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Research Article

Analysis of Load-Settlement Characteristics of Floating Stone Columns

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ABSTRACT

This research conducts a thorough examination of how the length vs diameter ratio affects the Behavioral study of settlement in floating stone columns under loading conditions, Derived from a comprehensive set of experimental investigations. The experiments were meticulously designed to evaluate the load-settlement behavior for stone columns with varying length to diameter ratio of 0 to 6. The detailed experimental results indicate that an increase in the length to diameter ratio improves the Capacity to withstand applied forces of floating stone columns up to an optimal point, after which additional length has minimal impact on performance. These outcomes offer important guidance for geotechnical engineering applications, especially in ground improvement techniques involving stone columns.

Keywords: Load-Settlement, Floating Stone Columns

INTRODUCTION

Stone columns are widely utilized for ground improvement across India and around the world. The method significantly enhances the capacity of soft ground to sustain structural pressure, offering a favorable balance between cost and effectiveness compared to alternative techniques (Hughes, 1974; Lee, 1998; Pradip Das, 2013).

This study explores the economic efficiency of using stone columns in geotechnical applications. To assess how different length-to-diameter ratios influence settlement behavior, The stone column maintained a fixed diameter of 60 mm throughout the study. while the length-to-diameter ratios were varied from 0 to 6. An L/D ratio of zero represents a condition in cases where the load is transmitted straight to the soil without any stone column reinforcement.

The outcomes of the experiments are illustrated using load vs settlement curves. Previous research—such as the works of S. Hadri et al. (2011), Jijo James and S. V. Sivapriya (2022), and Sudip Basack and Sanjay Nimbalkar (2023)— Investigated the relationship between load and settlement behavior of stone columns, focusing on factors such as column spacing, diameter, and the improvement of marine clay stability.

EXPERIMENTAL CONSIDERATIONS

To simplify the modeling of stone column installation, this study adopts a unit-cell approach utilizing a cylindrical steel tank as the test setup. The tank has dimensions of 300 mm in diameter and 600 mm in height, ensuring symmetrical conditions that allow accurate assessment of load-settlement behavior. This experimental procedure is aligned with the recommendations outlined in IS 15284 (Part 1: 2003), as well as the methodologies followed by Ali K. (2012) and other researchers.

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MODELING CONSIDERATION

The experimental setup aligns with the methodologies of Ambily AP (2007) and Gniel J. (2009), considering prototype parameters such as column diameter (0.6-1 m) and length (5-20 m), leading to an L/D ratio of 3 to 10 for the model tests. The model tank follows a unit-cell configuration to accurately simulate the field conditions of stone columns.

MATERIALS PROPERTIES

The clayey soil (CL classification) utilized in this research was collected from the SVNIT campus in Surat, Gujarat. It underwent preparation through air-drying, pulverization, and sieving processes. Stone columns were formed using aggregates smaller than 10 mm in size, with an average particle diameter (D_{50}) of approximately 1.5 mm. This corresponds to a d/D ratio of 36.67, based on a column diameter of 60 mm.

Table 1: Characteristics of soil used for the experimental investigation

Soil Property	Value
Soil Classification (as per IS: 1498-1970)	Soil of low plasticity
Bulk Unit Weight at 32% Moisture Content	18.5 kN/m³
Liquid Limit	45%
Undrained Shear Strength	30 kPa
Plastic Limit	20%
Optimum Moisture Content	18%
Maximum Dry Density	17 kN/m³
Plasticity Index	25%
Percentage of Silt Fraction	60%
Percentage of Clay Fraction	35%
Specific Gravity	2.6

Table 2: Characteristics of Stone Column Material

Material Property	Value
Clay Classification (Unified System)	GP
Dry Unit Weight (kN/m³)	18.5 kN/m³
Specific Gravity	2.75
Coefficient of Curvature (Cc)	1.125
Uniformity Coefficient (Cu)	2
Internal Friction Angle (°)	42°

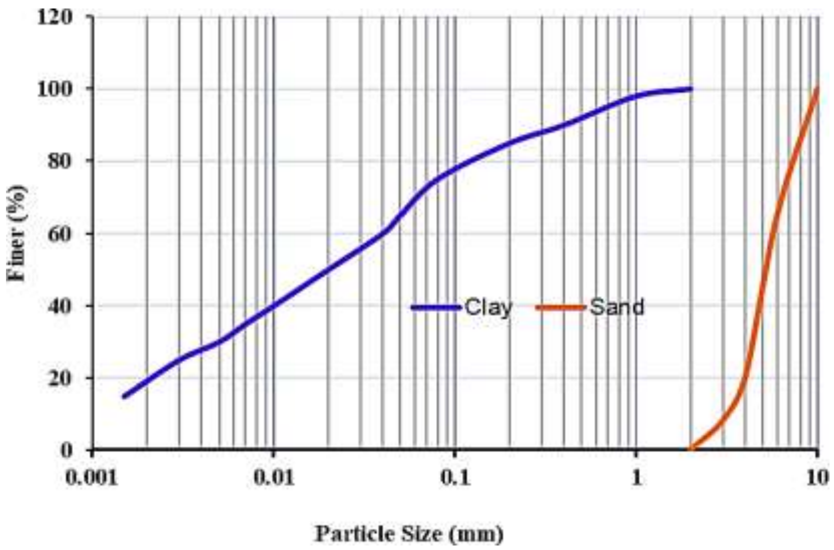

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Figure 1. Particle Size Distribution Curve of Clay and Stone Aggregates Utilized in Laboratory Experiments

FORMATION OF CLAY LAYER FOR TESTING

Unconfined Compressive Strength (UCS) tests were conducted on clay samples measuring 38 mm in diameter and 76 mm in height to identify the moisture content required for attaining an undrained shear strength of 30 kPa. The test outcomes revealed that a moisture content of 30% was optimal and was uniformly maintained throughout all experiments. Each clay bed was prepared using the same procedure to ensure consistency, resulting in a bulk unit weight of 18 kN/m³. To reduce friction between the clay and the tank walls during testing, a thin layer of grease was applied to the inner surface of the tank before the clay was introduced.

The soil was filled in five equal layers, with each layer manually compacted to a thickness of 120 mm to attain the desired unit weight. Stone columns were installed using the replacement method, employing seamless steel casing pipes that were open at both ends. These pipes featured an external diameter of 60 mm and a wall thickness of 2.5 mm. To allow smooth placement and extraction, the exterior of each pipe was lubricated with a thin coating of grease.

To construct a standard stone column, the steel casing pipe was positioned within the prepared soil and held firmly in place using a base plate with a circular indentation, which also prevented soil from entering the pipe. After the casing was inserted, the base plate remained in place as the pipe was withdrawn. Crushed stone aggregates were then placed in multiple layers and compacted to a thickness of 120 mm. During this process, the casing was gradually raised, ensuring that it always stayed at least 5 mm below the top surface of the compacted aggregate.

A 2 kg circular steel rod was used for compacting the material in order to ensure uniform density and limit lateral bulging. Each layer received ten gentle blows from a height of 100 mm, achieving a compacted unit weight of 18 kN/m³. This layer-by-layer compaction process was repeated until the stone column attained the desired height.

TEST PROCEDURE

The laboratory arrangement for testing both conventional and geosynthetically-reinforced stone columns is illustrated in Fig. 2. The tests were carried out using floating stone columns installed within uniformly prepared clay beds housed in unit cell containers. The performance of stone columns, with and without geosynthetic encasement, was assessed using a triaxial loading setup that applied vertical loads. To maintain consistency and avoid disturbances like particle displacement or the buildup of excess pore water pressure, the load was applied at a steady rate of 0.24 mm per minute.

Prior to recording settlement data, an initial seating load was applied, resulting in approximately 5 mm of deformation. To ensure even load distribution, a 10 mm thick steel plate, matching the diameter of the stone column, was placed on top. Settlement measurements were taken using a Linear Variable Differential Transformer (LVDT). The stone column was constructed using the replacement method. After preparing the soft clay bed, a casing pipe—corresponding to the column diameter—was manually inserted into the soil to the designated depth to minimize soil disturbance. In the case of encased columns, a geosynthetic layer was wrapped around the casing pipe before placement.

To facilitate smooth removal, the casing pipe's exterior was coated with a lubricant. Stone aggregates, pre-moistened for consistency, were added incrementally and compacted in layers 50 mm thick. A target density of 18.5 kN/m³ was consistently achieved. Lateral bulging was controlled by gently compacting each layer using a 2 kg steel rammer, delivering light taps from a height of 100 mm. During compaction, the casing pipe was gradually raised, ensuring it remained 5 mm below the surface of the compacted material. This process continued until the stone column reached the required depth, as shown in Figure 2.

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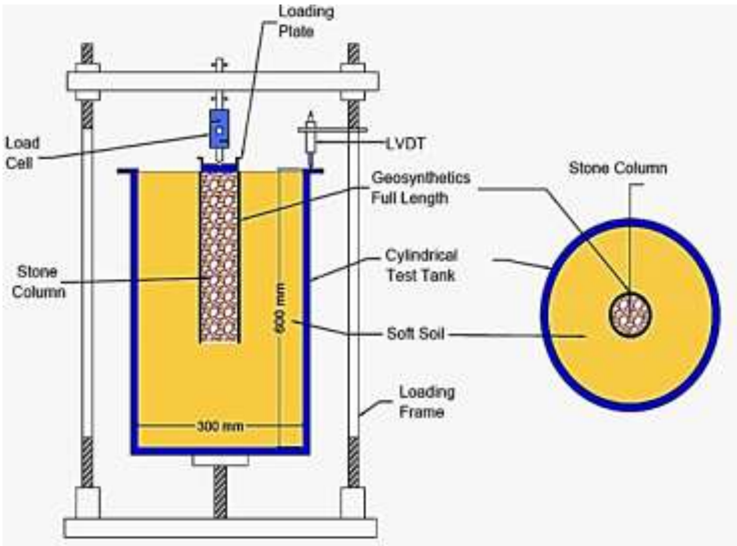

Fig. 2. Schematic Representation of Load Application on a Single-Stone-Column in a Unit-Cell Setup

LABORATORY TESTING PROCEDURE

To analyze how floating stone columns respond to loading, a set of laboratory experiments was carefully designed and executed. Table 3 presents an overview of the test conditions, highlighting the adjustments made to the length-to-diameter (L/D) ratios to evaluate their effect on column behavior.

Throughout all tests, the column diameter remained fixed at 60 mm. However, the column lengths were systematically altered to produce L/D ratios ranging from 0 to 6, as indicated in Table 3. This experimental layout was chosen to isolate and examine the impact of varying L/D ratios on the settlement performance of floating stone columns.

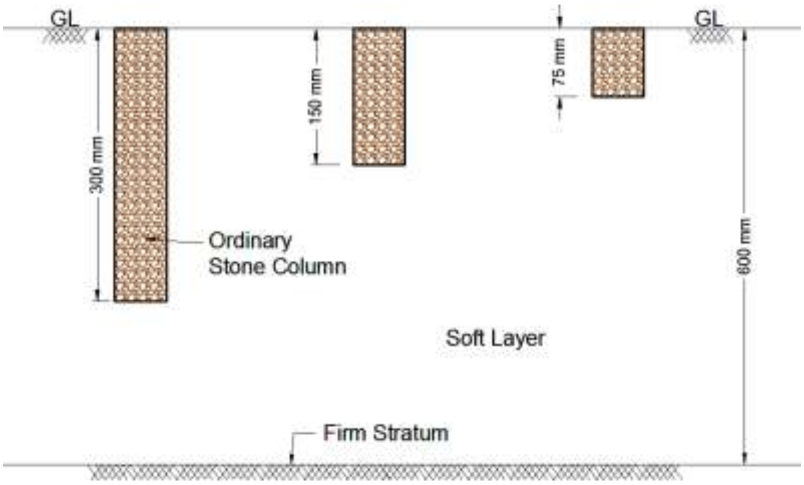

Figure 3. Laboratory Setup Diagram Showing Floating Stone Column with Different Length Configurations

Table 3. Overview of Laboratory Experiments Examining the Effect of L/D Ratio on Settlement Performance of Floating Stone Columns

Radial Measurement of Stone Column	L/D Ratio Measurements
60 mm	0, 2, 4, 5, 6

ANALYSIS AND DISCUSSION OF RESULTS

A series of controlled laboratory experiments, detailed in Table 3, were conducted to examine how varying length-to-diameter ratios affect the settlement behavior of floating stone columns. Throughout the testing process, the column

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diameter was consistently maintained at 60 mm, and a centrally placed circular loading plate of equal diameter was used for load application. The length to diameter ratios considered were 0 to 6 as per the table 3.

The experimental results indicated that incorporating a floating stone column into the clay bed notably improved its load-bearing capacity. To ensure precise and uniform load distribution, the circular plate was carefully aligned at the center of the stone column. Loads were applied in gradual increments until a total settlement of 40 mm was achieved, with key readings taken at 10 mm of settlement for each L/D configuration. The outcomes, as illustrated in Figure 4, highlight the influence of varying L/D ratios on the settlement response of the floating stone columns.

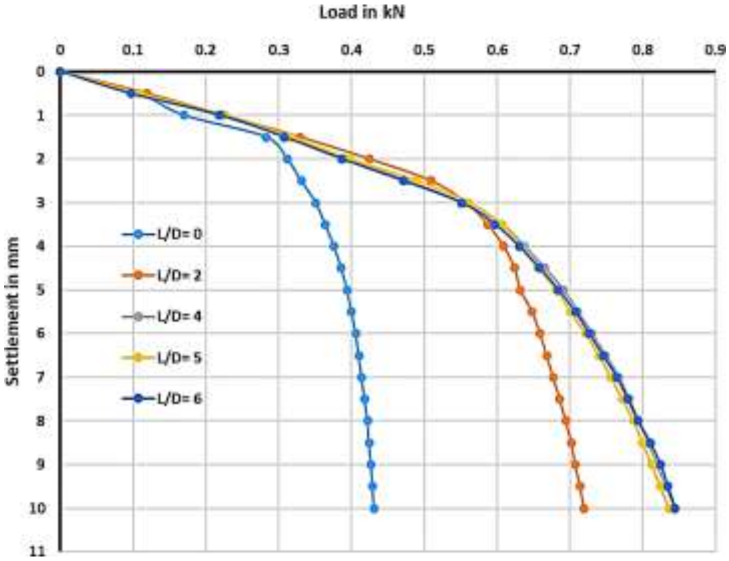

Figure 4. Relationship Between Load and Settlement for a Floating Stone Column Using a 60 mm Plate at 10 mm Displacement

SUMMARY OF FINDINGS

The test results revealed a notable improvement in soil strength when stone columns were incorporated. When examining a target settlement of 10 mm, the recorded load capacities for columns with L/D ratios of 0, 2, 4, 5, and 6 were 0.43 kN, 0.72 kN, 0.84 kN, 0.84 kN, and 0.83 kN, respectively. As shown in Figure 4, the increase in L/D ratio generally led to enhanced performance, but this improvement plateaued beyond a certain point.

Without a stone column, the system supported a maximum load of just 0.43 kN. Introducing columns of varying lengths substantially increased the load resistance. However, it was observed that increasing the L/D ratio past 5 produced negligible additional benefit. Therefore, a ratio of 5 appears to be the most efficient, balancing structural gain with construction cost. Extending the column length beyond this point may not justify the additional investment.

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