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Eco-Friendly Stabilization of Expansive Soil using stone Dust by-Product

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Abstract-- **Expansive soils present significant challenges in civil engineering due to their high swelling and shrinkage characteristics, which adversely affect the performance and durability of foundations, pavements, and other infrastructure. Black cotton soil, widely distributed across many parts of India, exhibits low bearing capacity and considerable volume changes with seasonal moisture variations. At the same time, stone dust generated from quarrying and crushing operations is produced in large quantities, creating environmental and disposal concerns. This study investigates the effectiveness of stone dust as a sustainable stabilizing material for improving the engineering properties of black cotton soil. Experimental investigations were conducted on untreated soil and soil blended with 5% and 10% stone dust by dry weight. Laboratory tests included grain size analysis, Atterberg limits, Modified Proctor compaction, Unconfined Compressive Strength (UCS), and California Bearing Ratio (CBR) tests under both soaked and unsoaked conditions. The results indicate that the inclusion of stone dust improves compaction characteristics, increases maximum dry density, enhances shear strength and bearing capacity, and reduces the adverse effects associated with expansive soil behaviour. Among the investigated mixes, the specimen containing 10% stone dust exhibited the most favourable engineering performance. The study demonstrates that stone dust can serve as an economical and environmentally sustainable stabilizing material for expansive soils while simultaneously promoting the beneficial utilization of quarry waste. This content is based on the experimental work presented in your manuscript.**

Keywords-- **Black Cotton Soil, California Bearing Ratio, Expansive Soil, Soil Stabilization, Stone Dust, Sustainable Construction.**

I. INTRODUCTION

A. General Background

Soil forms the fundamental foundation for all civil engineering structures and plays a crucial role in ensuring the stability and serviceability of buildings, highways, railways, embankments, and other infrastructure. The engineering performance of any structure is highly dependent on the strength, compressibility, and durability of the supporting soil.

However, many naturally occurring soils do not possess the required engineering characteristics and therefore require stabilization before construction. Soil stabilization is the process of improving the physical and mechanical properties of soil through physical, chemical, or mechanical methods to achieve the desired engineering performance. The primary objectives of soil stabilization include increasing bearing capacity, improving shear strength, reducing compressibility, controlling volume changes, and enhancing long-term durability under varying environmental conditions. These improvements contribute significantly to the safety, economy, and service life of civil engineering structures.

Among the various problematic soils encountered in geotechnical engineering, expansive soils represent one of the greatest challenges because of their pronounced shrink–swell behaviour. These soils undergo substantial volume changes in response to seasonal fluctuations in moisture content. During the rainy season, the absorption of water causes swelling, whereas moisture loss during dry periods results in shrinkage and the formation of deep cracks. Such cyclic volume changes induce differential settlement and heaving beneath foundations, leading to structural distress, pavement failures, cracking of floors, and damage to lightly loaded structures. Consequently, improving the engineering behaviour of expansive soils has become an important area of research in geotechnical engineering.

B. Black Cotton Soil

Black Cotton (BC) soil is one of the most widely distributed expansive soils in India, particularly across the Deccan Plateau. It is predominantly formed through the weathering of basaltic rocks and contains a high percentage of montmorillonite clay minerals. The mineralogical characteristics of montmorillonite provide the soil with a high cation exchange capacity and a strong affinity for water molecules, resulting in excessive swelling upon wetting and considerable shrinkage during drying. These characteristics make Black Cotton soil highly problematic for civil engineering applications.

International Journal of Recent Development in Engineering and Technology
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The major engineering problems associated with Black Cotton soil include high plasticity, excessive compressibility, low shear strength, and poor bearing capacity under saturated conditions. The soil generally exhibits liquid limits exceeding 50%, making it soft and highly compressible when wet. Seasonal moisture variations lead to the formation of deep surface cracks that may extend several metres below the ground surface. The sudden reduction in shear strength following water absorption frequently results in foundation settlement and pavement deterioration. Owing to these unfavourable engineering characteristics, untreated Black Cotton soil is generally unsuitable for supporting heavy civil engineering structures without appropriate stabilization measures.

C. Stone Dust as a Sustainable Stabilizer

Stone dust is a finely divided by-product generated during quarrying, crushing, and aggregate production processes. Large quantities of stone dust are produced every year, and its disposal has become an environmental concern because it occupies valuable land and contributes to air pollution. Owing to its non-plastic nature, relatively high specific gravity, and excellent compaction characteristics, stone dust has emerged as a promising stabilizing material for expansive soils. When mixed with clayey soils, stone dust fills the inter-particle voids, improves particle packing, enhances internal friction, and reduces the plasticity of the soil matrix. These improvements contribute to higher dry density, improved strength, and enhanced bearing capacity. Furthermore, the beneficial utilization of quarry waste supports sustainable construction practices by reducing environmental impacts while providing an economical alternative to conventional stabilizing materials.

D. Objectives of the Study

The present investigation aims to evaluate the effectiveness of stone dust in improving the engineering behaviour of Black Cotton soil. Laboratory experiments were conducted on untreated soil and soil mixtures containing 5% and 10% stone dust by dry weight. The study evaluates changes in index properties, compaction characteristics, unconfined compressive strength, and California Bearing Ratio under both soaked and unsoaked conditions. Based on the experimental results, the research identifies the optimum stone dust content capable of improving the engineering performance of expansive soil while promoting the sustainable utilization of quarry waste in geotechnical construction.

II. Literature Review

Mewade et al. (2025) investigated the stabilization of expansive soil using stone dust at different replacement levels and reported a consistent reduction in the Liquid Limit and Plasticity Index with increasing stone dust content. Their study also observed an increase in Maximum Dry Density (MDD) accompanied by a reduction in Optimum Moisture Content (OMC), indicating improved compaction characteristics. Furthermore, the Free Swell Index (FSI) decreased significantly from 85% to 22%, while the Unconfined Compressive Strength (UCS) improved considerably, particularly at higher stone dust replacement levels. These findings confirmed the effectiveness of stone dust in enhancing both the strength and volumetric stability of expansive soils.

Rajashekar et al. (2021) evaluated the engineering behaviour of Black Cotton soil stabilized with varying percentages of stone dust. Their investigation demonstrated that the addition of stone dust increased the dry density of the soil while reducing its moisture requirement during compaction. The optimum improvement was observed at approximately 10% stone dust replacement, where the Maximum Dry Density reached about 1.91 g/cm³ with a corresponding reduction in Optimum Moisture Content. The study concluded that moderate stone dust replacement significantly enhances the compaction characteristics and engineering performance of expansive soils.

Mishra and Mishra (2015) studied the stabilization of Black Cotton soil using fly ash, ferric chloride, and stone dust. Their experimental results indicated a substantial increase in Maximum Dry Density from 1.624 g/cm³ to 1.915 g/cm³ after stabilization. In addition, the California Bearing Ratio (CBR) improved by approximately 170.8%, leading to a considerable reduction in pavement thickness requirements. The researchers concluded that stone dust, when used either independently or in combination with other stabilizing materials, contributes significantly to improved subgrade performance and cost-effective pavement construction.

Divya Jyothi et al. (2024) investigated the application of layered stone dust in Black Cotton soil beds to evaluate its influence on permeability and consolidation characteristics. Their findings revealed that the incorporation of stone dust increased the permeability of the soil by nearly 70% and improved the coefficient of consolidation by approximately 50%. These improvements facilitated faster drainage and reduced swelling pressure, thereby enhancing the long-term stability of expansive soil foundations.

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Dhule et al. (2019) examined the suitability of quarry stone dust as a stabilizing material for weak cohesive soils. Their study concluded that stone dust effectively improves the engineering properties of expansive soils while serving as an economical and environmentally friendly construction material. The researchers highlighted the dual benefit of improving soil performance and utilizing industrial waste that would otherwise contribute to environmental pollution.

III. Materials And Methodology

A. Experimental Materials

1) Black Cotton Soil is used in this investigation was collected from Prathap Singaram Village, Medchal District, Telangana, India. The collected soil is classified as a highly plastic expansive clay containing a significant proportion of montmorillonite, which is responsible for its pronounced shrink–swell behaviour. The soil exhibits low bearing capacity, high compressibility, and considerable volume changes due to seasonal moisture fluctuations, making it unsuitable for direct use as a foundation or pavement subgrade material without stabilization. The chemical composition of the soil is predominantly composed of silica (SiO_2: 48–58%) and alumina (Al_2O_3: 13–22%), with smaller quantities of calcium oxide, magnesium oxide, iron oxide, and organic matter. The natural pH of the soil ranges from 8.7 to 9.5, indicating its alkaline nature.

2) Stone Dust used in the present investigation was obtained from a nearby aggregate crushing plant. The material passing through the 90 µm IS sieve was collected, oven-dried to eliminate moisture, and stored in airtight containers before laboratory testing. Stone dust is a non-plastic granular by-product generated during quarrying and stone crushing operations. Owing to its relatively high specific gravity (2.57), excellent compaction characteristics, and ability to occupy voids within cohesive soil matrices, it serves as an effective stabilizing material for expansive soils. In addition to improving engineering performance, the utilization of stone dust contributes to sustainable construction by reducing industrial waste disposal and minimizing environmental pollution.

B. Experimental Programme

To evaluate the influence of stone dust on the engineering behaviour of expansive soil, laboratory investigations were carried out on untreated Black Cotton soil and soil mixtures containing 5% and 10% stone dust by dry weight. The experimental programme was designed to assess changes in index properties, compaction characteristics, strength, and bearing capacity.

All laboratory tests were conducted in accordance with the relevant Indian Standard (IS) specifications to ensure accuracy and consistency of the experimental results.

C. Laboratory Testing Procedure

1) Grain Size Analysis (IS 2720 – Part 4)

Grain size analysis was performed using the dry sieve analysis method to determine the particle size distribution of the untreated Black Cotton soil. Approximately 500 g of oven-dried soil was passed through a series of standard IS sieves ranging from **4.75 mm to 75 µm** using a mechanical sieve shaker for **10 minutes**. The percentage retained on each sieve and the cumulative percentage passing were subsequently calculated to classify the soil according to its particle size distribution.

2) Atterberg Limits (IS 2720 – Part 5)

The consistency characteristics of the untreated and stabilized soil samples were determined by conducting Liquid Limit and Plastic Limit tests. The Liquid Limit was measured using the standard Casagrande apparatus by recording the moisture content corresponding to 25 blows required to close the groove over a specified distance. The Plastic Limit was determined by rolling the soil into threads of approximately 3 mm diameter until crumbling occurred. These tests were performed to evaluate the influence of stone dust on the plasticity characteristics of Black Cotton soil.

3) Modified Proctor Compaction Test (IS 2720 – Part 8)

Modified Proctor compaction tests were conducted to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the untreated and stabilized soil mixtures. The soil specimens were compacted in a standard cylindrical mould using a 4.9 kg rammer falling freely from a height of 450 mm. Compaction was carried out in five equal layers, each receiving the specified number of blows to ensure uniform compaction throughout the specimen. The resulting moisture-density relationship was used to identify the optimum compaction parameters.

4) Unconfined Compression Strength Test (IS 2720 – Part 10)

The Unconfined Compression Strength (UCS) test was performed to evaluate the improvement in shear strength due to the addition of stone dust. Cylindrical specimens having a height-to-diameter ratio of 2:1 were prepared and tested under axial compression without lateral confinement. The specimens were loaded at a controlled strain rate ranging from 0.5% to 2% per minute until failure occurred.

International Journal of Recent Development in Engineering and Technology
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The peak compressive load obtained during testing was used to calculate the unconfined compressive strength and the corresponding undrained cohesion of each soil mixture.

5) California Bearing Ratio Test (IS 2720 – Part 16)

California Bearing Ratio (CBR) tests were conducted to evaluate the load-bearing capacity of untreated and stabilized soil specimens under both **unsoaked** and **four-day soaked** conditions. The tests were performed using a standard **50 mm diameter plunger** operating at a penetration rate of **1.25 mm/min**. Load values corresponding to various penetration depths were recorded, and the CBR values were calculated in accordance with IS recommendations. These results were subsequently used to assess the effectiveness of stone dust in improving pavement subgrade performance under both dry and saturated field conditions.

D. Research Methodology

The overall research methodology adopted in this investigation is summarized below:

- Collection of Black Cotton soil from the selected site.
- Collection and preparation of stone dust from a local crushing plant.
- Preparation of untreated soil and stabilized mixtures containing **5%** and **10%** stone dust.
- Determination of index properties through Grain Size Analysis and Atterberg Limit tests.
- Evaluation of compaction characteristics using the Modified Proctor Test.
- Assessment of strength improvement through the Unconfined Compression Strength Test.
- Evaluation of subgrade performance using California Bearing Ratio tests under both soaked and unsoaked conditions.
- Comparative analysis of the obtained results to determine the optimum stone dust content for expansive soil stabilization.

IV. Results And Discussion

The laboratory investigations were conducted to evaluate the influence of stone dust on the engineering behaviour of Black Cotton soil. Comparative analyses were performed on untreated soil and soil mixtures containing 5% and 10% stone dust by dry weight.

The experimental programme included grain size analysis, Atterberg limits, Modified Proctor compaction, Unconfined Compression Strength (UCS), and California Bearing Ratio (CBR) tests. The results obtained from these investigations are presented and discussed below.

A. Grain Size Analysis

Grain size analysis was carried out to determine the particle size distribution of the untreated Black Cotton soil.

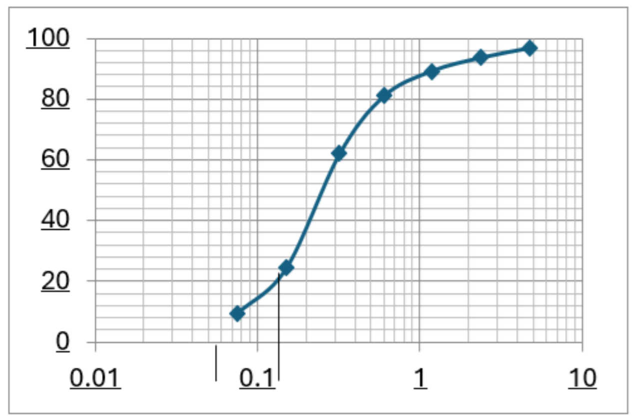

Fig 4.1 shows the results of sieve analysis

The test results indicate that the majority of the soil particles consist of fine-grained material. More than **90%** of the soil passed through the finer sieve sizes, confirming the predominance of clay and silt fractions within the soil matrix. Such a particle size distribution is characteristic of highly cohesive expansive soils and explains the observed high plasticity and susceptibility to moisture-induced volume changes. The presence of a large proportion of fine particles also justifies the need for stabilization before the soil can be used as a reliable foundation or pavement subgrade material.

B. Atterberg Limits

The Liquid Limit and Plastic Limit tests were conducted to evaluate the effect of stone dust on the consistency characteristics of Black Cotton soil.

1) Liquid Limit

The Liquid Limit values obtained for untreated and stabilized soil mixtures are presented

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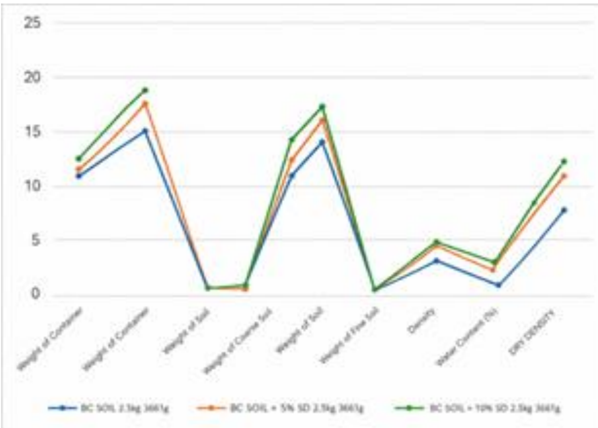

Fig 4.2 shows the results of liquid limit

The recorded Liquid Limit values varied with the addition of stone dust. The experimental values reported in this study are presented without modification and form the basis for the subsequent evaluation of soil behaviour under different stabilization levels.

2) Plastic Limit

The Plastic Limit values for untreated and stabilized soil specimens are presented

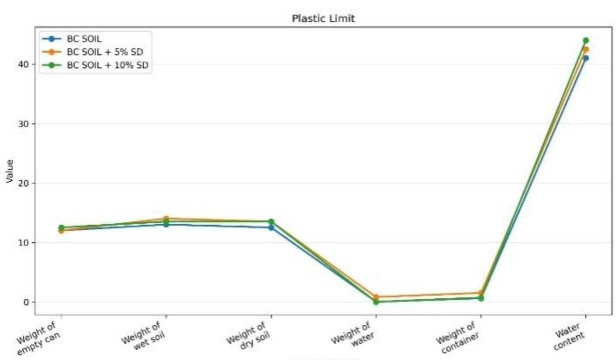

Fig 4.3 shows the results of Plastic Limit

The addition of stone dust influenced the plastic behaviour of the expansive soil. The gradual increase in the Plastic Limit observed in the experimental investigation indicates that the soil required comparatively higher moisture content before entering the plastic state.

This behaviour may be attributed to the interaction between non-plastic granular particles and the cohesive clay matrix, which modifies the consistency characteristics of the stabilized soil.

C. Modified Proctor Compaction Test

The Modified Proctor compaction test was carried out to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of untreated and stabilized soil mixtures.

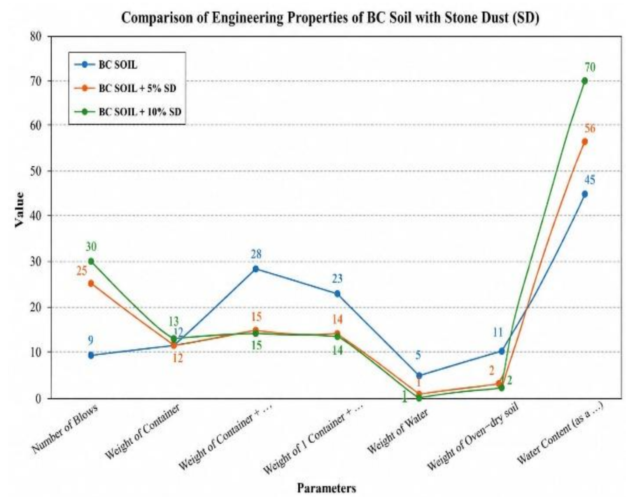

Fig 4.4 shows the results of Modified Proctor Test

The results clearly demonstrate a progressive increase in Maximum Dry Density with increasing stone dust content. The Maximum Dry Density increased from 1.53 g/cm³ for untreated soil to 1.67 g/cm³ at 10% stone dust replacement, indicating improved particle packing and reduced void ratio. The higher specific gravity of stone dust and its ability to occupy inter-particle voids contributed to better compaction characteristics. These findings suggest that the stabilized soil possesses improved structural integrity and is capable of supporting greater loads compared to untreated Black Cotton soil.

D. Unconfined Compression Strength (UCS)

The Unconfined Compression Strength test was conducted to evaluate the improvement in shear strength resulting from the addition of stone dust.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 08, August 2026)

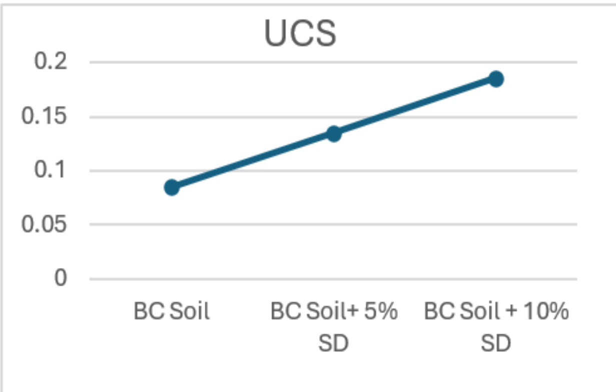

Fig 4.5 shows the results of UCS test

The addition of stone dust substantially improved the compressive strength of Black Cotton soil. The UCS increased from **0.085 MPa** for untreated soil to **0.186 MPa** at **10% stone dust replacement**, representing an improvement of approximately **118.8%**. The enhanced strength is primarily attributed to improved particle interlocking, increased internal friction, and a denser soil structure resulting from the incorporation of non-plastic granular particles. These improvements demonstrate the effectiveness of stone dust as a mechanical stabilizing agent for expansive soils.

E. California Bearing Ratio (CBR)

Tests were performed under both unsoaked and four-day soaked conditions to evaluate the load-bearing performance of stabilized soil.

1) Unsoaked CBR **t**est indicated a continuous increase in penetration resistance with increasing stone dust content. The stabilized specimens exhibited higher resistance throughout the penetration range, confirming that the inclusion of stone dust significantly improves the bearing capacity of Black Cotton soil under normal field conditions.

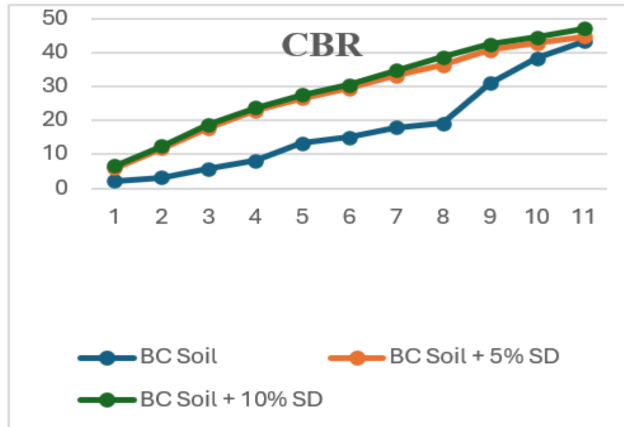

Fig 4.6 shows the Unsoaked CBR results

2) Soaked CBR

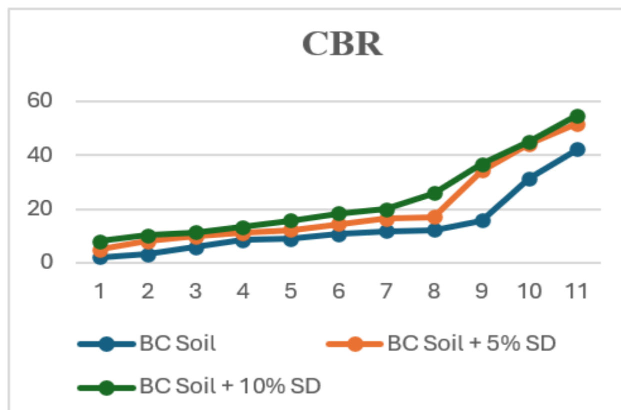

Fig 4.7 shows the results of Soaked CBR

The soaked CBR results demonstrated a considerable improvement in the bearing capacity of stabilized soil under saturated conditions. At **2.5 mm penetration**, the measured resistance increased from **9.1** for untreated soil to **15.9** for the specimen containing **10% stone dust**, representing an improvement of approximately **74.7%**.

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Similarly, at **5.0 mm penetration**, the resistance increased from **12.3** to **25.9**, corresponding to an improvement of approximately **110.5%**. These results confirm that stone dust effectively enhances the moisture resistance and subgrade performance of expansive soils subjected to prolonged saturation.

V. CONCLUSION

The present study investigated the effectiveness of stone dust by-product as a sustainable stabilizing material for improving the engineering characteristics of expansive Black Cotton soil. Laboratory investigations were carried out on untreated soil and soil stabilized with 5% and 10% stone dust by dry weight. Based on the experimental observations presented in the manuscript, the following conclusions are drawn:

- The incorporation of stone dust significantly modified the engineering properties of Black Cotton soil, demonstrating its suitability as an effective stabilizing material for expansive soils.
- The Modified Proctor compaction test indicated a progressive increase in Maximum Dry Density (MDD) from 1.53 g/cm^3 for untreated soil to 1.67 g/cm^3 for the soil containing 10% stone dust, indicating improved compaction characteristics and denser particle packing.
- The Unconfined Compression Strength (UCS) increased considerably with the addition of stone dust. The UCS improved from 0.085 MPa for untreated soil to 0.186 MPa at 10% stone dust replacement, confirming a significant enhancement in shear strength and load-carrying capacity.
- The California Bearing Ratio (CBR) values under both soaked and unsoaked conditions improved substantially with increasing stone dust content. The higher CBR values indicate improved pavement subgrade performance and suggest a reduction in pavement thickness requirements for stabilized soil.
- The experimental investigation identified 10% stone dust as the optimum replacement level among the mixtures investigated, providing the most favourable combination of strength, compaction characteristics, and bearing capacity.
- The utilization of stone dust contributes to sustainable construction practices by converting quarry waste into a value-added engineering material, thereby reducing environmental pollution and minimizing the disposal problems associated with stone crushing industries.
- Based on the experimental results obtained in this investigation, stone dust can berecommended as an economical, environmentally sustainable, and technically viable stabilizing material for expansive soils used in foundations, embankments, and flexible pavement subgrades.

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