaked conditions.
d. Stone columns provide a viable solution for improving the engineering properties of problematic soils.
e. Black cotton soil benefits more from stone columns than red soil, making this method ideal for expansive soils in India.

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