An Experimental Study on the Stabilization of Expansive Soil Using Marble Dust and Glass Fiber

Sarthak Shukla[1], R.K. Yadav [2]
[1]*M.E. (Student), Jabalpur Engineering College*
[2]*Proffesor, Jabalpur Engineering College*

Abstract — **Expansive soils, such as black cotton soil, cover approximately 20–25% of India's land area and pose significant geotechnical challenges due to their high swelling and shrinkage potential and low load-bearing capacity. These unfavorable properties often lead to structural failures and substantial economic losses. This study investigates the stabilization of black cotton soil using marble dust—an industrial by-product—and glass fibers to enhance its geotechnical performance. Marble dust was added in varying proportions to assess its effect on index properties, while a combination of marble dust and glass fibers was employed for strength-based tests, including Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR).**

The laboratory investigations demonstrated that incorporating marble dust significantly improves the engineering properties of black cotton soil by reducing swelling and shrinkage, improving compaction characteristics, and increasing strength. Further strength-based tests with glass fibers revealed additional gains in load-bearing capacity and ductility, indicating a synergistic effect when used together. This study highlights the potential of utilizing industrial waste materials like marble dust, combined with reinforcing fibers, as a sustainable solution for soil stabilization while contributing to improved geotechnical performance.

I. INTRODUCTION

Expansive soils, particularly black cotton (BC) soils, present considerable challenges in construction due to their pronounced volume changes in response to moisture fluctuations. Predominantly occurring in central India—including states such as Maharashtra, Madhya Pradesh, Karnataka, Andhra Pradesh, Tamil Nadu, and Uttar Pradesh—BC soils cover nearly 20% of the country's land area, amounting to approximately 0.8 million square kilometers. Similar soils are also found extensively in arid and semi-arid regions worldwide. Their expansive behavior is primarily attributed to the high content of the clay mineral montmorillonite.

BC soils generally originate from the weathering of basalt or trap rock. These soils swell significantly upon wetting and shrink when dried, leading to repeated cycles of expansion and contraction. Such behavior often results in severe structural damage to foundations, pavements, canal beds, and linings.

To address these issues, a range of soil stabilization methods has been developed. Historically, lime has been used in small proportions to stabilize expansive clays. However, in recent years, there has been growing interest in utilizing industrial waste materials for soil stabilization. This approach not only enhances the soil's engineering performance but also mitigates the environmental impact of industrial waste disposal. Among these materials, marble dust—a by-product of marble cutting and polishing operations—has shown promising potential.

In India, approximately 5–6 million tons of marble slurry are produced annually. Improper disposal of this slurry contributes to serious environmental problems, including air and water pollution and associated health risks. Employing marble dust in soil stabilization offers a sustainable and environmentally responsible solution to these challenges.

The present study investigates the effectiveness of marble dust in stabilizing BC soil. The research is structured in two phases: first, the characterization of BC soil and marble dust; and second, laboratory testing of soil–marble dust mixtures. The experimental program includes tests such as grain size distribution, differential free swell (DFS), Atterberg limits, compaction characteristics, and unconfined compressive strength (UCS) & California Bearing Ratio (CBR) Test.

Marble dust was incorporated into the soil at proportions of 5%, 10%, and 15% by dry weight to evaluate its effect on index properties. For strength-based tests such as UCS & CBR, a combination of marble dust and glass fibers was used, with glass fiber content varying at 0%, 1%, 2%, and 3%.

II. OBJECTIVES AND SCOPE OF THE STUDY

The primary aim of this experimental study is to evaluate the influence of marble dust and glass fiber on the engineering properties of black cotton soil. To achieve this, an extensive program of laboratory investigations was designed and carried out with the following specific objectives:

1. To critically review existing literature on the application of waste materials such as marble dust, fly ash, glass fiber, and synthetic fibers for soil stabilization.
2. To characterize the physical and engineering properties of black cotton soil, marble dust.
3. To conduct laboratory experiments to assess the changes in index properties and engineering behavior of black cotton soil mixed with varying proportions of marble dust and glass fiber.
4. To analyze and compare the results of laboratory tests on black cotton soil stabilized with different combinations of marble dust and glass fiber.
5. To determine the degree of improvement in the engineering characteristics of black cotton soil due to the addition of marble dust and glass fiber.
6. To promote eco-friendly soil improvement techniques through the effective use of industrial by-products, particularly marble dust and glass fiber.

By addressing these objectives, the study seeks to enhance understanding of the potential of marble dust and glass fiber as sustainable stabilizers for black cotton soil, thereby contributing to environmentally responsible and efficient geotechnical practices.

III. EXPERIMENT OVERVIEW

This chapter presents a review of literature related to the stabilization of problematic soils, particularly black cotton (BC) soil, using marble dust and glass fiber. It provides essential background information on the properties and behavior of BC soil, as well as the characteristics of marble dust and glass fiber as stabilizing agents. A critical examination of previous studies on the performance of BC soil treated with marble dust and glass fiber is also included. Furthermore, various methods and materials used for improving expansive soils are discussed to elucidate the behavior of stabilized soils. This review offers valuable insights into the effectiveness of marble dust and glass fiber in enhancing the engineering properties of BC soil. The objective is to establish a thorough understanding of the improvements in soil performance achievable through the incorporation of these stabilizers.

IV. IDENTIFICATION AND CHARACTERISTICS OF EXPANSIVE SOILS (Black Cotton Soil)

A. Origin and Formation

Black Cotton (BC) soils, widely recognized as swelling soils in India, are predominantly formed through the subaqueous decomposition or in-situ weathering of basaltic rocks. These soils are rich in montmorillonite, a clay mineral that typically develops under alkaline conditions. For this study, the soil sample was collected from Tewar village (Latitude: 23.1544532, Longitude: 79.8539627), located approximately 12 km from Jabalpur, Madhya Pradesh.

B. Soil Chemical properties

The chemical properties of BC soils can vary but generally fall within the following ranges:

Property	Range/Value
Silica (SiO_2)	Less than 20%
Alumina (Al_2O_3)	20–35%
Lime (CaO)	1–8%
Magnesium Oxide (MgO)	1.5–7.5%
Ferric Oxide (Fe_2O_3)	0.9–2.0%
Sulphate (SO_4)	0.5–6.6%
Carbonates (CO_3)	1.8–5%
Organic Matter	Less than 20%
Loss on Ignition (LOI)	4.8–16.5%
pH	6.7–8.9
Desiccation (DES)	13–22%

Table 1.1. Normal range of chemical properties of BC soils (**Kattesh Katti 1979**)

V. MARBLE DUST: CHARACTERISTICS

Marble is a metamorphic rock formed through the recrystallization of pure limestone under high pressure and temperature. The degree of purity of the parent limestone influences the color and texture of the resulting marble, with pure calcite ($CaCO_3$) producing white marble. Known for its strength, durability, and aesthetic appeal, marble is widely used in construction and decorative applications. However, the cutting and polishing processes in marble production generate substantial amounts of waste, creating environmental concerns due to improper disposal.

For the present study, marble dust was collected from a marble industry situated in Bhedaghat, approximately 15 km from Jabalpur, Madhya Pradesh. Marble dust is an ultrafine, densified powder, classified as an industrial waste material, and exhibits the following physical and chemical properties:

1) Calcium Oxide Content: About 30-80% of CaO.
2) Particle Size: Mean grain size between 0.1 to 0.2 mm.
3) Particle Shape: Spherical.

B. Chemical composition

The chemical composition of marble dust varies based on the type of marble and its mineral content. Typically, it includes. - Ghani, A., Ali, Z., Khan, F.A. et al (2020).

Property	Range/Value
Lime (CaO)	28–85%
Silica (SiO_2)	3–30%
Magnesium Oxide (MgO)	10–25%
Iron Oxides (FeO & Fe_2O_3)	Variable %

Table 1.2. Chemical composition of marble dust.

VI. GLASS FIBER AS A SOIL REINFORCEMENT

Glass fiber, commonly referred to as fiberglass, is a high-performance, lightweight material consisting of extremely fine strands of glass. It is primarily composed of silica (SiO_2), with additional constituents such as alumina, calcium oxide, boron oxide, and magnesium oxide. Glass fiber is commercially available in multiple forms, including chopped strands, mats, woven fabrics, and continuous filaments, making it suitable for a wide range of engineering applications. Its notable properties include high tensile strength, moderate stiffness, and excellent resistance to moisture and chemical degradation.

In geotechnical engineering, particularly in soil stabilization, glass fiber contributes significantly to the enhancement of tensile strength and ductility of expansive soils like black cotton soil. Its inclusion mitigates the shrink-swell behavior typical of such soils, thereby improving their load-bearing capacity and dimensional stability. Due to its non-biodegradable nature, glass fiber provides durable and long-term reinforcement, making it an effective component in sustainable ground improvement techniques.

In the present study, glass fiber was procured from a local vendor in Nagpur, Maharashtra, for its use in combination with industrial byproducts such as marble dust, aiming to develop an eco-friendly and cost-effective approach to enhancing the geotechnical performance of problematic soils.

S.no	Property	Specification	Method of Test
1	Zirconia (ZrO2)	16% minimum	X-ray fluorescence
2	Density	2.68 ± 0.3 g/cm³	EN 14649
3	Tensile Strength	1000 MPa to 1700 MPa	ISO 3341
4	Filament Diameter	8 to 30 microns	ISO 1888
5	Roving Tex	± 10% from nominal	EN ISO 1889
6	Cut Length	± 3 mm from nominal	
7	End Count	± 20% from nominal	Physical count
8	Loss on Ignition (Combustible Matter)	± 20% of the nominal value or ± 0.3% whichever is greater, subject to an upper limit of 3% by weight	ISO 1887
9	Strength Retention (Category A)	≥ 250 MPa	EN 14649
10	Strength Retention (Category B)	≥ 250 MPa	EN 14649
11	Strength Retention (Declared Value)	The declared value shall be the characteristic (5% fractile) strength retention	

Table 1.3. Physical properties of Glass Fiber (Rapid Building Solutions, Nagpur)

VII. SAMPLE PREPARATION

The oven-dried black cotton soil was uniformly blended with varying proportions of marble dust, calculated as a percentage of the dry soil weight. The dry mixtures were subsequently soaked in water to ensure thorough hydration and homogenization. After allowing the blends to rest for 24 hours, they were oven-dried in preparation for subsequent testing. For the strength-based experiments, the prepared samples consisted of different combinations of marble dust and glass fiber, as detailed below:

- 5% marble dust with 0%, 1%, 2%, and 3% glass fiber.
- 10% marble dust with 0%, 1%, 2%, and 3% glass fiber.

- 15% marble dust with 0%, 1%, 2%, and 3% glass fiber.

VIII. RESULTS

A. *Summarized Results of Investigation*

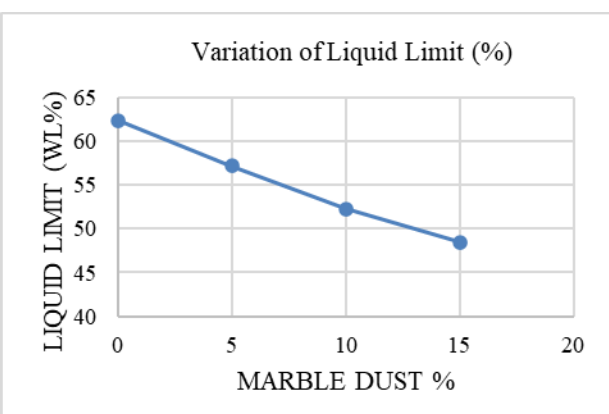
The Table 1.4 contains the summary of the series of tests done on black cotton soil with varying percentage of marble dust and glass fiber.

S. No.	Parameter	RESULTS						
		BC 0	BC 05		BC 10		BC 15	
I	INDEX PROPERTIES							
1	Soil Classification	CH	MH		MH		MI	
2	Liquid Limit (%)	62.34	57.14		52.28		48.43	
3	Plastic Limit (%)	32.12	31.64		31.2		30.27	
4	Plasticity Index (%)	30.22	25.5		21.08		18.16	
5	Shrinkage Limit (%)	10.41	12.57		14.67		17.17	
II	COMPACTION CHARACTERISTICS							
1	OMC (%)	21.06	19.03		17.84		16.76	
2	MDD (%)	1.59	1.68		1.76		1.81	
IV	SWELLING CHARACTERISTICS							
1	DFS (%)	61.90	38.10		30.00		25.00	
IV	STRENGTH CHARACTERITICS							
1	UCS (KN/m²)	80.06	0%	101.01	0%	117.53	0%	129.06
			1%	128.63	1%	135.76	1%	140.30
			2%	137.02	2%	167.23	2%	175.49
			3%	175.36	3%	187.30	3%	191.92

Table 1.4. Summary of results

B. *Liquid limit*

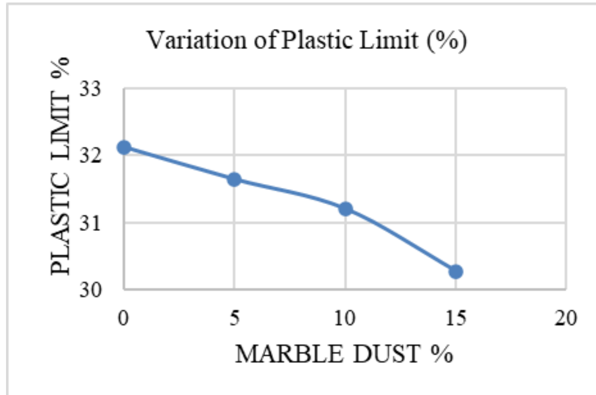
The liquid limit (LL) of the black cotton (BC) soil exhibited a notable reduction from 62.34% to 48.43% with the increase in marble dust content from 0% to 15%. This decline reflects a reduction in the soil's water retention capacity, which can be attributed to the coarser texture and non-plastic nature of marble dust, leading to a decrease in overall soil plasticity.



Graph 1.1. Variation of Liquid Limit

C. *Plastic limit*

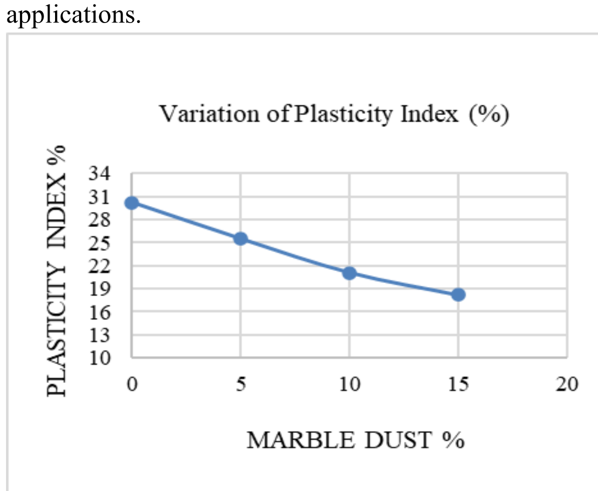
The plastic limit (Wp) of black cotton (BC) soil decreased from 32.12% to 30.27% with the addition of marble dust,. This decrease indicates a reduction in soil plasticity, which enhances soil stability and reduces swell–shrink behavior — characteristics that are beneficial for geotechnical and foundation engineering applications.



Graph 1.2. Variation of Plastic Limit

D. *Plasticity Index*

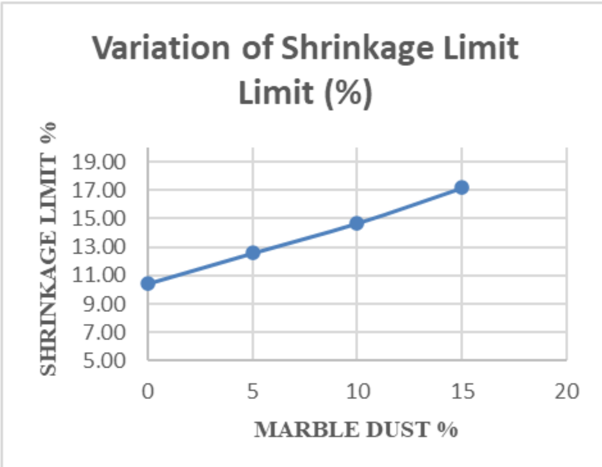
The plasticity index (PI) of black cotton (BC) soil decreased significantly from 30.22% to 18.16% with the increasing addition of marble dust. This reduction indicates an improvement in soil workability and a decrease in its expansive behavior, both of which are crucial for enhancing the soil's performance in construction and geotechnical applications.



Graph 1.3. Variation of Plasticity Index

E. *Shrinkage Limit*

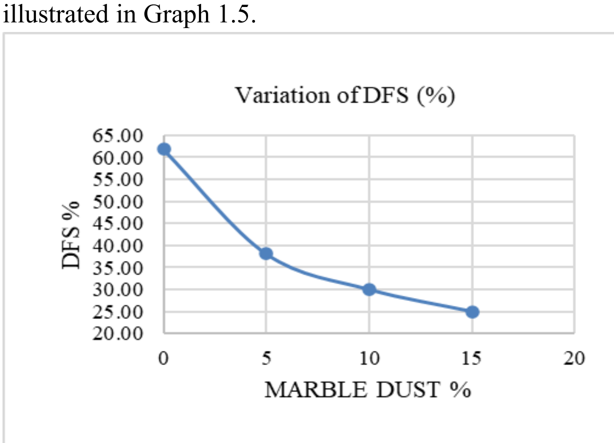
The shrinkage limit (SL) of the black cotton soil increased from 10.41% to 17.17% with the incremental addition of marble dust. This increase signifies a reduction in the soil's shrinkage potential, thereby improving its dimensional stability during drying, which is beneficial for maintaining structural integrity in construction applications.



Graph 1.4. Variation of Shrinkage Limit

F. *Swelling Characteristics*

The Differential Free Swell (DFS) value of the black cotton soil decreased markedly from 61.90% to 25.00% with the addition of marble dust, indicating a substantial reduction in the soil's swelling potential. This decline underscores the effectiveness of marble dust in mitigating the expansive characteristics of BC soil, thereby enhancing its suitability for construction and geotechnical applications. The trend in DFS variation with increasing marble dust content is illustrated in Graph 1.5.

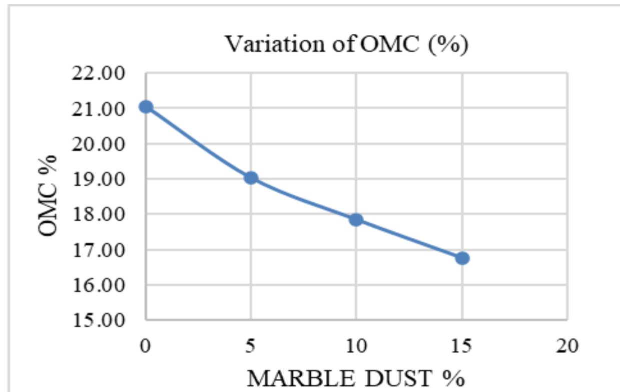


Graph 1.5. Variation of DFS

G. *Modified (Heavy) Compaction Characteristics*

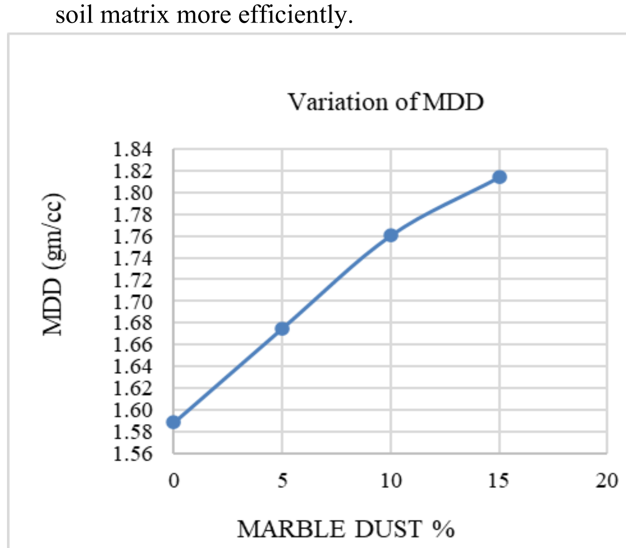
Proctor compaction tests (Heavy Compaction Method) were carried out on black cotton soil–marble dust mixtures in accordance with IS: 2720 (Part 7). The results revealed the following significant trends:

- The Optimum Moisture Content (OMC) decreased from 21.06% to 16.76% with the addition of marble dust. This reduction suggests that less water is required to achieve maximum compaction, likely due to the coarser and non-plastic nature of marble dust, which leads to reduced water absorption by the soil matrix.
- Maximum compaction was achieved with the addition of marble dust, primarily due to its lower water absorption capacity compared to black cotton (BC) soil. The presence of marble dust reduces the amount of moisture retained in the mix, thereby facilitating denser packing of soil particles during compaction.



Graph 1.6. Variation of OMC

- The Maximum Dry Density (MDD) increased from 1.59 g/cc to 1.81 g/cc with the incorporation of marble dust, indicating an improvement in soil strength and a reduction in void ratio. This enhancement is attributed to the densification effect provided by the finer and heavier marble particles, which fill the voids within the soil matrix more efficiently.



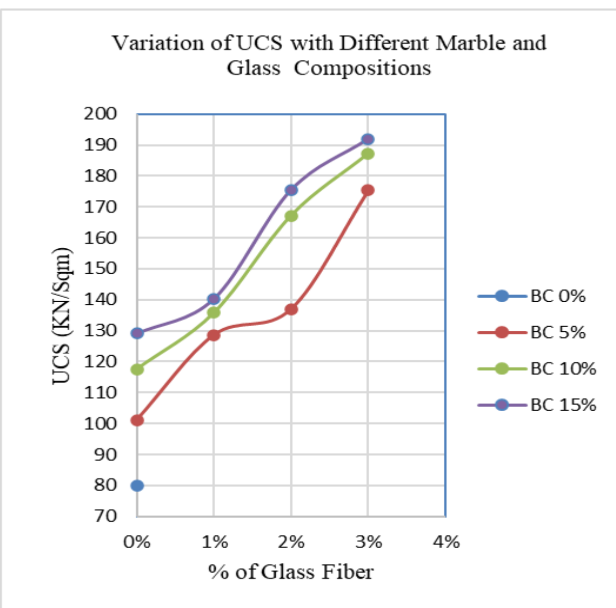
Graph 1.7. Variation of MDD

The variations in Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) are presented in graph 1.6 and graph 1.7, respectively. These results indicate that the addition of marble dust significantly improves the compaction characteristics of black cotton soil, thereby enhancing its suitability for construction and geotechnical applications.

H. Unconfined Compressive Strength(UCS)

The Unconfined Compressive Strength (UCS) of the black cotton (BC) soil exhibited a consistent increase with the incremental addition of marble dust. The UCS improved from 80.07 kN/m² for untreated soil (BC 0) to 101.09 kN/m² with 5% marble dust (BC 5 – 0% fiber), 117.53 kN/m² with 10% marble dust (BC 10 – 0% fiber), and 129.07 kN/m² with 15% marble dust (BC 15 – 0% fiber). This trend demonstrates the beneficial effect of marble dust in enhancing soil strength.

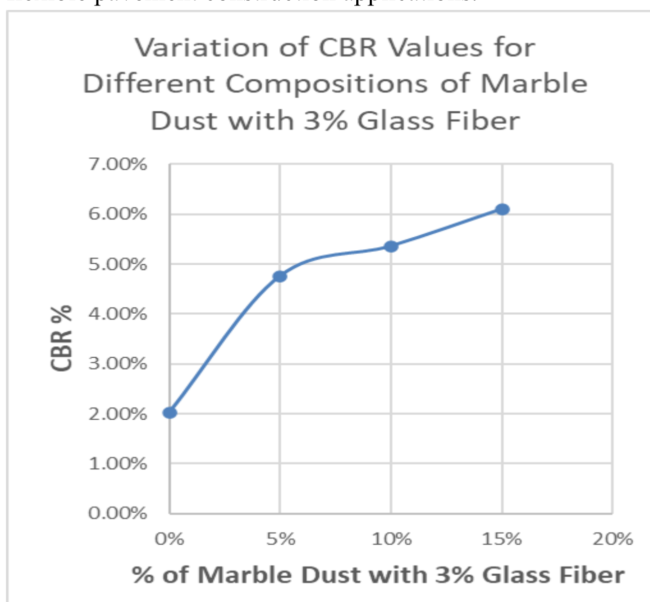
The addition of glass fiber further amplified the UCS at each level of marble dust. For BC 5, UCS increased from 101.09 KN/m² (without fiber) to 175.36 kN/m² at 3% glass fiber. Similarly, for BC 10, UCS rose from 117.53 kN/m² to 187.30 kN/m², and for BC 15, the maximum UCS of 191.92 kN/m² was attained at 3% glass fiber. These findings suggest that the optimum blend for strength enhancement is a combination of 15% marble dust and 3% glass fiber, resulting in the highest UCS value of 191.92 kN/m².



Graph 1.8. Variation of UCS with different composition of marble dust and glass fiber

I. California Bearing Ratio (CBR Test)

The CBR test was conducted for the virgin BC soil (BC 0) and for selected optimum mixtures of marble dust and glass fiber. The optimum mixes identified based on earlier strength tests were 5% marble dust with 3% glass fiber (BC 5 3%), 10% marble dust with 3% glass fiber (BC 10 3%), and 15% marble dust with 3% glass fiber (BC 15 3%). The CBR of the untreated BC soil was found to be 2.08%. With the addition of 5% marble dust and 3% glass fiber, the CBR increased to 4.76%. Similarly, for the BC 10 3% mix, the CBR further improved to 5.36%, and the highest CBR of 6.10% was attained with the BC 15 3% mix. These results indicate that the optimum blend for maximum subgrade strength and improved load-bearing capacity is 15% marble dust combined with 3% glass fiber. This improvement suggests the treated soil is more suitable for pavement subgrades, offering enhanced durability, reduced deformation under load, and better performance in flexible pavement construction applications.



Graph 1.9. Variation of CBR Values for Different Compositions of Marble Dust with 3% Glass Fiber

IX. CONCLUSION

This study was conducted to assess the effectiveness of marble dust, an industrial byproduct abundantly produced by the stone processing industry, as a soil stabilizing additive for improving the geotechnical properties of black cotton (BC) soil. The experimental investigation examined the influence of varying percentages of marble dust on the index properties, swelling and shrinkage behavior, compaction characteristics, and unconfined compressive strength (UCS) & California Bearing Ratio (CBR) of BC soil.

Based on the experimental results and observations, the following conclusions were drawn:

1. Index Properties:

- The liquid limit of black cotton soil decreased significantly from 62.34% to 48.43% as the marble dust content increased from 0% to 15%, indicating a reduction in water retention capacity and plasticity.
- The plastic limit decreased slightly, from 32.12% to 30.27%, indicating reduced soil plasticity, improved workability, and lower moisture sensitivity.
- The plasticity index declined markedly from 30.22% to 18.16%, reflecting a notable reduction in soil plasticity and expansive behavior, making the soil more stable for construction purposes.
- The shrinkage limit increased from 10.41% to 17.17%, indicating better dimensional stability during drying, which is advantageous for minimizing volume changes in foundation soils.

2. Compaction Characteristics:

- The Optimum Moisture Content (OMC) of black cotton soil decreased from 21.06% to 16.76%, indicating a reduction in water demand required to achieve maximum compaction due to the coarser, less absorbent nature of marble dust.
- The Maximum Dry Density (MDD) increased from 1.59 g/cc to 1.81 g/cc, reflecting a denser and stronger soil matrix, attributed to the effective filling of voids and improved particle interlocking with the addition of marble dust.

3. Swelling Characteristics:

- The differential free swell (DFS) reduced from 61.90% to 25%, indicating a reduction in the expansive nature of the soil.

4. Unconfined Compressive Strength (UCS):

- The UCS of the BC soil improved significantly, increasing from 80.06 kN/m² to 191.92 kN/m², indicating enhanced load-bearing capacity.

5. California Bearing Ratio (CBR):

- The CBR of the BC soil improved significantly, increasing from 2.08 % to 6.10 %, indicating improved subgrade strength and load-carrying capacity.

The laboratory investigations clearly demonstrate that the incorporation of marble dust significantly enhances the index properties of black cotton (BC) soil. The experimental results revealed a substantial reduction in swelling and shrinkage behavior, improved compaction characteristics, and a marked increase in unconfined compressive strength. The simultaneous reduction in plasticity and expansiveness, along with enhanced strength parameters, confirms the effectiveness of marble dust as a stabilizing agent and Glass Fiber as a soil reinforcement for BC soil in a variety of geotechnical applications.

This study underscores the potential of utilizing industrial waste materials, such as marble dust, as a sustainable and cost-efficient solution for soil stabilization. Beyond improving soil performance, this approach also contributes to environmental sustainability through effective waste management and resource reuse in civil engineering practices.

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