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Investigation on Behavior of Stone Columns in Soils under Predominant Settlement

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Abstract: Recent advances have made stone columns more efficient and effective for addressing soil instability and improving the load-bearing capacity of weak soils. The present study aims to show that the behavior of stone columns can support most of the load transferred to the soil. The use of innovative materials, such as recycled glass, plastic, or tire shreds, as a replacement for traditional stone fill, has been investigated in recent years and has shown promising results in cost and sustainability. The development of advanced numerical modeling techniques, such as finite element analysis, has enabled engineers to understand the behavior of stone columns better and optimize their design for specific soil conditions. The load-displacement characteristics are considered governing parameters for understanding the capacity of stone columns. The study reveals that, stone column method significantly increases strength with the use of concrete waste lo demolished waste rather than stone aggregate, which can overcome this soil behavior. Additionally, stone columns are helpful for soil stabilization in areas with high water tables when other stabilization techniques are ineffective.
Keywords: Stone column, CBR value, ground improvement technique, recycled construction waste, sustainable stabilization.

I. INTRODUCTION

Stone columns, also known as stone piles or stone pillars, are a ground improvement technique to strengthen compressible soils. These soils are typically weak and prone to settlement under the weight of structures or heavy loads. The soft soils without stone columns results in uniform settlement (no fractures), tipping settlement (frequently without cracks), and differential settlement (with cracks), as inidacted in figure .1 below

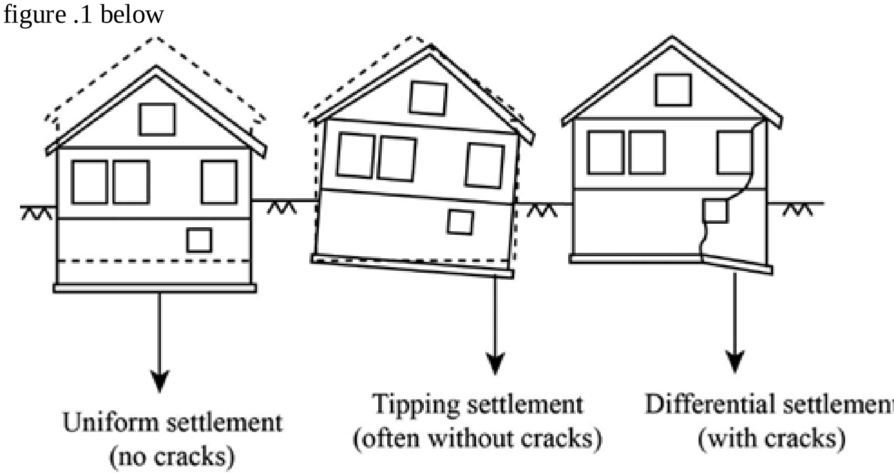

Figure.1 Typical settlement effect without ground improvement *(Chegg.com)*

Stone columns are constructed by drilling vertical holes into the soil and filling them with compacted gravel or crushed stone. The resulting columns improve the soil's ability to bear weight and reduce the likelihood of settlement. The construction of stone columns involves several stages. Firstly, a hole is drilled into the soil using a drilling rig. The hole is then partially filled with a layer of crushed stone or gravel and compacted using a vibrating probe. This process is repeated until the column is complete. The stone columns are often installed in a grid pattern and are designed to support the structure's weight or load by transferring it to deeper, more competent soil layers. The use of innovative materials, such as recycled glass, plastic, or tire shreds, as a replacement for traditional stone fill, has been investigated in recent years and has shown promising results in cost and sustainability Nitish, S. S. S, et. al (2021).

Stone columns have several advantages over other ground improvement techniques. They are relatively inexpensive compared to other methods such as deep soil mixing or replacement. They are also a faster ground improvement method, as the installation process can be completed quickly and with minimal disruption to the site. Additionally, stone columns can be installed in various soil types, including cohesive and non-cohesive soils. However, there are also some limitations to the use of stone columns. They may not be suitable for all soil conditions, such as high organic or expansive soils. However, they also control the liquefaction effect Adalier.K, et.al (2003). In addition, the effectiveness of stone columns may be limited in very soft or very dense soils. Therefore, the design of stone column foundations must be carefully considered to ensure their suitability and effectiveness for a given site and structure. Ayothraman (2009) researched using the material for stone columns made from crushed-up tires and discovered that the mix proportions of 20%T+80%S, 60%T+40%S, and 40%S+60%T can support the weight of a stone column made entirely of stone aggregates. Combining the aggregate and chip improves the stone column's load-carrying ability.

II. METHODOLOGY AND MATERIALS

The effectiveness of this ground improvement technique could be assessed by carrying out an experiment on stone columns in idealistic soils having more significant settlement. Several approaches could be used to evaluate the response of the stone column. However, it shall begin with the ideal choice of location. The stability of the soil can be ascertained by evaluating the engineering characteristics like strength and permeability. Installing several stone columns in the clay soil that range in diameter and length would be the test configuration. The columns would be put in position using a vibro-replacement technique or drilling.

Furthermore, various methods, including settlement monitoring and geotechnical instrumentation, would be used to track the performance of the stone columns over time Malarvizhi. S. N & Ilamparidhi (2007). Researchers could quantify the deformation and stress in the soil using equipment like strain gauges, pressure cells, and inclinometers. The monitoring data will evaluate the efficacy of the stone columns in increasing the soil's load-bearing capacity, lowering settlement, and enhancing its drainage properties. The effectiveness of the stone columns in soils and their potential use in various geotechnical engineering projects could be inferred from the experiment's findings.

The uniaxial compression behaviour of encased stone columns indicated no effect of compressive strength due to initial void ratio. However, is affected by tensile strength of additional material. The behaviour is linear as indicated by J.F.Chen et.al (2018). In case of encased stone columns, the settlement is dependent on their stiffness and arrangement, which can be better understood by the load settlement relationship Sahi, W. D., and Alhawamdeh, B. M. (2022), Christoulas.S, et.al (2000).

In the present study, the soil samples are collected from site location at the depth of 1 m below the ground level in Aganampudi location, Visakhapatnam, India. Experimental investigations are initially carried out to access the index and few engineering properties of the soil. The details are mentioned in Table.1 below:

Table.1: Properties of the soil samples

Properties	Quantities
Soil Sample	
Liquid Limit (%)	43.56
Plastic Limit (%)	21.55
Plasticity Index (%)	22.01
Undrained Shear Strength (kPa)	46.7
Indian Standard Soil Classification	ML
Bulk Unit Weight (kN/m^3)	22.35
Dry Unit Weight of Soil (kN/m^3)	16.56
Specific Gravity	2.66
Water Content	35%

Additionally, demolished waste material is gathered to recycle to dust/chips. The recycled dust is maintained not larger than 600 microns and chips not larger than 10mm in size is collected. The optimum moisture content of the site-specific soil is evaluated by conducting standard proctor test. The oven dried soil sample is then maintained with optimum moisture content to perform experimentation. The vertical cut for model stone column is made with a vertical excavation tool with thin diameter (nearly 10mm) and sharp edge. The recycled dust/chips are then filled in the excavated regions layer by layer carefully. The top surface of the samples is levelled to place a top plate to distribute the load evenly as represented in figure 2 & 3 below:


Figure.2: Site-Specific soil


Figure.3: Soil with stone column arrangement

The samples are then tested for stress strain behaviour using a CBR testing machine apparatus. The following procedure is adopted to perform the test (IS 2720 Part-16) (IS 15284-1, 1970). Lift the mold with a soil sample, remove the spacer disc along with filter paper. Place the mold such that the compacted surface is at the bottom facing. Place the annular surcharge weight at the top of the sample of the mold and place the assembly on the pedestal of the loading machine. Set the proving ring and dial gauge in position place the assembly on pedestal of the loading machine. Fix the plunger bring the plunger in contact with the soil surface and add another slotted surcharge weight at the top set the dial gauge to zero as shown in figure.4 below:


Figure.4: Specimen under test

III. RESULTS AND DISCUSSIONS

Load-settlement curve for the considered silty soil is plotted from trials with respect to the improvement of the soil by stone column model and the nominal site-specific soil as addressed earlier. Experimental results of stone column tests can vary depending on various factors, such as the type of soil, column diameter, length, spacing, and applied loads. However, some general findings from experimental study are included below:

Table.2: CBR Test results of Normal Site-Specific soil

S.NO	Dial Gauge Reading	Penetration (mm)	Proving Ring Reading	Load(kg)
1	0	0	0	0
2	50	0.5	9	36
3	100	1	14	56
4	150	1.5	15.3	61.2
5	200	2	16.2	64.8
6	250	2.5	17.2	68.8
7	300	3	18	72
8	350	3.5	19	76
9	400	4	20.2	80.8
10	450	4.5	21	84
11	500	5	24.2	96.8
12	550	5.5	33	132
13	600	6	44.3	177.2
14	650	6.5	55	220

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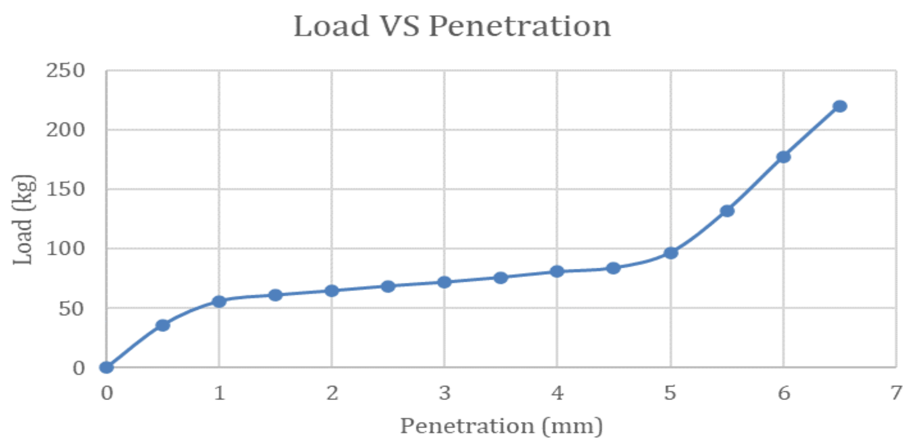

Figure.5: Load vs Penetration plot for site-specific soil

Table.3: CBR Test results of Improved soil with stone column

S.NO	Dial Gauge Reading	Penetration (mm)	Proving Ring Reading	Load(kg)
1	0	0	0	0
2	50	0.5	27	111.2
3	100	1	49	196
4	150	1.5	63	252
5	200	2	72	288
6	250	2.5	77	308
7	300	3	81.2	324.8
8	350	3.5	85.2	340.8
9	400	4	89	356
10	450	4.5	94	376
11	500	5	97	388
12	550	5.5	100	400
13	600	6	102.3	409.2
14	650	6.5	106.2	424.8

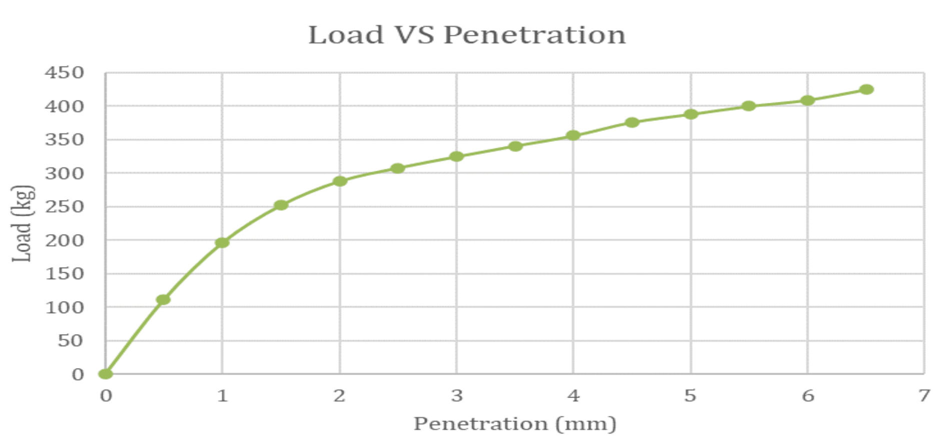

Figure.6: Load vs Penetration plot for improved soil

The CBR Value at 2.5mm and 5mm penetration are then obtained to understand the behaviour. A comparison is then made with respect to the investigational results as shown below in figure.7.

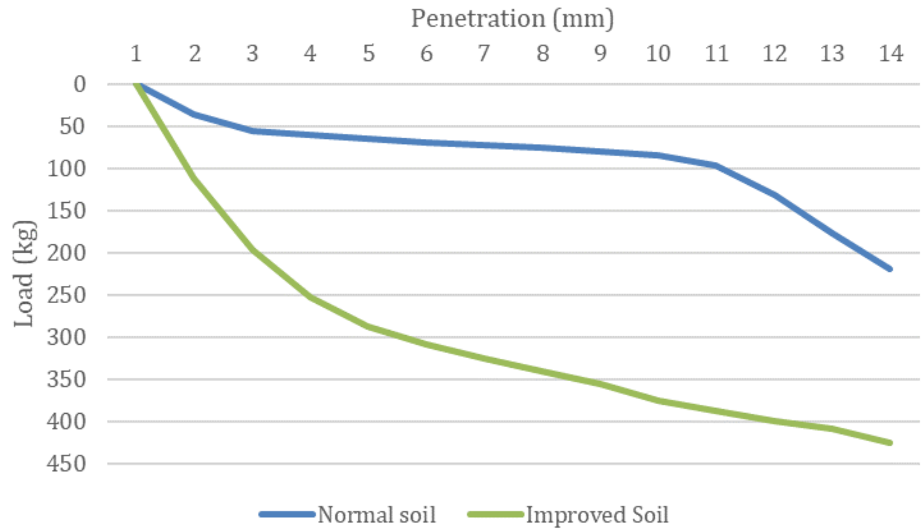

Figure.7: Comparison of Load vs Penetration for normal and improved soil

From the experimental results, it can be clearly understood that stone columns can significantly increase the bearing capacity of the soil. The bearing capacity of the soil can be improved by up to 5 times for an acceptable settlement of 10mm using stone column with the help of recycled materials. The CBR value at 2.5 mm penetration increased from 5.02 to 22.5 for normal soil to improved soil respectively. The CBR value at 5 mm penetration increased from 4.71 to 18.88 for normal soil to improved soil respectively. It can be observed from the comparison curves that the settlement is controlled by a larger margin of load for the improved soil.

IV. CONCLUSION

From the experiment conducted and comparative graphs plotted, the following conclusions are made:

1) The bearing capacity of the soil can be improved by up to 5 times for an acceptable settlement of 10mm using stone column with the help of recycled materials.
2) A significant improvement in strength over 4 to 4.5 times the normal site-specific soil can be observed with improvement by stone column with recycled waste. Despite lesser value than general stone column material, recycled waste can be off good use for small scale works.
3) Recycled waste material as additive in the stone column indicate better performance and are reliable material as they are easily available, and cost-effective material.
4) Stone columns can also reduce the settlement of the soil up to 90% or even more in some cases.
5) Other recycled materials, such as the demonstrated waste material, Crushed concrete, recycled aggregates, tyre chips, railroad ballast, and crushed glass may have significant potential for usage in the building of stone columns.

In summary, the experimental results of stone column testing suggest that they can be an effective method for improving the load-bearing capacity and reducing the settlement of soft soils. However, the design of stone columns should be carefully considered based on the soil properties and applied loads to achieve the desired performance.

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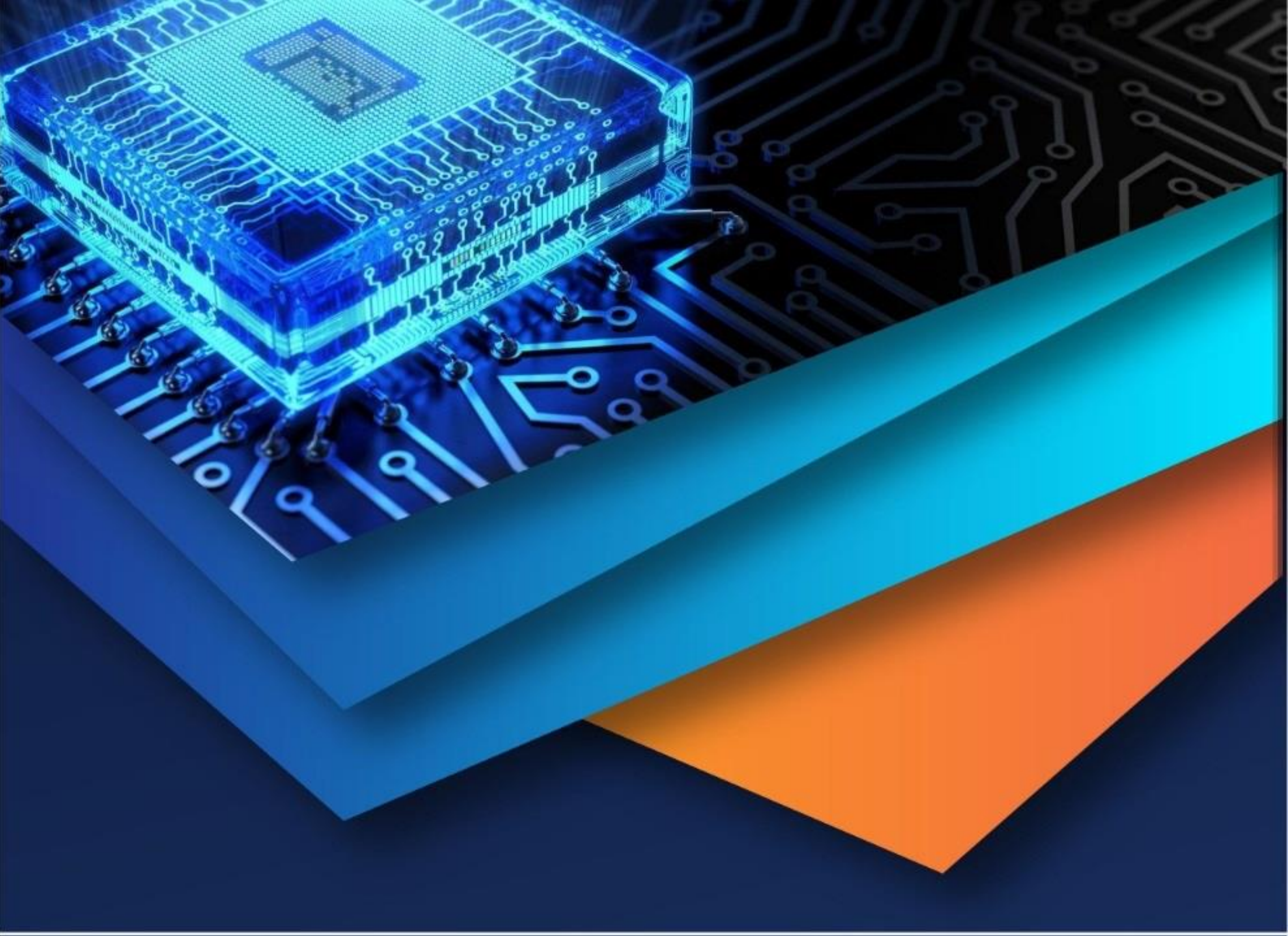

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