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Effects Of Stone Dust On Stabilizing Expansive Soil

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Abstract:
This project focuses on the effective use of stone dust (SD), an industrial by-product, as a sustainable additive for Black cotton soil (BCS) stabilization. Varying proportions of stone dust such as 0%, 2%, 4%, 6%, 8%, 10%, 12%, 14%, 16%, 18%, and 20% by dry weight are incorporated into BCS to evaluate their impact on liquid limit (W_L), plastic limit (Wp), maximum dry density ($\gamma_{d(m)}$), optimum moisture content (W_{opt}), unconfined compressive strength (UCS), California bearing ratio (CBR), and ultrasonic pulse velocity (UPV). The results indicate that SD significantly improves these geotechnical properties of BCS. Among all proportions, 12% SD emerges as the optimum replacement level, showing a notable improvement in both UCS and CBR. Additionally, correlations between UCS and CBR with UPV have been explored. The outcomes of this study are expected to contribute to the planning of field-scale applications for stabilizing BCS using SD.

KEY WORDS: *Unconfined compressive strength (UCS), California bearing ratio (CBR), Ultrasonic pulse velocity (UPV), Geotechnical properties, Optimum moisture content (Wopt), Maximum Dry Density.*

Introduction: Black cotton soil, known for its high clay content and expansive behavior, is one of the most problematic soils encountered in geotechnical engineering. Its tendency to undergo significant volume changes with moisture fluctuations leads to excessive swelling during the wet season and severe shrinkage during dry periods, resulting in ground heave, cracks, and structural failures in pavements, buildings, and other infrastructure. Due to its low shear strength, high plasticity, and poor workability, black cotton soil often requires modification before it can be safely used as a foundation material. Among various ground improvement methods, stabilization using industrial waste materials has gained increasing attention for its economic and environmental benefits. Stone dust, a by-product from stone crushing operations, has shown promise as an effective stabilizing agent for such problematic soils. It is readily available, cost-effective, and capable of altering key geotechnical properties of expansive soils.

Several researchers have examined the role of stone dust in enhancing the performance of black cotton soil. Rajashekar and Manyamkonda (2021) demonstrated that the inclusion of stone dust reduces the plasticity index and improves the maximum dry density and California Bearing Ratio (CBR), indicating better load-bearing capacity and compaction behavior. Bilal and Ahmad (2020) further emphasized the stabilizing effect of stone dust on expansive soils by documenting a significant reduction in swelling potential and an increase in strength parameters with higher dosages of stone dust. In a similar vein, Dar and Bhalla (2020) explored a hybrid approach, combining stone dust with jute fiber, and found that this combination not only improved strength but also enhanced ductility and reduced brittleness in the treated soil. These studies highlight the versatility and effectiveness of stone dust as a sustainable stabilizing agent capable of transforming black cotton soil into a more reliable subgrade material. As such, the use of stone dust in soil stabilization not only addresses the engineering challenges posed by expansive soils but also contributes to sustainable construction practices through the reuse of industrial waste materials.

Materials:

Black Cotton Soil: The soil used in this project was collected from Guntur, a region known for its expansive black cotton soil (Regur Soil), which covers about 20% of India's land area, primarily in tropical and subtropical climates. This soil is rich in clay, particularly montmorillonite, and is known for its dark colour. While it is fertile and supports crops like cotton, it poses significant challenges for construction due to its expansive nature. Black cotton soil undergoes considerable volume changes with moisture fluctuations – swelling when wet and shrinking when dry. This shrink-swell behavior leads to cracking, instability, and poor load-bearing capacity, making it difficult to use for foundations, roads, and other infrastructure. As a result, construction on black cotton soil can lead to foundation failure, surface damage, and overall structural instability. These issues make it essential to apply soil stabilization techniques to improve its properties and ensure the safety and durability of structures built on it.

Fig.1 Black Cotton Soil

Stone Dust: Granite stone dust was sourced from Royal Marbles and Stones, located along the Tirupati to Renigunta route. It is a byproduct of granite cutting and polishing processes, which produce large quantities of fine dust during stone shaping and finishing. This dense, inorganic material is commonly used in construction for applications such as road sub-base, concrete filler, and pavement stabilizer due to its high compressive strength and durability. Its utilization offers significant environmental and engineering benefits by reducing industrial waste accumulation near processing sites and minimizing the risk of dust pollution and surface runoff. Unmanaged granite dust can contribute to environmental degradation and respiratory issues from airborne particles. Incorporating it into soil stabilization and construction promotes sustainable reuse of industrial byproducts, enhances resource efficiency, and reduces environmental impact.

Fig 2 Stone Dust

Experimental Study

i) Specific Gravity: Specific gravity of soil is the ratio of the weight of soil solids to the weight of an equal volume of water at a specified temperature (usually 27°C). It is a key physical property used to identify soil type and calculate other parameters like void ratio and degree of saturation. For most soils, the specific gravity (G_s) ranges from 2.60 to 2.80. The test is commonly performed using a pycnometer or a density bottle. Accurate measurement helps in geotechnical designs involving compaction, consolidation, and shear strength analysis.

Table 1 Specific Gravity values of BC Soil and Stone Dust

Property	Black cotton soil			Stone Dust		
	Trial 1	**Trial 2**	**Trial 3**	**Trial 1**	**Trial 2**	**Trial 3**
Weight of empty SG bottle (W_1) (g)	24.18	24.18	24.18	24.18	24.18	24.18

Weight of SG bottle + Material (W_2) (g)	52.95	58.41	58.41	50.70	48.14	47.78
Weight of SG bottle + Material + Water (W_3) (g)	92.48	95.53	95.53	93.75	91.45	91.13
Weight of SG bottle +Water (W_4) (g)	76.82	76.82	76.82	76.82	76.82	76.82
Specific Gravity	2.194	2.20	2.36	2.70	2.56	2.54
Average	2.26			2.6		

ii) Sieve Analysis: Wet sieve analysis is a method used to determine the particle size distribution of fine and cohesive soils by washing the sample through a set of sieves using water. This helps prevent clumping and ensures accurate separation of particles, especially for soils with high clay or silt content. After washing through a 75 µm sieve, the coarser particles are oven-dried and passed through standard sieves. The weight retained on each sieve is recorded to calculate the percentage retained and percentage passing, which is useful for soil classification and geotechnical analysis.

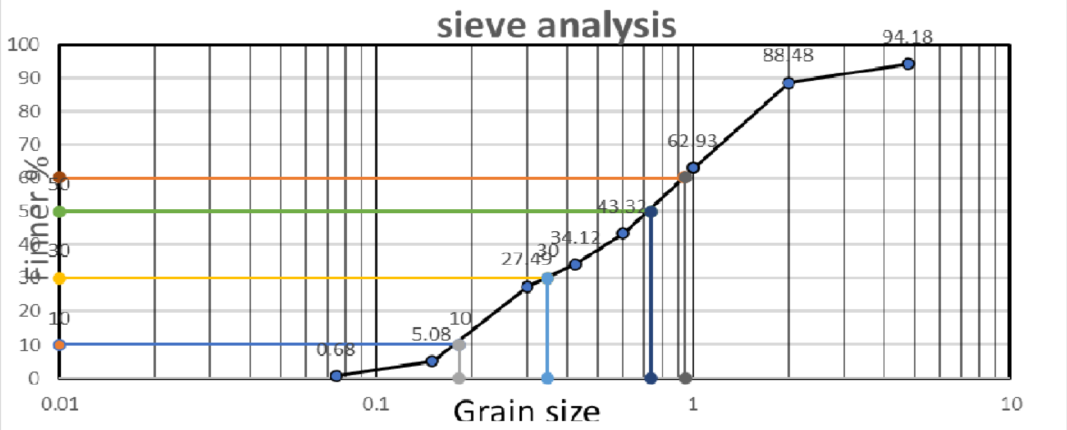

Fig. Grain Size distribution

iii) Atterberg limits: Atterberg limits are a set of tests used to define the moisture content ranges that determine the consistency and behavior of fine-grained soils. The three primary limits are:

Liquid Limit (LL): Moisture content at which soil changes from plastic to liquid state.

Plastic Limit (PL): Moisture content at which soil changes from semi-solid to plastic state.

Shrinkage Limit (SL): Moisture content at which further loss of moisture does not cause a decrease in volume.

The **Plasticity Index (PI)** is calculated as PI = LL – PL, indicating the plasticity range. These parameters are essential for soil classification, predicting soil behavior, and assessing its suitability for construction.

Table. Atterberg Limits

Replacement	Liquid limit	Plastic limit	Plasticity index
0	66.17	30.69	35.48
4	64.05	31.62	32.43

8	59.01	32.05	26.96
12	57.2	32.85	24.35
16	59.04	34.95	24.09
20	59.58	37.02	22.56

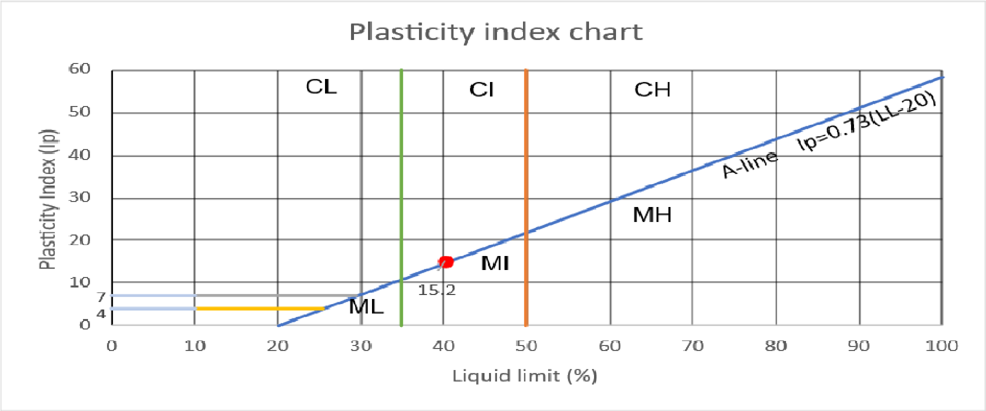

Fig. Plasticity Index chart

Standard Proctor Test:

The fig. illustrates the variation in dry density with water content for soil samples treated with different percentages of stone dust (0%, 4%, 8%, 12%, and 16%). A general trend observed across all mixtures is that dry density increases with rising water content up to an optimum point, after which it declines. This behavior reflects typical soil compaction characteristics, where moisture facilitates better particle rearrangement until saturation begins to reduce compaction efficiency. Among the samples, the untreated soil (0% stone dust) exhibits the lowest dry density throughout the range, indicating poor compaction characteristics. With the addition of 4% and 8% stone dust, there is a noticeable improvement in maximum dry density, with 8% showing a higher peak (~1.62 g/cc) compared to 4%. The most significant enhancement is seen at 12% stone dust replacement, which achieves the highest peak dry density (~2.05 g/cc), suggesting that this is the optimum percentage for stabilization. Beyond this, the 16% replacement shows a decline in dry density, implying that excessive stone dust may lead to over-replacement, which disrupts the soil matrix and reduces compaction efficiency. Overall, the analysis indicates that 12% stone dust replacement yields the most effective stabilization, enhancing the soil's load-bearing capacity and compaction properties.

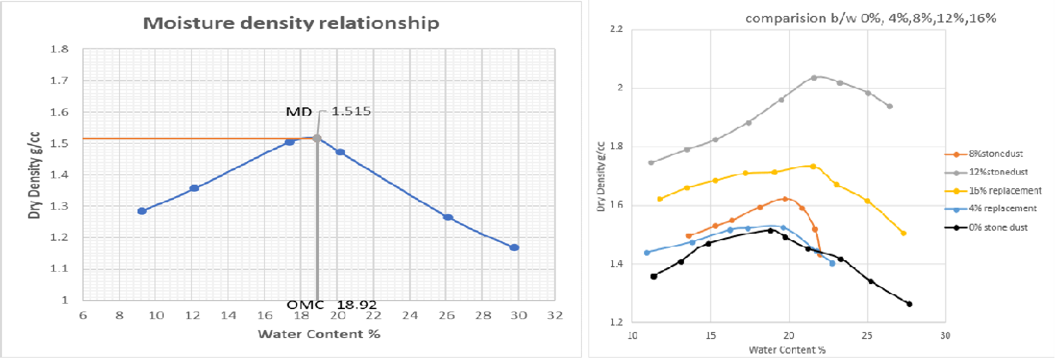

Fig. Standard Proctor Test

Unconfined Compressive Strnegth: The Fig. illustrates the variation in unconfined compressive strength (UCS) of samples with different additive contents over a 7-day curing period. As observed, the UCS increases with additive content up to 12%, which exhibits the highest strength at 39.15 kN/m². The control sample (0% additive) shows the lowest strength, 28.57 kN/m², while intermediate percentages (4%, 8%, and 16%) yield UCS values of 29.98, 34.74, and 37.21 kN/m² respectively. This trend indicates that the inclusion of additives significantly enhances strength up to a certain point, with 12% proving to be the most effective dosage. Beyond this, such as at 16%, a slight reduction in strength suggests that over-addition may be counterproductive. Additionally, the stress–strain curves reveal that the 12% mix not only achieves the highest peak stress but also shows broader strain distribution, implying better ductility and energy absorption. Overall, the analysis highlights that 12% additive content offers optimal performance in terms of early-age compressive strength.

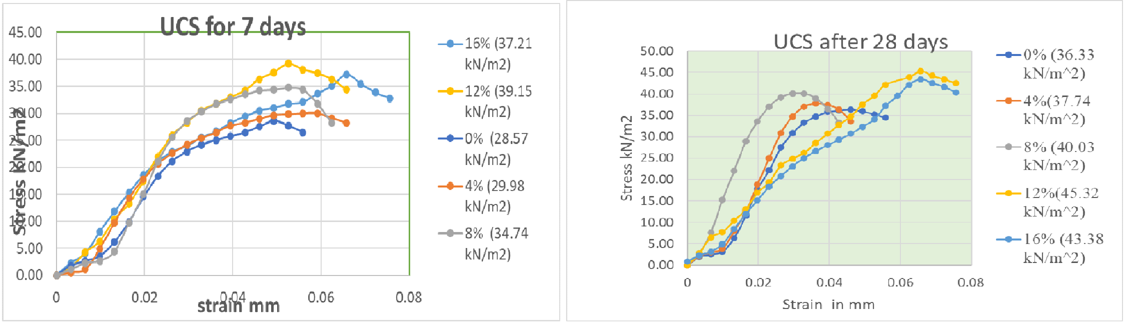

Fig. UCS test data

California Bearing Ratio (CBR): The graph titled "SD Replacement V/S UPV" depicts the relationship between stone dust (SD) replacement percentage and Ultrasonic Pulse Velocity (UPV), an indicator of concrete quality and density. The x-axis represents the percentage of stone dust replacement, while the y-axis indicates the UPV values. From the data, it is evident that the UPV increases steadily as the stone dust content rises from 0% to 12%, peaking at this point. The 12% SD replacement achieves the highest UPV, indicating the densest and most homogenous matrix. This suggests that moderate replacement of stone dust enhances the material's compactness and integrity. However, beyond 12%, the UPV begins to decline, although the values at 14%, 16%, and 18% remain higher than those at lower replacement levels. This downward trend implies that excessive SD content may lead to microstructural discontinuities or poor bonding, slightly compromising the ultrasonic pulse travel. A stone dust replacement of around 12% appears to optimize the internal quality of the material as reflected by UPV. Replacement levels beyond this threshold may reduce the effectiveness, although they still perform better than the control (0%).

Table CBR Test Values

Percentage	0	2	4	6	8	10	12	14	16	18
CBR	25.3	26.8	29.78	31.27	32.75	38.73	38.71	37.22	35.22	35.73

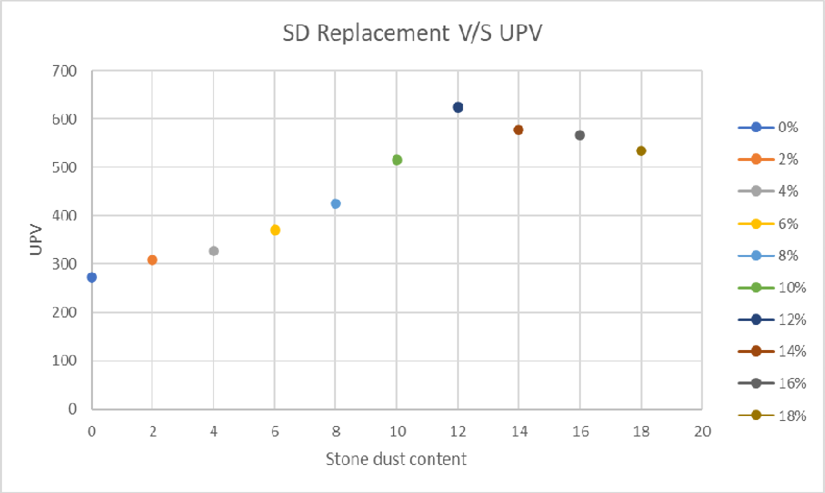

Fig. CBR Test Values

Ultrasonic Pulse Velocity (UPV): The graph titled "SD Replacement V/S UPV" represents how varying percentages of stone dust (SD) replacement affect the Ultrasonic Pulse Velocity (UPV), a key parameter used to assess the quality and uniformity of concrete. The x-axis denotes the SD replacement percentage, while the y-axis shows the UPV values. As the stone dust content increases from 0% to 12%, the UPV shows a consistent upward trend, indicating improved internal density and reduced voids within the material. The peak UPV value is observed at 12% SD replacement, signifying the most compact and homogenous matrix, which likely corresponds to optimal particle packing and better bonding among constituents. Beyond 12%, however, the UPV begins to decline slightly from 14% onward, suggesting that excessive replacement may introduce microstructural weaknesses or lead to suboptimal binder-filler ratios. Overall, the analysis indicates that 12% stone dust replacement yields the highest UPV, hence the best internal quality. While higher replacement levels (up to 18%) still maintain better UPV values than the control sample (0%), the slight reduction beyond 12% implies a threshold beyond which further addition may no longer be beneficial.

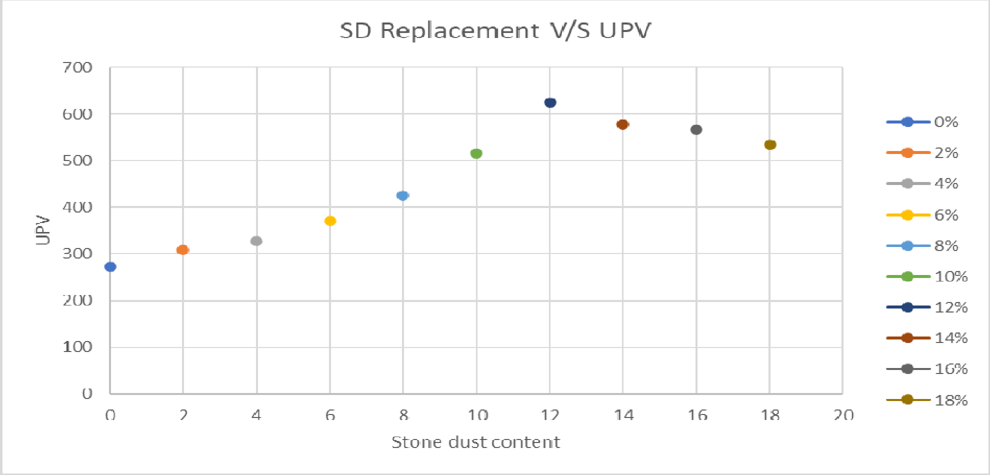

Fig. UPV Test values

Conclusion

The following are the conclusions drawn from the research study based on different experiments that were conducted to stabilize the BC soils.

- Stone dust is effective in stabilizing expansive soils like black cotton soil.

- It significantly improves geotechnical properties such as plasticity index, liquid limit, and shrinkage.
- UCS and CBR values increase with higher stone dust content, enhancing strength and load-bearing capacity.
- UPV tests offer a reliable, non-destructive strength assessment method.
- A clear correlation is observed between UPV and CBR results.
- The optimal stone dust content for maximum improvement is 12%–16%.
- Using stone dust promotes sustainable, eco-friendly, and cost-effective soil stabilization using industrial waste.

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