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Original Article

Bearing Capacity and Microstructural Study of Weak Soils Stabilized with Tyre Waste Powder and Kota Stone Powder

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Abstract *- The weak soils are beneath the expanding well known clayey soils. Generally speaking, weak soils have a significant volume of settlement and a limited bearing capacity because of the insufficient bonding and microstructural arrangements of the clayey soil particles. The aim of this investigation is to elaborate on the improvement in bearing capacity and microstructural characteristics in an expansive clayey soil that has already been stabilized by the optimal combinations of Kota stone powder and tyre waste powder. This ongoing study aims to characterize the alterations in micro fabric and mineralogical structures resulting from the incorporation of stabilized weak soil with optimized blends of tyre waste powder (12%) and Kota stone powder. The clay-waste tyre powder and Kota stone powder mixture, designated as 0.5, 1B, and 2B, were used in the trials at three different depths. Both the virgin soil and the stabilized soil samples' X-ray diffraction pattern (XRD) and scanning electron microscopy (SEM) pictures were collected and examined. The XRD pattern shows that stable compounds are forming. SEM micrographs show how the introduction of the ideal mixture of Kota stone powder and waste tyre powder led to the development of an ordered and flocculated structure. The results of this study show that stabilized weak soils have notable improvements in both bearing capacity and microstructural configurations.*

Keywords *- Weak soils, Bearing capacity, Microstructure, SEM analysis, XRD analysis.*

1. Introduction

The global production of waste materials presents issues with pollution to the environment and stability for building projects worldwide. Reducing and controlling the effects of this kind of waste is essential for resilient and sustainable construction methods in various areas. For this kind of soil, it is imperative to find suitable techniques or apply changes in order to improve foundation stability and reduce pollution.

The dispersion and swelling value is reduced due to the addition of stabilizers [1]. When curing for up to 28 days, there is a noticeable and continuous modest improvement in the bearing capacity ratios. Remarkably, the bearing values of treated samples that were exposed to curing times longer than seven days, such as twenty-eight days, show increases in strength, matching the levels noted during the first seven days of curing.

A comparison between the three depths (0.25 B, 0.5B, &1 B) clearly shows differences in bearing ratios. It is shown that the acceptability of the soft soil improves proportionately with increasing depth and length of curing time beyond one day.

Additionally, the depth elevation is correlated with an increase in the bearing ratio [2]. The various investigators from several fields have tried to find links between the microstructure of clayey soils and geotechnical characteristics. The materials and conditions covered by these investigations are varied and used different materials such as Fly Ash-Modified Red Clay in Cement Industry Waste, Cement-Stabilized Zinc-contaminated Kaolin, Lime and Gypsum, Bauxite Residue, Red Muds under Acidic and Alkaline Conditions, Fly Ash-Based Geopolymer Stabilised Riverside Soft Soil and silica fume [3-16].

Exploring the fine features of specimens has never been easier thanks to Scanning Electron Microscopy, or SEM. The obtained enlarged images reveal the size, form, composition, crystallography, and other physical and chemical aspects of an object thanks to this potent technology, which Knoll first demonstrated between 1935 and 1939. Beyond the limitations of conventional microscopy, scanning electron microscopy (SEM) offers a comprehensive and perceptive look into the microscopic world. [17-18]. Then SEM was improved by von Ardenne [19]. In the 1930s and 1940s, Charles University of Cambridge students spearheaded significant advancements in commercial scanning electron microscopy research, laying the groundwork for contemporary scanning electron microscopy technology [20]. Historical developments and their application to clay for SEM were provided by Birnie and McHardy [21]. In SEM, material and surface sciences involve magnifying structures multiple times to observe and assess surface differences in detail [22-24]. SEM makes use of an electron beam in a vacuum to examine materials and produce high-resolution images through electromagnetic lenses. The Energy Dispersive X-ray Spectrometer (EDS) collects X-ray spectra from the sample that has been bombarded with electrons to enable localized chemical analysis, while reflections or electrons interacting with the material produce images for a microscope. The incorporation of an X-ray spectrometer in SEM facilitates element mapping and point analysis while acquiring electron images [25-28].

The Authors namely Deng, Y and Dixon, J.B. (2009, the process of identifying minerals using X-ray powder diffraction involves two distinct stages. [6].The starting procedure involves assessing the X-ray diffraction (XRD) pattern of the sample with a reference mineral pattern through the highest peak matching. However, analysing soil using XRD can pose challenges due to its intricate composition, comprising diverse crystalline and non-crystalline components. [29]. By the authors, Cook studies the IV Various factors are likely to shift the 2-theta peak positions from 1 sample to another. Some of these factors include small variations in automatic goniometer alignment, intermittent changes in the sample and correctly placing the sample [30]. The researcher, Nazile Ural, has overviewed the importance of microstructure study for improved clay [31]. This paper analyses the effect of combinations of wastetyre powder and Kota stone powder on weak soils in terms of bearing capacity and alterations of the microstructural studies.

2. Soil Sample

The representative clayey soil samples were collected from Chennai near Puzal Lake, which has coordinates of 13° 10′20″N 80° 10′17.5″E. Puzhal Lake, often written as Puzhal Lake and also called the Red Hills Lake, is a lake in Chennai, India's Red Hills neighbourhood. This lake, which is located in the Tamil Nadu district of Thiruvallur, is one of the two main rain-fed reservoirs that supply water to Chennai. Chembarambakkam Lake, Pulhal Lake's equivalent, and Porur Lake together make up a substantial portion of the city's water supply.

Table 1. Classification of table CH

S.No	Classification	Liquid Limit Value (%)
1	Clay of Low Compressibility(CL)	<35%
2	Clay of Intermediate Compressibility(CI)	35%-50%
3	Clay of High Compressibility(CH)	>50%

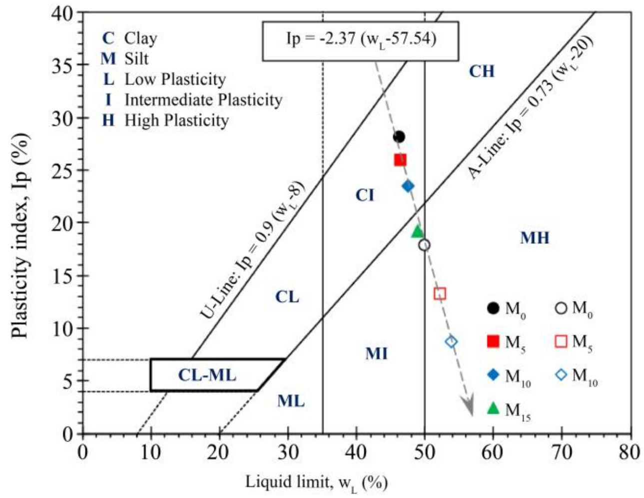

Fig. 1 Plasticity chart – clay of high compressibility

The high compressibility of clay soils is indicative of their vulnerability to compression when subjected to structural loads.

This property is explained by the closely spaced mineral particles in clay, which leave little room for the existence of water or air. The soil characteristics of the clay sample are listed below.

Table 2. Geotechnical properties of clayey soil sample

Sl. No	Geotechnical Properties	High-Compressibility Clay
1	Liquid Limit, %	62 %
2	Plastic Limit, %	34 %
3	Shrinkage Limit, %	27 %
4	Plasticity Index %	28%
5	Swelling %	65%
6	Maximum Dry	1.85
7	Optimum Moisture	23.29 %
8	UCS Strength, (N / mm^2)	0.182
9	Soil dispersion %	74 %

3. Tyre Waste Powder

An important economic and environmental potential exists in waste tyre powder, a by-product of tyre recycling procedures. Tyre powder is an environmentally responsible way to address the problem of tyres that are abandoned. This finely powdered material has uses in a number of industries, including building, rubber production, and even as an addition to asphalt for use in road surfaces.

Reusing discarded tyre powder not only lessens the negative environmental effects of tyre disposal but also helps certain businesses establish sustainable processes and use fewer raw materials. The physical properties of tyre waste powder as tabulated below

Table 3. Physical properties waste tyre powder

S.NO	Physical Properties	Waste Tyre Powder
1	Specific Gravity	2.30
2	pH Value	6.50
3	Fineness Modulus	1.56
4	Density	0.82
5	Size	75µm – 1.80 mm
6	Rate of Steel fiber	0%

4. Grain Size Distribution

Below, Table 4 represents the value obtained through sieve analysis, and Figure 2 represents the graph of sieve analysis of waste tyre powder and Kota stone powder.

Table 4. The value obtained through sieve analysis

SIEVE SIZE (mm)	Empty Weight +Wt. Retained	Wt. Retained	% Wt. Retained	Cum. %	% Passing
4.75	406	12	1.2	1.2	98.8
2.36	428	10	1	2.2	97.8
1.18	349	5	0.5	2.7	97.3
600	324	6	0.6	3.3	96.7
300	329	7	0.7	4	96
150	211	3	0.3	4.3	95.7
75	335	9	0.9	5.2	94.8
PAN	1200	948	94.8	100	0

From the tabulation:
% of Gravel = 1.2%
% of Sand = 4%
% of Silt & Clay= 94.8%

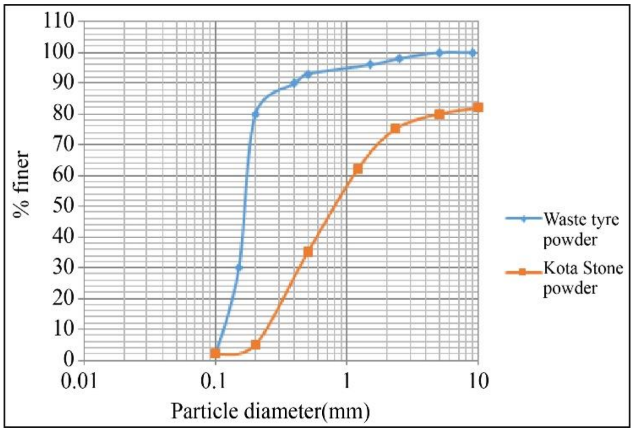

Fig. 2 Grain size distribution curve for the WTP & KTP

5. Kota Stone Powder

Kota stone powder is a by-product obtained through the cutting process of Kota stone, a popular natural stone used in construction. Powder-like residue is produced when Kota stone is cut for shape and sizing purposes. Although this powder is frequently seen as waste, it has several uses. Because of its distinct composition and fine texture, it can be used as a filler in various industrial processes or as a building element in concrete mixtures. The method of cutting Kota stone powder finds useful uses that not only maximize resource utilization but also support sustainable practices in the construction and associated sectors.

Table 5. Physical properties kota stone powder

S.NO	Physical Properties	Kota Stone Powder
1	Specific Gravity	2.62
2	pH Value	8.52
3	Fineness Modulus	1.36
4	Density	0.95
5	Size	80µm – 1.16 mm
6	Permeability	3.20×10^{-3} cm/s

Clayey Soil Sample, Tyre Waste Powder and Kota Stone Powder.

Fig. 3 Soil sample & stabilizers

6. Bearing Capacity Study

In construction projects, the stability and integrity of foundations are largely dependent on the carrying capacity of the soil. It represents the highest weight that the earth can support without experiencing undue settling or failure. Because bearing capacity has a direct impact on foundation design and construction, engineers and builders must understand it. In order to ensure that the structure can safely hold the applied loads, a thorough examination of the soil's bearing capability helps in the selection of suitable foundation types and in calculating the necessary dimensions. Ignoring the bearing capacity could result in foundation failure, which would jeopardize the built structure's overall stability and longevity.

In order to determine the best combinations of tyre waste powder and Kota stone powder to use while mixing with highly compressible clay, the study carried out methodical tests. Vertical static loading effects and different cure times were investigated. (0.5B, 1 B & 2B), where B is the footing wide, are the three depths of the clay-additives combination that were assessed.

On the basis of the clay soil's dry weight, the chosen ratios for tyre waste powder and Kota stone powder were 12% and 8%, respectively. Uniaxial compressive strength tests of the stabilized soil yielded these optimal proportions.

Fig. 4 Loading frame

After the soil layer preparation steps, the following protocols were put into place:

- The loading frame was meticulously positioned to line up the footing's centre with the box's centre, as seen in Figure 3.
- A loading disc was used to apply loads methodically and incrementally.
- After every load increase, there was a 6-minute pause to allow for stabilization before incorporating the subsequent load increases.
- Prior to implementing the subsequent load increment and at the conclusion of each time step, measurements from the dial gauges were recorded
- This procedure continued until the sample failed.

7. Scanning Electronic Microscope (Analysis) & X-Ray Diffraction

Two soil samples were collected, one of which was made up of virgin clayey soil and the other of which was combined with the optimal ratios of Kota stone powder and tyre waste powder.

To get photographs of the microstructure, these materials were subjected to Scanning Electron Microscopy (SEM) at IITM. After that, the acquired images were analyzed with Image software to find details like particle and pore sizes. We conducted a detailed quantitative and qualitative analysis of the microscopic examination results. Figure 5 shows a SEM Images.

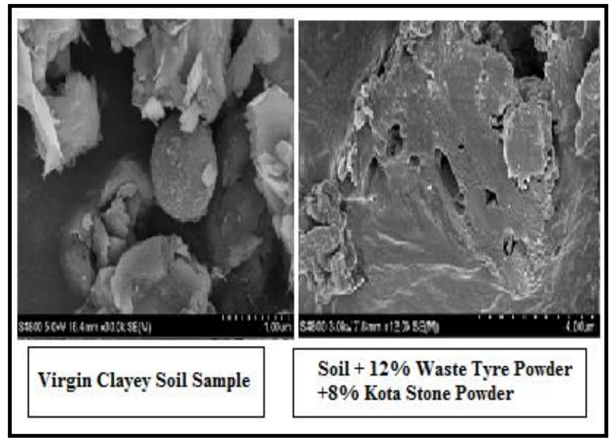

Fig. 5 Soils microstructure magnified images (SEM)

For the X-ray diffraction investigation, virgin clayey soil, as well as the ideal dose of Kota stone powder and tyre waste powder, is analyzed. The mineral content and crystalline structure of the clayey soil sample were discovered by X-ray Diffraction (XRD) investigation. Characteristic peaks in the diffraction pattern corresponded to minerals, including kaolinite, illite, and montmorillonite, that are frequently found in clay soils. The presence of these minerals reveals which clay minerals are most important for the soil's cohesiveness and flexibility.

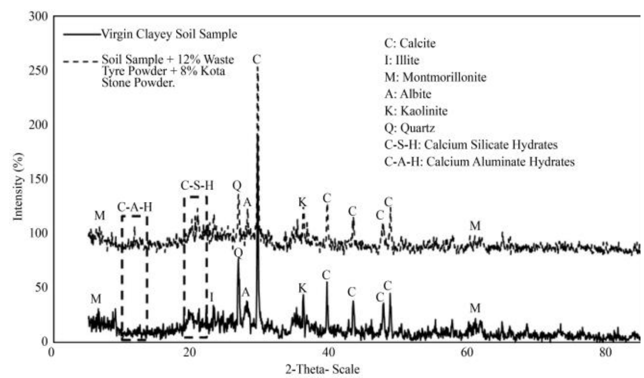

Fig. 6 Soils microstructure magnified images (XRD)

The sample containing hydrated calcium silicate and hydrated calcium aluminate compounds phases along with calcite, illite, and montmorillonite was subjected to X-ray Diffraction (XRD) analysis, which revealed a complex mineral assemblage with important implications for material properties and behavior. Each mineral phase could be easily identified and measured thanks to the unique peaks in the diffraction pattern. Cementitious materials' characteristic C-calcium silicate and hydrated calcium aluminate phases indicate possible interactions with other minerals and the environment that could affect the material's development of strength and durability. Furthermore, the presence of calcite suggests that carbonate minerals have an impact on the sample's mechanical and chemical characteristics. In contrast, the existence of illite and montmorillonite suggests the existence of clayey soil minerals, which may have an impact on the sample's swelling behavior and plasticity. The mineralogical composition and possible reactivity of the sample are revealed by this thorough XRD analysis, which will help guide future investigations and engineering uses.

8. Results and Discussion

8.1. Settlement Vs Bearing Capacity (D = 0.5 B, D= B & D= 2B)

The sample failures at the applied load stress that correlated to the S/B =10% Figure 4 represents the relation between settlement proportion (S/B) and bearing proportions (q/cu) for the conditions of virgin soil and treated soil (12% Tyre waste powder and 8% Kota stone powder) for D=0.5 B. From the Figure 3 the bearing proportions for the virgin soil is 4.8%.

The variation of q/cu with S/B for treated soil with (12% Tyre waste powder and 8% Kota stone powder for D=0.5 B at the end of 1, 7 and 28 curing days is shown in Figure 7. The bearing proportions show a trend, increasing from 4.8% for virgin soil to 8.83%, 10.5%, and 11.40% for stabilized soil at the end of the 1, 7, and 28-day curing periods, respectively.

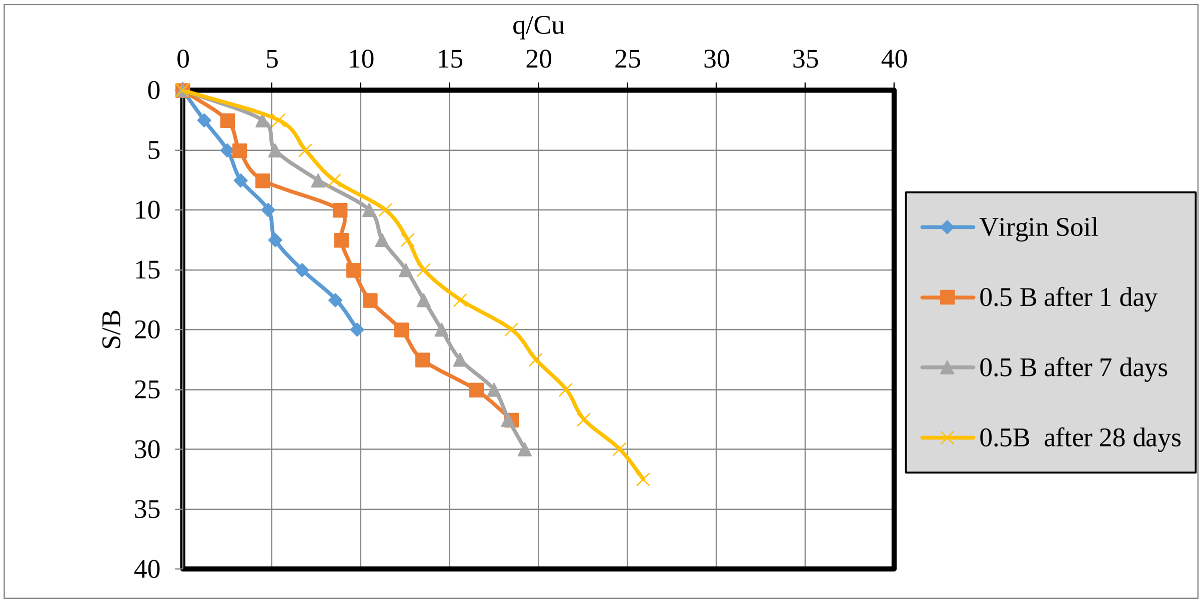

Fig. 7 Variations of S/B with q/Cu for stabilized soil- 12% WTP + 8% KSP for D=0.5B (0, 1, 7, 28 days curing)

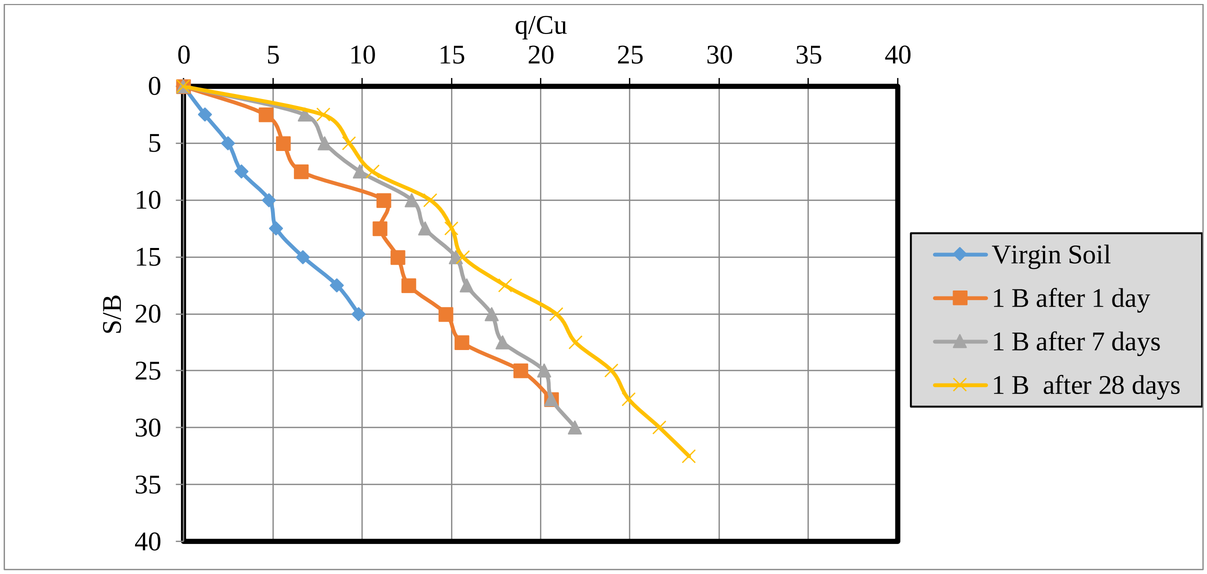

Fig. 8 Variations of S/B with q/Cu for stabilized soil- 12% WTP + 8% KSP for D= 1 B (0, 1, 7, 28 days curing)

The sample failures at the applied load stress that correlated to the S/B =10% Figure 7 represents the relation between settlement proportions (S/B) and bearing proportions (q/cu) for the conditions of virgin soil and treated soil (12% Tyre waste powder and 8% Kota stone powder) for D=1 B. From the Figure 8 the bearing proportion for the virgin soil is 4.8%. The variation of q/cu with S/B for treated soil with (12% Tyre waste powder and 8% Kota stone powder for D=1 B at the end of 1, 7, and 28 curing days is shown in Figure 3. The bearing proportions show a trend, increasing from 4.8% for virgin soil to 11.23%, 12.80%, and 13.83% for stabilized soil at the end of the 1, 7, and 28-day curing periods, respectively.

The sample failures at the applied load stress that correlated to the S/B =10% Figure 8 represents the relation between settlement proportions (S/B) and bearing proportions (q/cu) for the conditions of virgin soil and treated soil (12% Tyre waste powder and 8% Kota stone powder) for D=2 B. From the Figure 9 the bearing proportion for the virgin soil is 4.8%. The variation of q/cu with S/B for treated soil with (12% Tyre waste powder and 8% Kota stone powder for D=1 B at the end of 1, 7 and 28 curing days is shown in Figure 3. The bearing proportion shows a trend, increasing from 4.8% for virgin soil to 14.13%, 15.85%, and 16.81% for stabilized soil at the end of the 1, 7, and 28-day curing periods, respectively.

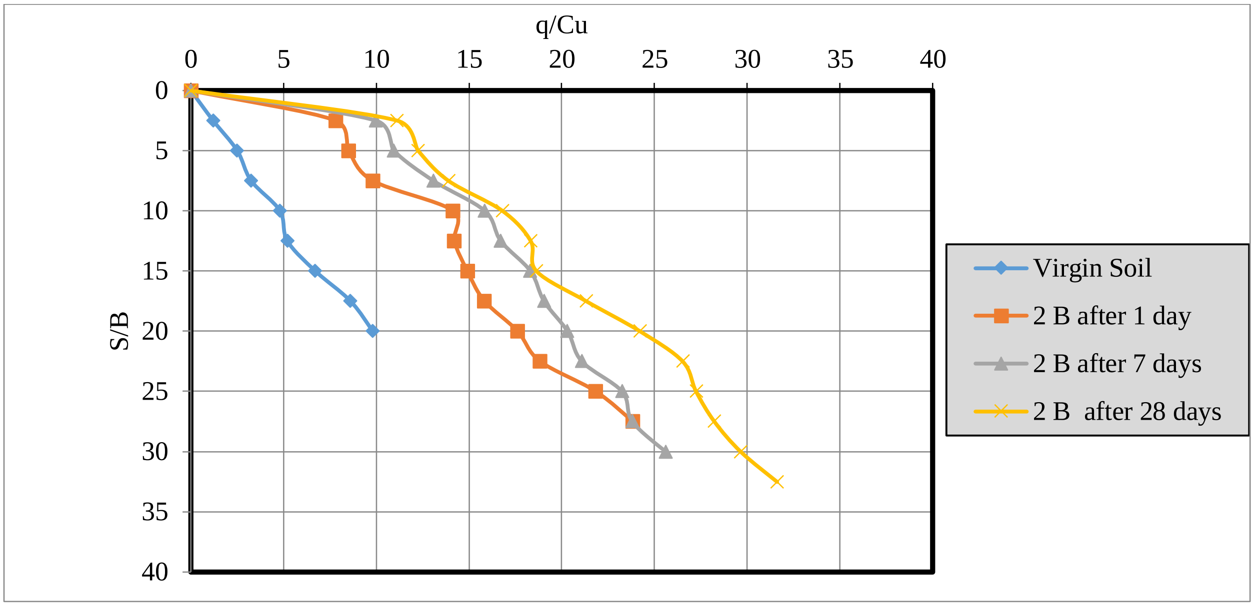

Fig. 9 Variations of S/B with q/Cu for stabilized soil- 12% WTP + 8% KSP for D= 1 B (0, 1, 7, 28 days curing)

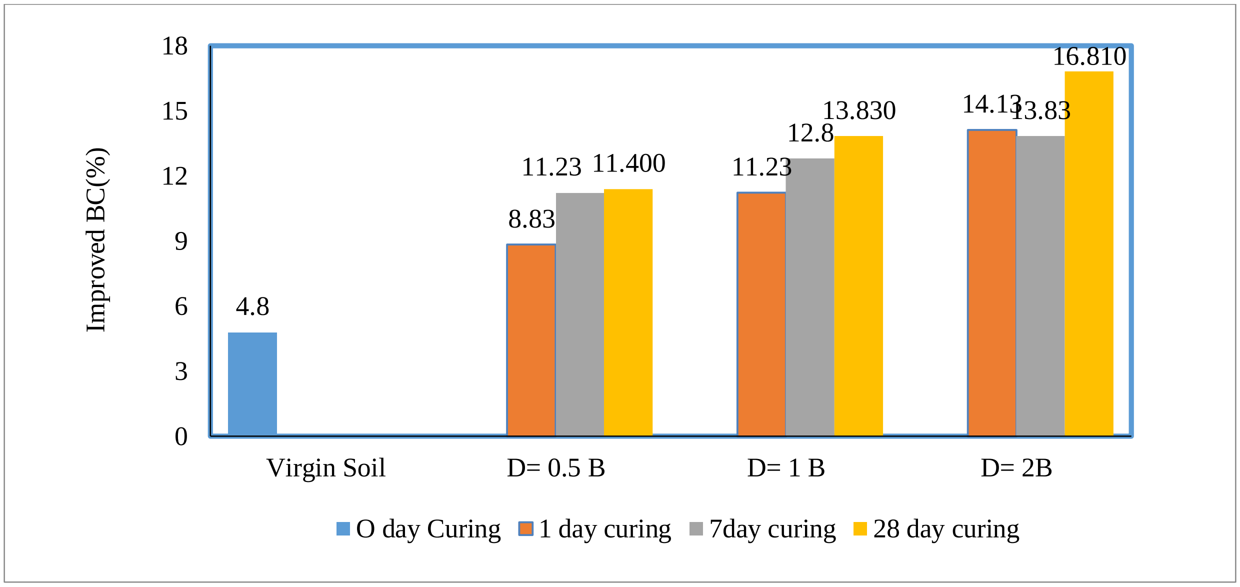

Fig. 10 Improvement of bearing capacity, D=0.5B, D =1B & D=2B (0, 1, 7, 28 days curing)

The test findings show that adding the optimal combination dosage of Kota stone powder and rubber tyre powder significantly increases the bearing capacity of clayey soil. The pozzolanic reactions between the chemicals and the clay soil grains are responsible for this enhancement. Effective packing of connected voids is the outcome of including these stabilizers. It is noted that the bearing capacity values exhibit a significant increase in the D=2B ratio when three ratios (D=0.5B, D=B, and D=2B) are taken into consideration. Moreover, Figure 10 shows the 28-day curing time shows the best carrying capacity value in terms of curing days.

8.2. SEM & XRD Analysis

The SEM image of virgin clay soil shows huge voids in the microstructure of the clay soil with a small bonding. On the other hand, SEM images of the clayey soil particles fill the significant voids and create a significant bonding found in the connections established among the individual soil particles at the optimum combinations of Wastetyre powder and Kota stone powder and also subsequent improvement in Uniaxial compression test of the sample when added with 12% waste tyre powder and 8% Kota stone powder showed the highest compressive strength among all the samples. In addition to this, the dispersion of clay particles also comes to significance in non-dispersive soil. Finally no voids or Spaces are seen in the microstructure of the sample with optimal combinations of the stabilizers.

The addition of waste tyre and Kota stone powder to virgin clay has been demonstrated to alter the distinctive C-S-H and C-A-H phases of cementitious materials using X-ray diffraction research, indicating possible interactions with other minerals and the environment. These interactions impact the strength development and durability of the material, highlighting how crucial it is to comprehend the compositional changes brought about by the addition of additional components in order to improve or alter the material's qualities. Furthermore, the presence of illite and montmorillonite suggests the presence of clay minerals.

However, the identification of calcite suggests the influence of carbonate minerals on the sample's mechanical and chemical properties. These clay minerals and stabilizers may change the sample's flexibility and swelling behavior, demonstrating the intricate interactions between different elements that shape its characteristics.

9. Conclusion

The following conclusions were drawn from the test results.

- At day 28 of curing, there is an enhancement ranging from 4.7% to 16.81% when compared to the bearing capacity values of virgin clayey soil. Conditions D=0.5B, D=1B, and D=2.5B indicate improvements of 11.4%, 13.83%, and 16.81%, respectively.
- As the depth ratio rises, cohesive soil's bearing capability shows an increasing tendency. The increase in overburden pressure linked to deeper depths is the cause of this occurrence. As a result of the increased load, the soil stiffens, which adds to the reported increase in bearing capacity.
- The final result showed a distinct microstructure, which was ascribed to the stabilizing procedure that included Kota stone powder and waste tyre powder. It demonstrated the accurate placement and dispersion of stabilizing agents in the clayey matrix, which resulted in better dispersion, less swelling, and increased bonding, all of which contributed to long-term stability.
- Lastly, the XRD results show that adding waste tyre and Kota stone powders reduces peak intensities in all clay minerals, particularly in montmorillonite. Reduced interplanar spacing indicates stabilization, which is supported by the stabilized soil sample's decreased plasticity, even though there is no obvious connection to soil swelling.

Acknowledgments

Author 1 completed this research work under the guidance of Author 2.

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