Experimental Studies on Ground Improvement Using Stone Column with Borehole Method

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Abstract—This research examined the ground improvement technique for enhancing the load-bearing capacity and enhancing of weak or compressible soils. In this study, we minimize the cost of ground improvement and make environment friendly solution for ground improvement. The research involves a review of the existing literature, including the Objectives, methodology, and case studies related to stone column implementation. Laboratory testing and field investigations are conducted to assess the geotechnical properties of the soil and the behavior of stone columns under different loading conditions. The project aims to provide insights into the geotechnical behavior of stone columns and their effectiveness in stabilizing weak soils. Furthermore, the study will explore the economic and environmental aspects of this ground improvement technique. The findings of this research are expected to contribute valuable knowledge to the field of geotechnical engineering, assisting engineers and construction professionals in making informed decisions regarding ground improvement methods.

Keywords: Black Cotton Soil, Cost effective, Environment friendly, Ground Improvement, Load Bearing Capacity, Stone Column, Soil Sample, Soil Stabilization.

I. INTRODUCTION

Stone column represent a method that frequently used in civil engineering to enhance and to stable soils that categorized as weak such as soft or loose sand. This technique facilitates the construction of wide range infrastructure, including highway facilities, storage tanks, embankment and bridge abutments, by bolstering the stability of the underlying ground. Stone columns are typically constructed by drilling or vibrating into the ground. This process involves creating holes or cavities in the soil. Ground improvement, this technique can help consolidate loose or soft soils, making them more stable. Stone column ground improvement is a versatile and effective geotechnical solution used to enhance the load bearing capacity. A Novel method stone column has emerged as a solution for enhancing the bearing capacity of weak deposits, such as soft clay and loose sands. It's application has been on the rise in India in recent years. In this method a pre bore hole filled with granular material and compacted by a heavyweight rammer over the borehole.

I.I. BACKGROUND

There are numerous ground improvement techniques are in practice to improve the properties of the ground. Stone column technique is a well-established technique and is best suited for improving soft clays, silts and also for loose sand deposits. The concept of Granular column was first adopted in France in 1830 to improve the properties of soil and later this is adopted all over the world to increase the bearing capacity, to reduce settlement, and also to increase the resistance to liquefaction (Barksdale and Bachus 1983, Alamgir et al 1996). Granular columns are formed utilizing either an electric or hydraulic vibrating probe activated mechanism. The original development of this probe can be attributed to Steuerman. The vibratory probe, essentially in cylindrical shape consists of a hydraulic or electric motor mounted within a cylindrical casing of 350mm-450mm in diameter and 2.0m – 4.5m in length. The motor operates a rotating eccentric weight, delivering lateral vibration and compaction. Granular columns are constructed using this vibrating probe either by wet process or dry process.

I.II. DESCRIPTION

Stone columns are cylindrical shape structures constructed beneath the ground level, comprising granular material ranging from 25 to 100 mm in size. The process involves creating a cavity in the soft soil using various techniques, followed by filling it with compacted layers of stones to form the complete column. Upon the placement of a structure above the treated area, a significant portion of the load (around 80-90%) is borne by the stone columns due to their higher stiffness, while the remaining 10-20% is supported by the surrounding clay deposit. This distribution of load, along with the surcharge load, enables the soft clay to provide ample confinement to the cylindrical columns. Predicting the maximum permissible actual stress on the columns relies on established theoretical frameworks. Notably, areas treated with stone columns are suitable for supporting flexible structures like embankments and oil storage tanks, as they may still experience notable settlement post-treatment, typically ranging from

50-200 mm. Without stone columns the settlement could have been 3-4 times higher and the bearing capacity would have been much less.

II. LITERATURE REVIEW

II.I. REVIEW PAPER ON GROUND IMPROVEMENT USING STONE COLUMN

Arvind I. Chaudhary, Shubham R. Bhoye, Manthan M. Jadhav, Prof. Nivrutti Jadhav (2024) in this review paper we completed our Major project part 1 research on Ground Improvement using stone column. We found cost effective and environmental friendly method from this review paper study.

II.II. COMPARISON OF ENCASED STONE COLUMN WITH CONVENTIONAL COLUMN FOR VARIED PARAMETERS THROUGH EXPERIMENTAL AND NUMERICAL INVESTIGATIONS

Sivapriya S. V. , Jijo James , K. Pavithra, S. Renuka Devi,K. Sangeetha, and M. Sasikala (2023) In this research, experiments were conducted in the laboratory to investigate how the load-carrying capacity of modified soil is affected by variations in column number, spacing, and encasement. The study utilized the unit cell concept, examining column diameters of 25.4 and 31.75 mm, with one or two columns, and spacing's of 50, 70, and 90 mm, both with and without encasement. Additionally, finite element analysis was performed to assess settlement characteristics and stress concentration ratio. The results indicated that the load-carrying capacity generally increased with the number of columns and spacing. Notably, larger diameter columns exhibited a more pronounced increase in load-carrying capacity compared to smaller diameter ones, particularly in the presence of encasement.

II.III. GROUND IMPROVEMENT BY STONE COLUMNS A REVIEW MR. SURENDRA PATEL, MR. AJAY PRATAP SINGH RATHOR, DR. JITENDRA KUMAR SHARMA (2023)

in their review paper Stone columns serve to improve the load-bearing capacity of loose soils in an environmentally sustainable as well as cost- effective manner. The review investigates the mechanical performance of encased stone columns compared to traditional ones and highlights the role of Geosynthetics in enhancing their ability to bear loads and increase their stiffness. It is also explored the obstacles related to the installation of stone columns, encompassing possible construction complexities, compatibility with the prevailing site conditions, and the impact of groundwater on their effectiveness.

II.IV. TO STUDY THE BEHAVIOUR OF DIFFERENT MATERIALS FOR STONE COLUMN CONSTRUCTION KWA SALLY FAHMI, E.S KOLOSOV, MOHAMMED Y. FATTAH (2019)

in their paper "Behaviour of different materials for stone column construction", the objective of paper was to study the Behaviour of different materials for stone column construction. They conducted Study of two different materials stone and sand in addition settlement versus load response was determine. Under the same loading condition, the weak soil was also analyzed and it has been found that the stones are the most effective material. Furthermore, experimental study on the behaviour of a group of four and eight columns was carried out through the finite element analysis with the PLAXIS 3D by using 16-Noded triangular elements. Through studying different pile materials which were used in the study it has been found that the most effective than sand for single column and group of columns. It was concluded that the inclusions of Piles considerably improve the low deformation properties of a clay soil. It has been found that stones are more effective than sand for single column and group of columns. The load capacity increases with decrease of spacing between columns.

II.V. ENHANCEMENT OF BEARING CAPACITY OF BLACK COTTON SOIL SAMPLE BY USING STONE COLUMN HARISH C, SHASHISHEKAR T , RADHIKA K AND MANJUNATH ITAGI (2016)

The study aims to assess the enhancement of bearing capacity in black cotton soil utilizing stone columns, both with and without geosynthetic encasement. Laboratory footing tests were conducted on single stone columns of various lengths and diameters, with and without geosynthetic encasement, to evaluate their effect on the soil's strength characteristics. The experiments were performed in a steel cylindrical tank, simulating real-world conditions. Parameters such as the number of encased columns and depths were varied to analyze their impact on soil reinforcement. Both unreinforced and reinforced soil samples underwent testing, with the latter involving quarry dust column encasement.

II.VI. TO STUDY THE BEHAVIOUR OF STONE COLUMNS BASED ON FEM ANALYSIS A.P. AMBILY & SHAILESH GANDHI (2013)

in their journal the objective is to study the Behaviour of Stone Columns Based on FEM analysis. They research and investigating the behavior of individual columns and groups of seven columns has been conducted, involving the manipulation of parameters such as column spacing, shear strength of soft clay, and loading conditions. Experimental tests have been performed using 100 mm diameter columns surrounded by various types of soft clay. These experiments involve either applying load to the entire equivalent area to assess the stiffness of the improved ground or loading a single column to determine its maximum axial capacity. During the group experiment's, the actual stress on column and clay were measured by fixing pressure cells on loading plate. Finite Element Analysis have been performed using 15-noded triangular elements with software PLAXIS.A drained analysis was carried out using Mohr's-Coulomb's criterion for soft clays, stones and sands. The numerical findings obtained from Finite Element Method (FEM) simulations were juxtaposed with experimental data, revealing a favorable concordance. It was observed that columns arranged with spacing's exceeding three times the diameter of the column did not yield substantial enhancements. Therefore, it is recommended that the spacing between stone columns should not exceed three times the diameter of the column for optimal results. Stone columns spacing's should not be more than 3 times the diameter of the column.

II.VII. BEHAVIOUR OF STONE COLUMN IN LOCAL SOFT AND LOOSE LAYERED SOIL PRADIP DAS & DR. SUJIT PAL (2013)

published their research paper on "The research investigates the performance of stone columns in soft and loosely layered local soil. Its aim is to analyze how stone columns enhance the stability and strength of such soil conditions. The study demonstrates that stone columns are a viable, cost-effective solution for improving soft and loose soil. Additionally, the implementation of stone columns leads to an increase in soil density and bearing capacity, contributing to improved soil stability during construction. The improvement of a soft soil by stone columns is due to different sizes of aggregate (size between 2 to 10 mm) in the soft soil. This paper presents the utilization of stone column to improve the load

II.VIII. SUITABILITY OF DIFFERENT MATERIALS FOR STONE COLUMN CONSTRUCTION DIPTI SARIN ISAAC AND GIRISH M. S.(2009) published paper on Suitability of different materials for stone column construction to study the suitability of different materials of stone column construction. Laboratory experiments were conducted to investigate the impact of column material on the effectiveness of stone columns in clay soil. Model stone columns were installed, and five different reinforcement materials were tested to assess their performance. Five reinforced materials were studied: stones, gravel, river sand, sea sand and quarry dust. Load versus settlement response was determined. The unreinforced soil under the same loading condition was analyzed. Quarry dust, though a waste product is effective in improving the load deformation characteristics of the soil used. A research investigation was undertaken to explore the behavior of groups of three and seven columns. Additionally, a finite element analysis employing 15-noded triangular elements within the PLAXIS software package was conducted. The findings indicated that the grain size of the stone column material emerges as a significant factor influencing the design of stone columns. There is no significant difference in the load deformation behaviour of soil with stone columns using river sand and sea sand. It is found that stones are the most effective stone column material. Adopt stone as a granular material for construction.

II.IX. LOAD SETTLEMENT BEHAVIOUR OF GRANULAR PILE IN BLACK COTTON SOIL SIDDHARTH ARORA, RAKESH KUMAR & PK JAIN (2008)

"Load – settlement behaviour of granular pile in Black cotton soil" with the objective to study Load – settlement behaviour of granular pile in Black cotton soil. The paper presents findings from a study conducted on floating granular piles built within soft black cotton soil. Model tank experiments were conducted to prepare the soil beds for the investigation tank diameter173 mm and height 605 mm. The study investigated the load carrying capacity of a granular pile with a diameter of 55mm, placed at the center of a soil bed and constructed using crushed stone chips. Various lengths to diameter ratios (L/d ratio) ranging from 1 to 11, with intervals of two, were tested to analyze the impact of pile length on load capacity. Additionally, the study explored the influence of encasing the pile material geo grid and the load test was conducted. TheAccording to the test findings, the ultimate load carrying capacity (Qult) of the granular pile rises with an increase in the L/d ratio, regardless of whether the pile is encased with a geo grid. This upward trend in Qult with increasing L/d ratio persists even at the highest ratio tested, namely 11, as observed in the study.

II.X. BEHAVIOUR OF ENCASED STONE COLUMN AND CONVENTIONAL STONE COLUMN MALARVIZHI AND ILAMPARUTHI (2008)

In their journal, "Comparative study on the behaviour of Encased stone column and conventional stone column" with the objective to have a Comparative study on the behaviour of Encased stone column and conventional stone column. The experimental investigation and numerical analysis focused on a stabilized bed featuring encased stone columns. The numerical analysis incorporated simulations of material behavior, employing Soft Soil, Mohr Coulomb, and Geogrid models to represent clay, stone material, and encasement, respectively. These simulations were then compared against experimental findings to validate the results. The investigation conducted on altering the ratio of length to diameter (L/D) of the column, the stiffness of the geogrid, and the angle of internal friction of the stone material provides valuable insights into the physical behavior of the clay bed stabilized by encased stone columns. It increases bearing capacity and reduce total and deferential settlements of structures constructed on soft clay. Stone columns also act as vertical drains, thus speeding up the process of consolidation. In numerous cases, the settlement of a stabilized bed remains unaffected due to insufficient lateral restraint. However, introducing a geo grid around the stone column can significantly bolster its bearing capacity while concurrently diminishing settlement. Stone columns stand out as a prevalent method for enhancing soil conditions and have found extensive application in soil improvement endeavors. Encased stone column is better than un-encased stone columns.

II.XI. SOLUTIONS FOR CONSOLIDATION RATES OF STONE COLUMN REINFORCED. J. HAN AND S.L. YE (2002)

Published paper on "A Theoretical Solution for Consolidation Rates of Stone Column Reinforced. (Foundations Accounting for Smear and Well Resistance Effects.)" with the objective to study "A Theoretical Solution for Consolidation Rates of Stone Column Reinforced". A simplified theoretical closed-form solution has been developed in this article for computing the rate of consolidation accounting for smear and well resistance effects. The parametric study indicates that the reduction of the permeability of the stone column and/or the smeared zone and/or the stress concentration ratio decreases the rate of consolidation. Compared with other solutions for drain wells or the authors' previous solution for stone columns without smear and well resistance effects, the proposed solution. In this article has addressed more comprehensive issues related to the consolidation rates of stone column reinforced foundations.

III. METHODOLOGY

III.I. COLLECTION OF BLACK COTTON SOIL

Land scarcity, especially in urban regions, has prompted the utilization of sites with weak strata for commercial, industrial, and transportation development. As the demand for land continues to rise, there's a necessity to utilize marginal areas with inadequate engineering properties. Employing stone columns has emerged as an economically feasible and technically sound method for enhancing the ground on soft soils in construction projects. The stone columns are usually designed for carrying vertical loads from the structures. Ground improvement is the modification of foundation soils or project earth structures to provide better performance under operational loading conditions. There's a growing trend in employing ground improvement techniques for new projects, enabling the utilization of sites with unfavorable subsurface conditions. This approach facilitates the design and construction of necessary projects even in areas with previously prohibitive subsurface conditions, making them economically viable and technically feasible.

Materials Used : Black Cotton Soil Sample.

Soil samples were obtained from trail pits, specifically extracted from a depth of 2 meters below the surface to minimize contamination from organic matter and other extraneous substances. Particular attention was given to ensuring the collected soil samples exhibited uniform characteristics. and stored in steel drums for further testing. Soil will be collected near thane district regions with availability of black cotton soil.

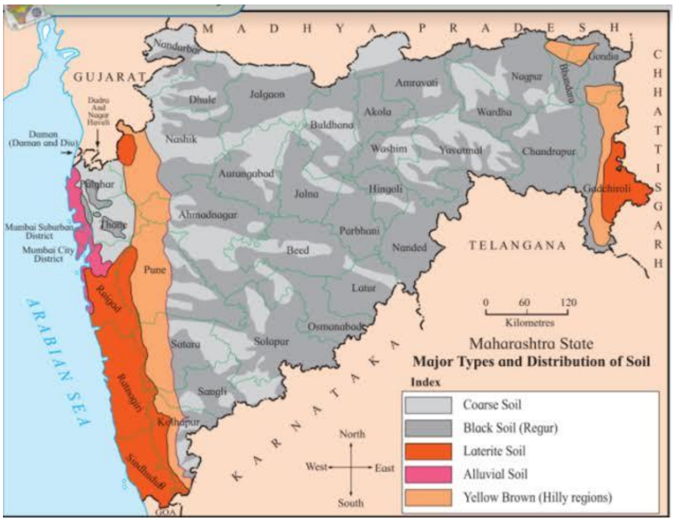

Fig No. 1 : Maharashtra State Distribution of Soil.

III.II. TESTING TO BE CONDUCTED ON BLACK COTTON SOIL SAMPLE

- Moisture Content
- Liquid Limit
- Plastic Limit
- Specific Gravity

Moisture Content - This test was conducted in college lab for which IS 2720 part 2 (1973) was used, a series of three samples of different weights of 89, 75 and 105 gm respectively were conducted and average value was considered as final one. Following are the test results obtained after testing the soil. The average water content in the soil was found to be 8.53.

Liquid Limit - The liquid limit of soil is a property that indicates the moisture content at which the soil changes from a plastic state to a liquid state. In other words, it is the minimum moisture content at which the soil behaves as a liquid under the influence of a small shearing force. The liquid limit is determined by performing a standardized laboratory test called the Casagrande's method, which involves measuring the number of blows required to close a standard groove in the soil sample. The liquid limit is defined as a percentage relative to the weight of the dry soil. It represents the moisture content at which the groove created by a standardized tool in a soil sample contained within a standard cup closes over a distance of 12 millimeters after undergoing 25 blows in a prescribed manner. The test is conducted, conforming to IS: 2720: 1985 part 5.

Plastic Limit - The plastic limit of soil is a property that indicates the moisture content at which the soil changes from a plastic state to a semi-solid state. In other words, The minimum moisture level required for soil to be molded into a 3mm diameter thread without fracturing signifies its plastic limit. The plastic limit is determined by performing a standardized laboratory test called the rolling method, which involves rolling a soil sample into a thread of 3mm diameter. The plastic limit is expressed as a percentage of the weight of the dry soil. The difference between the liquid limit and the plastic limit of soil is an important parameter known as the plasticity index, which is used to classify soils into different groups based on their engineering properties. This test was also conducted at our college which was conducted, conforming to IS: 2720:1985 part 5. Plastic limit in the black cotton soil was found to be 21.16

Specific Gravity - The specific gravity of soil is a measure of the density of a soil sample relative to the density of water. The specific gravity of soil is described as the proportion of the weight of a particular volume of soil particles to the weight of an equal volume of water at a designated temperature. The specific gravity of soil is an important property that is used to determine the void ratio, porosity, and degree of saturation of a soil sample. The specific gravity of soil can be determined by performing a standardized laboratory test called the pycnometer method. In this method, a known mass of dry soil is placed in a pycnometer, which is then filled with water to a known volume. The pycnometer is then weighed, and the specific gravity of the soil is calculated as the ratio of the specific gravity of soil refers to the ratio of the weight of the dry soil to the weight of an equivalent volume of water. The specific gravity of soil Is typically reported as a dimensionless number between 2.0 and 3.0, depending on the type of soil. Soils with high specific gravity values are typically denser and have lower porosity and void ratios than soils with low specific gravity values. The determination of soil's specific gravity holds significant importance within the field of geotechnical engineering. This parameter plays a crucial role in various aspects of soil mechanics and foundation design , as it can be used to calculate the weight-volume relationships of soil samples and to estimate their compressibility and shear strength. This test conforms to IS 2720 (Part III) – 1980.The average specific gravity was found to be 2.83.

IV. RESULTS AND DISCUSSION

IV.I. TESTING RESULT

The testing results on black cotton soil sample are shown in the table below.

Table No.1 : Black Cotton soil testing results

Tests	Results
Moisture Content	8.46%
Liquid Limit	55.8%
Plastic Limit	24.17%
Specific Gravity	2.46

IV.II. LOAD V/S SETTLEMENT TEST ON SOIL

This test was conducted to determine the bearing capacity of soil when the soil is subjected to Loads and corresponding amount of settling that will occur in soil. This test gives a good Comparison of soil reinforced with stone column against the normal soil. The procedure is repeated for 10,20,30,40 kg weight and against weight settlement was recorded.

Table No.2 : Values for soil with and without stone columns

Loading	Soil Sample without Stone Column	Soil Sample with Stone Column
10kg	16mm	12mm
20kg	26mm	20mm
30kg	33mm	25mm
40kg	38mm	27mm

IV.III. DETERMINATION OF SPECIFIC GRAVITY OF AGGREGATES

A dry pycnometer is prepared and weighed to obtain its empty weight. Approximately 1000 grams of a clean sample is carefully added to the pycnometer and weighed again. Then, water at a temperature of 270°C is poured into the pycnometer containing the aggregate sample until the sample is fully immersed. Upon immersion, the entrapped air within the sample is evacuated by vigorously shaking the pycnometer and sealing the hole at the top with a finger. Subsequently, the pycnometer is entirely filled with water until reaching the aperture at the top. After ensuring the absence of any remaining entrapped air, the pycnometer is then weighed. The pycnometer contents are emptied, followed by thorough cleaning. Subsequently, water is carefully added until it reaches the brim, ensuring no air bubbles are trapped. The pycnometer is then weighed. As for the mineral filler, a specific gravity bottle is employed, with the material being filled to a third of the bottle's capacity. The rest of the process of determining specific gravity is similar to the one described for aggregate finer than 6.3 mm. The remainder of the procedure for calculating specific gravity follows a similar method as outlined for aggregates finer than 6.3 mm. The specific gravity of aggregates was found to be 2.7

V. CONCLUSION

Many of the properties of soil will enhanced by the application of the stone column. The settlement of soil will considerably reduced after installation of stone column. Generally, black cotton soil is mostly seen in agricultural fields specially in Maharashtra hence light weight structures can be constructed on such soils. As per the tests carried out, it was found out that black soil is weaker compared to red soil and stone column can significantly increase the strength of loose and permeable soil. For, Stone Column to take maximum load & serve at its best it should have optimum diameter and length which varies from soil to soil. The Cost of this ground improvement using stone column will minimized by using Borehole Method. Intensive excavation will be reduced in this ground improvement using stone column method.

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REFERENCES

1. Experimental Studies on Ground Improvement Using Stone Column https://ijsrem.com/download/experimental-studies-on-ground-improvement-using-stone-column/
2. Comparison of Encased Stone Column with Conventional Column for Varied Parameters through Experimental and Numerical Investigations Sivapriya S. V. , Jijo James , K. Pavithra, S. Renuka Devi,K. Sangeetha, and M. Sasikala (2023).
3. Ground Improvement by Stone Columns: A Review Mr. Surendra Patel, Mr. Ajay Pratap Singh Rathor, Dr. Jitendra Kumar Sharma
4. Kwa Sally Fahmi, E.S Kolosov, Mohammed Y. Fattah, (2019), Behavior of different materials for stone column construction. Journal of engineering and applied science ISSN 1816-949X
5. Harish C, Shashishekar T , Radhika K and Manjunath Itagi (2016), in their journal Improvement of Bearing Capacity of Black Cotton Soil Using Stone Column
6. A.P. Ambily & Shailesh Gandhi, (2013), Behaviour of Stone Columns Based on Experimental and FEM Analysis. Geo tech. and Geo-environ Eng., ASCE, 133(6), 415–425.
7. Pradip Das & Dr.Sujit Pal, (2013), A study of the behaviour of stone column in Local Soft and loose layered Soil. Journal of EJGE Vol 18, PP: 1777-1786.
8. Dipty Sarin Isaac, Girish M.S. (2009) “Suitability of different materials for stone column construction”. EJGE 14.
9. Siddharth Arora, Rakesh Kumar & PK Jain, (2014), settlement behaviour of granular pile in Black cotton soil. IJAET ISSN: 22311963.
10. Malarvizhi, S.N. and Ilamparuthi, K. (2008), Numerical Analysis of Encapsulated Stone Columns, The 12th International Conference of International Association for Computer Methods and Advances in Geo mechanics (IACMAG), 3719-3726.
11. J. Han and S.L. Ye, (2002), A Theoretical Solution for Consolidation Rates of Stone Column Reinforced. Foundations Accounting for Smear and Well Resistance Effects. The International Journal of Geo mechanics Volume 2, Number 2, 135–151 (2002).
12. Maharashtra State Board of Technical Education Practical Manual of Geotechnical Engineering 22404.
13. Indian Standards (IS). (2003). “Indian standard code of practice for design and construction for ground improvement-guidelines. Part 1: Stone columns.” IS 15284 (Part 1), New Delhi, Indi