BLACK COTTON SOIL STABILIZATION BY USING BIO-ENZYME AND MARBLE DUST POWDER FOR PAVEMENT SUB-GRADE

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ABSTRACT

Black Cotton Soils (BCS) pose challenges due to their susceptibility to vertical ground movements, particularly affecting Geotechnical Structures and Pavement. These issues are exacerbated in areas with poor subgrade soil, where pavement construction becomes prohibitively expensive. To address this, there's a growing shift towards exploring non-traditional, sustainable, and cost-effective alternatives. Despite this need, research on the reaction mechanisms of non-traditional soil stabilization methods is limited. In this context, the study explores the use of Marble Dust (MD) as a soil stabilizer and Bio Enzyme (BE), a natural and non-toxic liquid enzyme that expedites soil stabilization during construction. The study's objectives include evaluating geotechnical parameters like compaction, Atterberg's limits, and unconfined compressive strength while varying the ratios of marble dust and bio enzyme. Additionally, it employs microstructural-driven analytical techniques to investigate the reaction mechanism behind this soil stabilization approach. The findings hold promise for mitigating reactive soil expansion and promoting sustainable solid waste management practices.

Key Words: *Subgrade, Black Cotton Soil, Marble Dust, Bio-enzyme, Stabilization.*

1 INTRODUCTION

1.1 GENERAL

Black soils, also known as Regur soils, constitute a substantial portion of India's landscape, encompassing about 20% of the country's total land area. Their distinctive black color is attributed to the presence of humus, and they exhibit a sticky texture when wet due to their high clay content. While black soils are deficient in nitrogen, they contain sufficient phosphorous for plant growth. In hilly regions, particularly in the Deccan Plateau and the plateaus of Madhya Pradesh, Saurashtra, Malwa, and Maharashtra, these soils tend to be thin and sandy. These soils are characterized by essential clay minerals such as montmorillonite and cover an extensive area of approximately 300,000 square kilometres. However, from an engineering standpoint, black soils possess certain properties like high compressibility, low bearing capacity, and low shearing strength. For instance, Maharashtra, a state in India, is renowned for its black cotton soil, which constitutes over three-fourths of its land area, particularly in semi-dry plateau regions. However, constructing roads on highly clayey soils like black cotton soil in Maharashtra can be intricate and is generally discouraged due to potential complications.

In summary, black soils are a significant soil type in India, distinguished by their unique characteristics and engineering challenges. The current research effort on subgrade improvement focuses on the study of soil samples collected from Wagholi, Pune, Maharashtra.

1.2 AN OVERVIEW OF SOIL STABILIZATION

The most successful approach of ground improvement found worldwide is soil stabilization. In the last forty years, particularly, a variety of soil stabilization techniques have been rigorously applied in field applications and have undergone thorough testing by researchers. These include mechanical stabilization, which densifies the soil by expelling air from the spaces without significantly changing the water content, and chemical stabilization, which contains chemicals to improve soil characteristics, which in turn improve ground strength. For soil stabilization, it is essential to comprehend the properties of the materials that will be combined and the outcomes after mixing. There is other more variables that affect this method's success in addition to the choice of materials and doses.

1.3 OBJECTIVES

1. The research aims to evaluate the engineering properties of native soil and blended soil samples with varying proportions of Marble Dust and bio enzyme, aiming to determine the optimal blend proportion for desired soil characteristics and stability.
2. The study aims to investigate the engineering properties of blended soil samples using CBR and UCS methods to identify the most effective blend.
3. It will design and compare flexible pavements using different proportions of the Blends to assess their suitability for pavement construction.
4. The research will perform a cost analysis based on flexible pavement thickness, comparing the expenses of traditional methods to the proposed Blends for soil stabilization.

2 MATERIALS

2.1 BLACK COTTON SOIL

Usually made up of silicates of aluminium, iron, magnesium, and/or other metals, clayey soil is a particular form of soil that contains these tiny particles. Due to the significant amount of clay deposited, this soil gets sticky when wet. Because of its extreme hardness, the lumps are difficult to cure so they can be used in road building.

The chemical composition of this black cotton soil is given in the following Table 1

Serial Number	Parameter	Unit	Observed Value	Methods
1	Moisture	%	4.67	IS:1514-1959
2	Calcium Oxide	Ppm	14.10	IS:6932(Part1)-1973
3	Magnesium Oxide	Ppm	17.20	IS:6932(Part1)-1973
4	$CaCO_3$	%	4.00	IS:1514-1959
5	Alumina	%	0.30	IS:6932(Part1)-1973
6	Iron	%	0.15	No Specific Standard values are available
7	Volatile Matter at 150^0C	%	0.40	

8	Carbonate	%	1.00	
9	Acid Insoluble Matter	%	0.60	
10	pH	-	6.90	
11	Total Solids	%	4.60	
12	Calcium Carbonate	%	0.08	
13	Specific Gravity	-	2.00	

2.2 MARBLE DUST

Waste marble dust is produced because of the building industry's rising demand for marble products. About 25% of the marble that is cut into blocks ends up as dust because of the marble dust and water mixing during the cutting process. Brick, building materials, ceramics, and infiltration techniques are the most prevalent fields and uses.

The chemical composition of this marble dust is given in the following Table 2

Serial Number	Parameter	Unit	Observed Value
1	Specific gravity (G_s)	-	2.64
2	Uniformity coefficient (C_u)	-	2.85
3	Coefficient of curvature (C_c)	-	1.19
4	Density(g/cm^3)	-	2.8
5	SiO_2	%	71.18
6	Al_2O_3	%	19.42
7	Fe_2O_3	%	3.7
8	CaO	%	4.45
9	MgO	%	1.25

2.3 BIO-ENZYME

The engineering properties of soil are improved, higher soil compaction densities are made possible, and stability is increased by the use of bio-enzyme, a natural, nontoxic, non-flammable, noncorrosive liquid enzyme formulation fermented from vegetable extracts. The bio-enzyme binds to the soil's microorganisms and encourages their fusion through the formation of strong covalent connections. It was offered by an organisation called "Infinita Biotech," and the bio enzyme's name is "ECO TERRAIN."

The following combinations of Marble Dust and bio enzyme are used for various Blends:

Sr.no	Notation for various Blends	Blend Combination
1	S1	100% Virgin Black Cotton Soil
2	S2	5% Marble Dust + 2% Bio enzyme + 93% Black Cotton Soil
3	S3	10% Marble Dust + 2% Bio enzyme + 88% Black Cotton Soil
4	S4	15% Marble Dust + 2% Bio enzyme + 83% Black Cotton Soil

3 RESEARCH METHODOLOGY

To assess the engineering properties of both the virgin soil and the blended soil combination, a series of tests have been conducted following the initial basic physical and chemical composition analysis, with the test results previously outlined.

Laboratory Testing	
• Index properties of soil ➢ Grain Size analysis. ➢ Consistency Indices.	• Engineering Property of Soil ➢ Specific Gravity test. ➢ Free Swell Index. ➢ Permeability. ➢ Compaction test. ➢ Direct Shear test. ➢ Unconfined compression test. ➢ California Bearing ratio.

4 RESULTS AND DISCUSSION

1. Grain Size Analysis

For the Sieve analysis, 14 Soil samples are taken for sieving. Each soil sample is sieved with standard sieve sizes of, 4.75, 2.36, 1.18, 1, 0.600, 0.300, 0.150, 0.075, PAN, respectively.

Table 3 Grain Sieve Analysis of Black Cotton Soil

Sr.no	Samples	Mechanical Sieve Analysis			Total
		Gravel (%)	Sand (%)	Silt and Clay (%)	
1	1	32.95	66.85	0.2	100
2	2	31.2	68.6	0.2	100
3	3	17.05	82.7	0.25	100
4	4	12.8	87	0.2	100
5	5	15.5	84.3	0.2	100
6	6	12.75	86.3	0.95	100
7	7	16.95	82.75	0.3	100
8	8	18.75	80.85	0.4	100
9	9	19	80	1	100
10	10	15.5	84	0.5	100
11	11	18	81.5	0.5	100
12	12	17.5	81.7	0.8	100
13	13	10.5	89.3	0.2	100
14	14	33	66.9	0.1	100

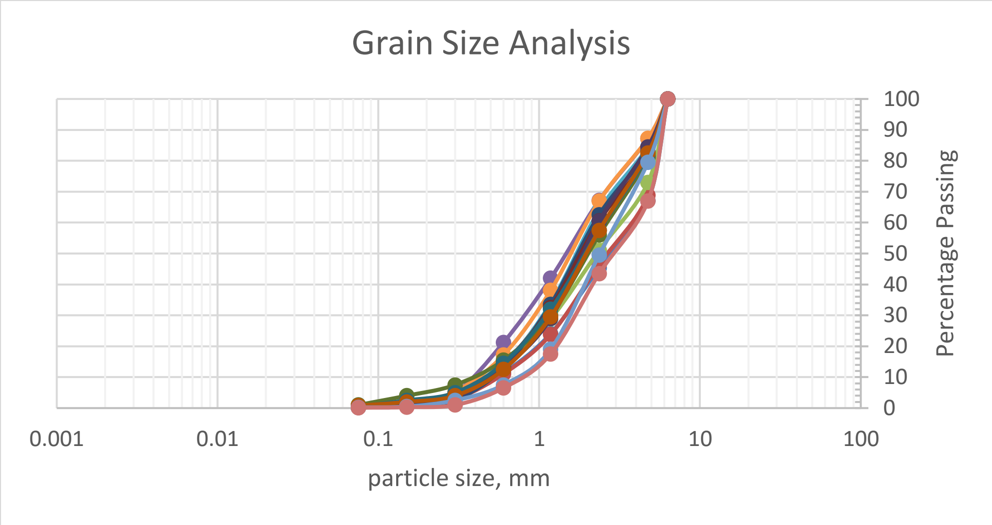

Figure 1 Grain sieve analysis graph

The particle size distribution curves of black cotton soil are shown in the above figure and summarised in Table 3.

2. Atterberg's Limit - Consistency Indices

The study focused on establishing the Consistency Indices, namely the Liquid Limit, Plastic Limit, and Shrinkage Limit, for both Black Cotton Soil and three distinct Blended samples. The outcomes of these assessments are detailed in Table 4, with Figure 2 offering a visual representation of the collected data.

Table 4 Consistency Indices for different Blends of Black Cotton Soil

Blends	S1	S2	S3	S4
Liquid Limit	56.07	51.053	61.32	58
Plastic Limit	39.95	23.623	44.995	44.63
Shrinkage Limit	38.5	28.2	25.8	22.35

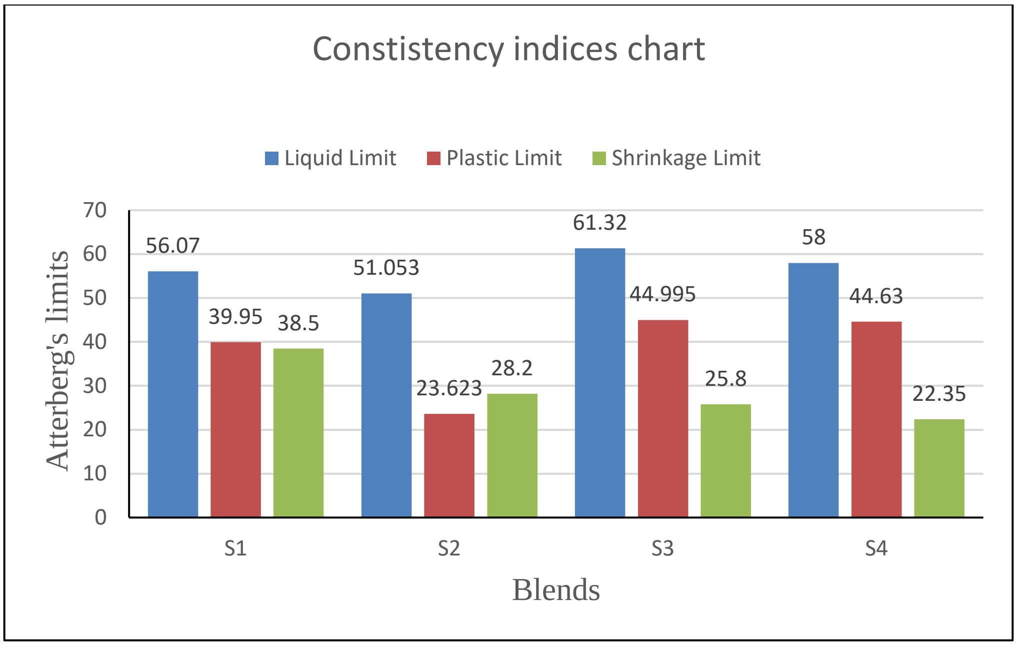

Figure 2 Consistency Indices Chart of Various Blended Soil Samples

3. Specific Gravity

In the laboratory, Specific Gravity was determined for Black Cotton Soil samples blended with Marble Dust and Bio-enzyme. The average values for each blend can be found in Table 5, while Figure 3 provides a graphical representation of how Specific Gravity varies with different blend proportions. These findings have a substantial impact on the assessment of soil stability, compaction, and behaviour, particularly in the context of pavement design and construction.

Table 5 Specific gravity of Soil Samples

Notation	Blended Soil Mixture	Specific Gravity
S1	100% BCS	2.2
S2	5% MD + 3% BE + 92% BCS	2.34
S3	10% MD + 6% BE + 84% BCS	2.42
S4	15% MD + 9% BE + 76% BCS	2.45

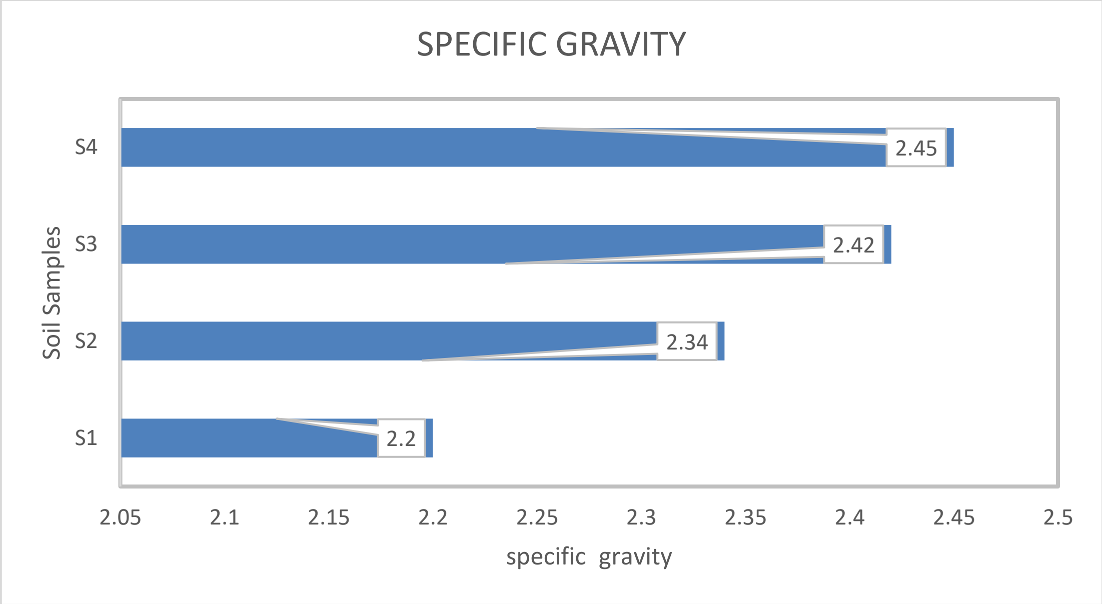

Figure 3 Specific Gravity for Soil sample of different Blends

The Specific Gravity of the Virgin Soil sample (S1) is measured as 2.2, while for the S2 blend, it increases to 2.34. Further, for the S3 and S4 Blends, the Specific Gravity values are determined as 2.42 and 2.45, respectively.

4. Compaction Test

The compaction test, which aims to increase soil density by eliminating voids, was conducted to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for Blends containing Marble Dust and Bio-enzyme. The results for optimum moisture content and maximum dry density across various soil sample Blends presented in Table 6. These findings are visually represented in Figure 4. This data is crucial for understanding the compaction properties of the soil Blends and assists in identifying the necessary moisture content for achieving maximum density during road construction and pavement design.

Table 6 OMC and MDD for Soil Sample of different Blends

Blends	OMC, (%)	MDD, (g/cc)
S1	15	1.39
S2	21	1.43
S3	18	1.453
S4	21	1.85

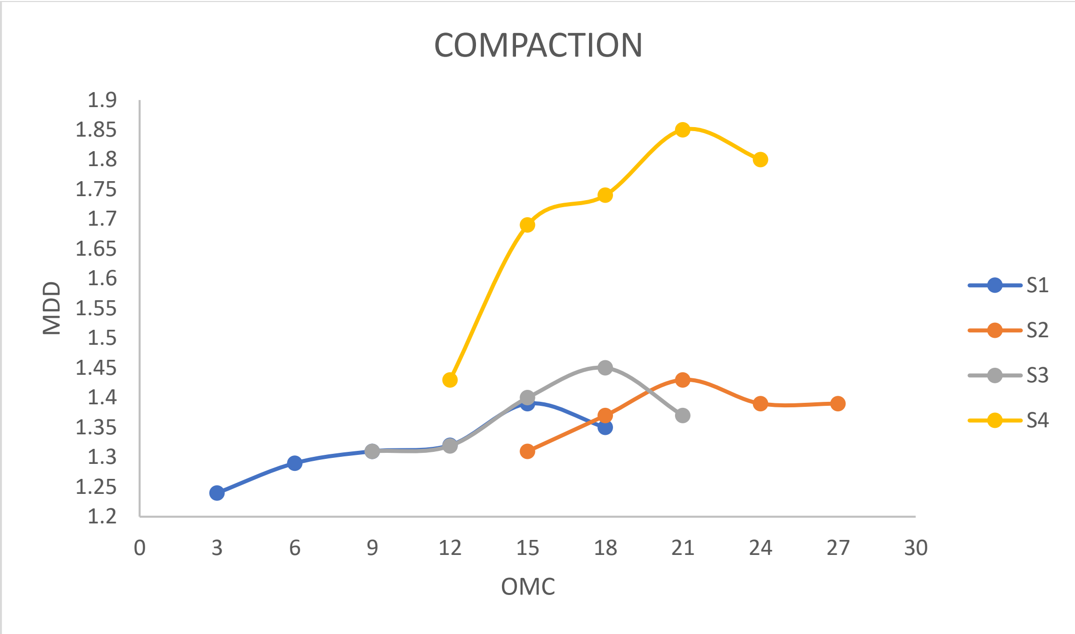

Figure 4 Moisture Content and Dry Density for Soil sample of different Blends

It is observed that the optimum moisture content for the soil sample of Blend S1 and Blend S3 increases by 40% compared to the virgin soil sample (S1), while for the soil sample of Blend S4, it increases by 20%. In terms of maximum dry density, the soil samples of Blends S1, S2, and S3 exhibit increases of 2.8%, 4.5%, and 33.09%, respectively, compared to the virgin soil sample (S1).

5. Free Swell Index Test

The free swell index test assesses soil's swelling potential, a critical factor linked to substructure distress and foundation failure. Results presented in Table 7 and visualized in Figure 5 offer insights into the soil's free swell index, representing the percentage increase in volume upon water exposure. Analyzing data in Table 7 and referring to the bar graph helps identify variations in swelling behaviour among different soil samples, including Blends and the virgin soil.

Table 7 Free Swell Index for Soil Sample of Various Blends

Blended Soil Samples	Free Swell Index, (%)
S1	55.49
S2	48.78
S3	29.09
S4	21.61

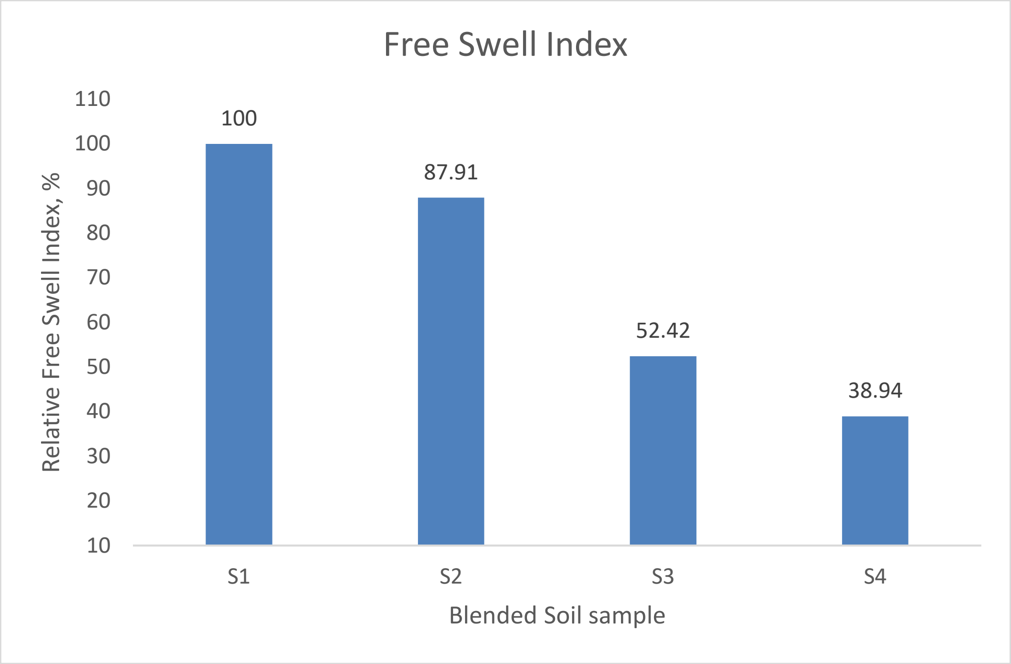

Figure 5 Free Swell Index for Soil sample of Various Blends

This indicates a decrease in the Free Swell Index by 12.09%, 47.57%, and 61.05% respectively, when compared to the Free Swell Index of the virgin soil (S1).

6. Permeability Test

The Permeability test measures how quickly water can flow through soils, a property influenced by soil grain structure and pore spaces. This test is essential for geotechnical investigations, helping assess how efficiently water can permeate soil layers in the designated area, crucial for construction planning. The results of the Permeability test can be found in Table 8, along with a graphical representation in Figure 6. These findings offer valuable insights into soil permeability, guiding construction project planning and execution.

Table 8 Coefficient of Permeability for different Blends of Soil

Blended Soil sample	Coefficient of Permeability, cm/s (10^{-4})
S1	232
S2	156
S3	144
S4	148

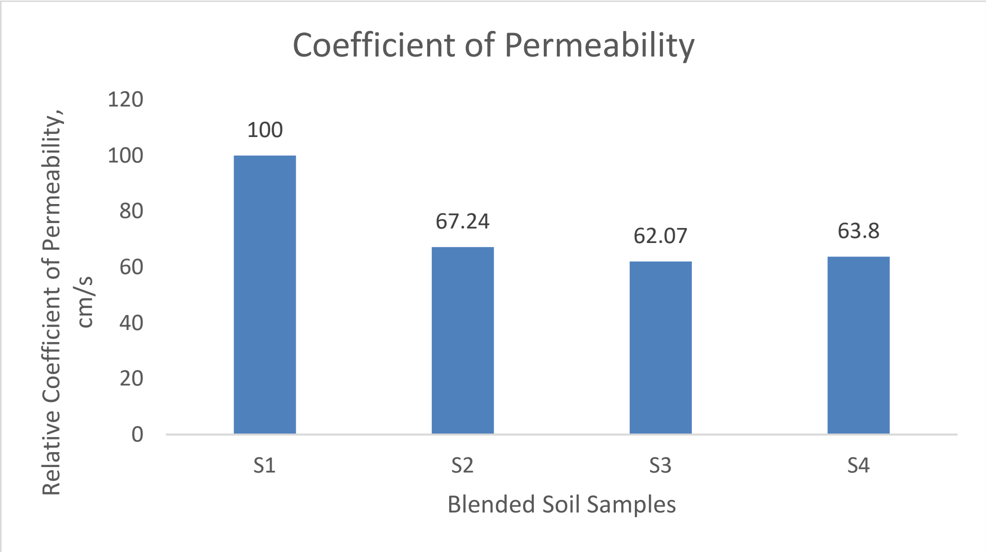

Figure 6 Coefficient of Permeability for various Blends of Soil

Specifically, the Relative Coefficient of Permeability for the soil sample of virgin soil (S1) decreases by 67.24%, 62.07%, and 63.8% for Blends S2, S3, and S4, respectively.

7. Direct Shear Test

The Direct Shear test is a method used to determine the consolidated drained shear strength of soils. The outcomes of this test are presented in Table 9 and visually represented in Figure 7. By scrutinizing these results, one can evaluate the shear strength characteristics of the soil Blends. These findings play a critical role in comprehending the stability and load-bearing capacity of the soil in geotechnical applications. They inform the design and analysis of structures like foundations, retaining walls, and facilitate slope stability assessments. Furthermore, they provide valuable insights into the soil's shear behavior, aiding in the development of suitable soil stabilization and reinforcement techniques.

Table 9 Maximum Shear Stress for different Blends

Normal Stress, N/cm2	Max Shear Stress, N/cm2			
	S1	S2	S3	S4
5	5.32	6.48	9.21	11.51
10	6.07	10.2	12.36	14.38
15	7.82	11.53	17.44	20.15

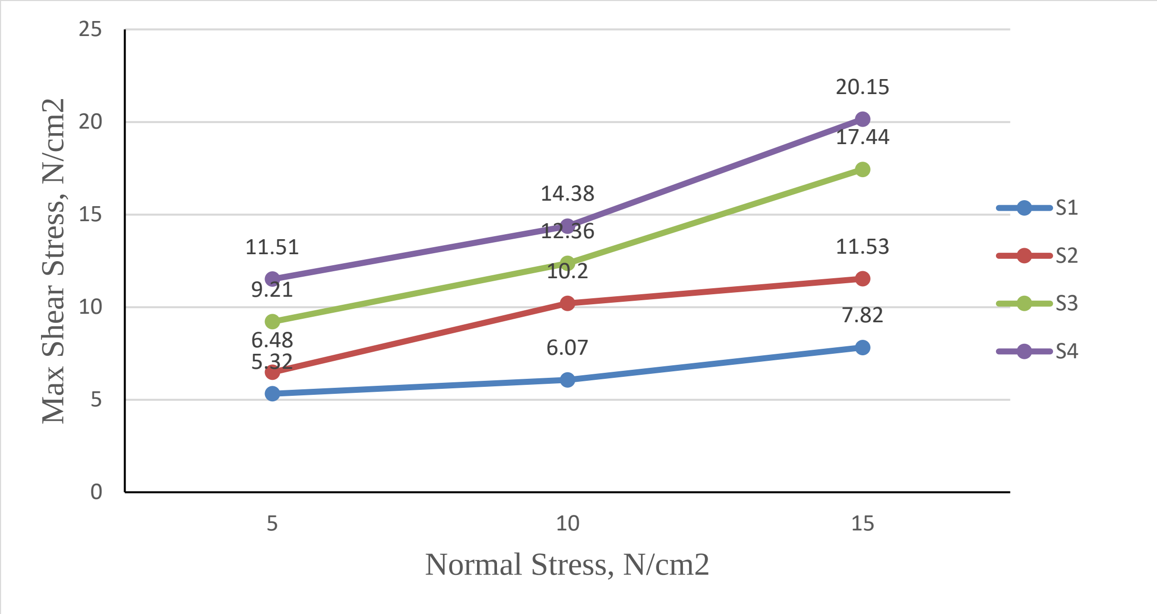

Figure 7 Shear Stress for different Soil samples

Table 10 Cohesion and Angle of Internal Friction for various Blends

Blended Soil sample	**Cohesion (C), N/cm²**	**Angle of Internal Friction (φ)**
S1	3.9033	14^0
S2	4.3533	27^0
S3	4.7733	40^0
S4	6.7067	41^0

The angle of internal friction increased by approximately 1.9 times, 2.8 times, and 2.9 times, respectively, compared to 100% virgin soil (S1). Similarly, the cohesion increased by 11.52%, 22.28%, and 71.82%, respectively, compared to the virgin soil (S1) for the various soil samples of Blends S2, S3, and S4.

8. Unconfined Compression Strength

The Unconfined Compression Test is a widely employed method for evaluating the Unconfined Compressive Strength of cohesive soil specimens. The results of this test, displayed in Table 11 and visually depicted in Figure 4.8, offer valuable insights into the strength properties of the studied materials. This test is instrumental in gauging the material's capacity to withstand compressive forces without experiencing substantial deformation or failure, providing essential data for engineering and construction applications.

Table 11 Unconfined compression strength values

Blends	Strain	Strain, %	UCS Test Value (KPa)
S1	0.01956	1.9	104
S2	0.03476	3.5	212
S3	0.05862	5.9	360
S4	0.06585	6.6	375

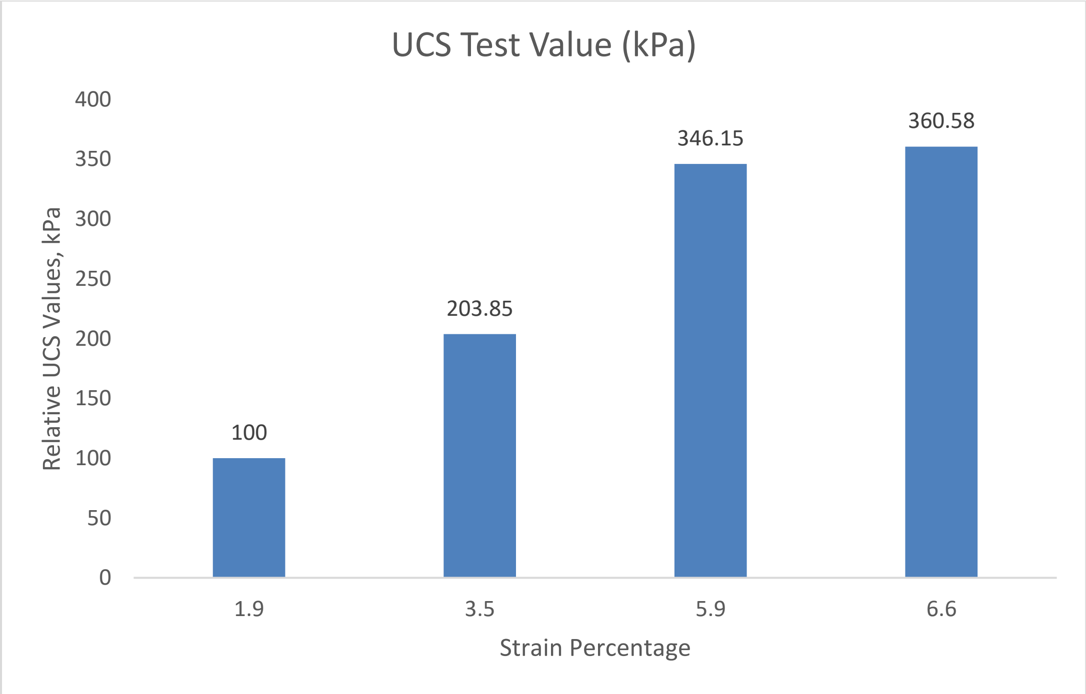

Figure 8 Unconfined Compression Strengths for various Soil sample

The Relative UCS values for Blends S2, S3, and S4 are 203.85%, 346.15%, and 360.58%, respectively. In other words, the UCS values increased by approximately 2 times, 3.46 times, and 3.6 times, respectively.

9. California Bearing Ratio Test

The California Bearing Ratio (CBR) test was conducted on soil samples containing various Blends of Black Cotton Soil, Marble Dust, and Bio-enzyme, assessing the strength characteristics of both soaked and unsoaked soil samples. The resulting CBR values for each condition can be found in Tables 12 and 13. Furthermore, the Unconfined Compression Test established the penetration depth versus load relationship for the diverse soil Blends. The CBR values, calculated at penetrations of 2.5mm and 5mm, were illustrated in Figure 9 for the unsoaked soil samples. These findings are pivotal in assessing the suitability and performance of the soil Blends in construction applications, offering insights into their load-bearing capacity and behavior under varying moisture conditions.

Table 12 CBR Values for Unsoaked Soil sample Blends

Blends	CBR unsoaked, (%)
S1	2.54
S2	5.63
S3	7.69
S4	15.91

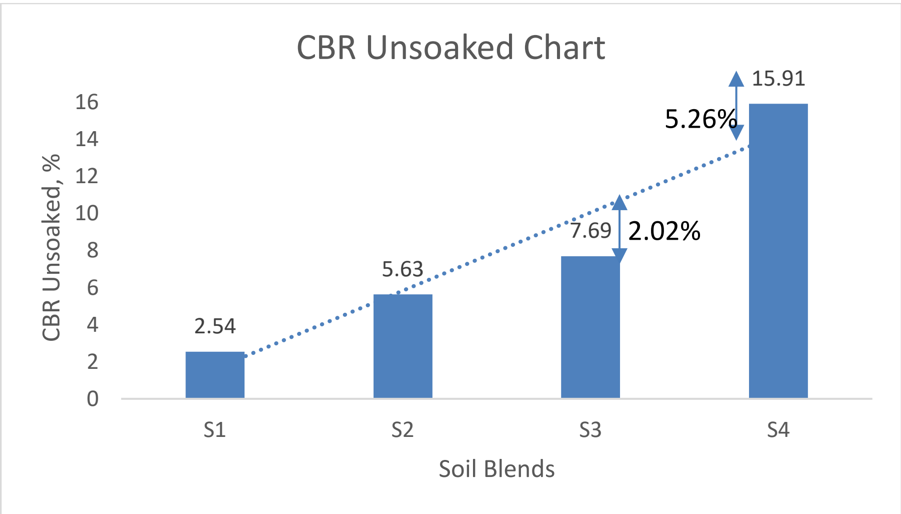

Figure 9 Unsoaked CBR Values for Soil sample of Various Blends

The results indicate a consistent increase in the Unsoaked CBR values for each soil sample blend. Specifically, compared to the Virgin Soil (S1), the Unsoaked CBR value increased by approximately 2.21 times for Blend S2, 3 times for Blend S3, and 6.26 times for Blend S4.

Table 13 CBR Values for Soaked Soil sample Blends

Blends	CBR soaked, (%)
S1	1.26
S2	4.32
S3	6.84
S4	13.91

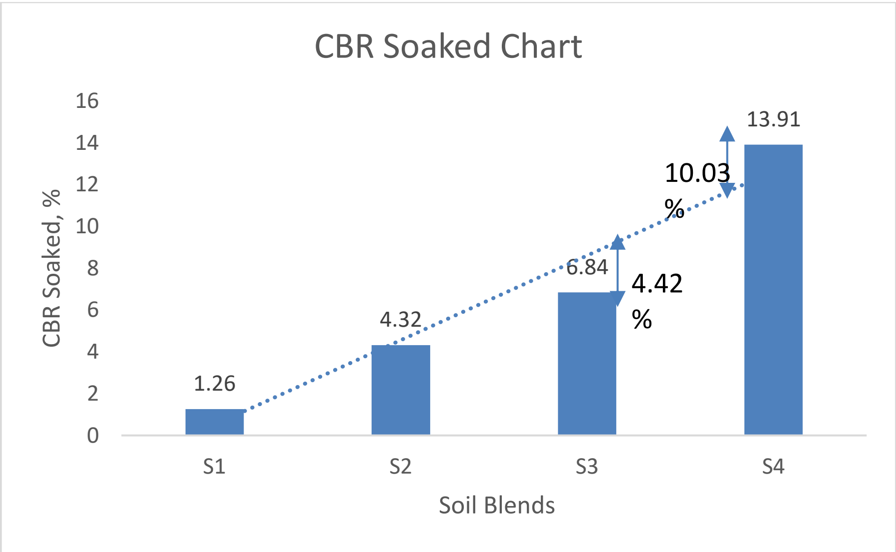

Figure 10 Soaked CBR Values for Soil sample of various Blends

Compared to the Black Cotton Soil, the Soaked CBR values increased approximately by 3.43 times for Blend S2, 5.42 times for Blend S3, and 11 times for Blend S4. These increments indicate a substantial enhancement in the soil's stability and strength. Overall, these findings demonstrate the positive effects of the various soil sample Blends on soil stability, particularly under soaked conditions. The increased Soaked CBR values signify improved strength and densification of the soil, suggesting enhanced suitability for construction applications.

10. COST ANALYSIS

Cost analysis is concluded for following data

1. Four lane dual carriageway
2. Initial traffic in the year of completion of construction = 1495 CVPD (sum of both directions)
3. Traffic growth rate = 7 %
4. Design life = 15 years
5. Vehicle damage factor based on axle load survey = 3.9 standard axle per commercial vehicle
6. Design CBR of sub-grade Soil = 5%
7. Lane Distribution factor = 0.45

In the context of designing flexible pavements, a critical cost analysis has been conducted to assess the financial implications of different Soaked California Bearing Ratio (CBR) values—specifically, 5%, 7%, and 15%. The analysis estimates expenses related to implementing the pavement design under various CBR conditions, including material costs, construction methods, labor, and equipment expenses.

Table 14 Estimated Cost Comparison of Designed Flexible Pavement

Sr. No.	CBR Value, %	Pavement Thickness, mm	Estimated Cost, ₹
1	5	605	3,83,44,180
2	7	590	3,76,67,700
3	12	555	3,15,79,380

5 CONCLUSIONS

1. The results of Grain Size Analysis indicate that the maximum dominancy of Silt and Clay is around 79.2% and above in most of the 14 samples which clearly indicate that the given Soil sample is Expansive in nature. Grain Size Analysis indicate that particle size distribution is more or less same across all the Soil samples.

2. The Atterberg's limit test results reveals that the Shrinkage Limit of the various Blended Soil samples decreases by 42% compared to Virgin Soil sample (S1), whereas the Plastic Limit and Liquid Limit for Soil sample of all three Blends increase by 12% and 3%,

respectively over that for Virgin Soil sample (S1). This is due to the addition of marble dust to soil which led to decrease in plasticity and water-holding capacity and reduced shrinkage potential. These enhancements in the soil's characteristics improve its strength and stability, making it more suitable for various engineering applications.

3. The Specific Gravity of blended Soil sample S2, S3, and S4 increases by 6.4%, 10%, and 11.4% respectively, when compared with Virgin Soil sample (S1). This is due to porosity of particles decreases and leads to densification.

4. The Compaction test results indicates the Maximum Dry Density for Soil sample of Blend S4 increased to 1.85 g/cc at Moisture Content 21% from 1.39 g/cc at Moisture Content 15% for Virgin soil sample (S1). However, the Maximum Dry Density for Soil sample of Blend S3 is 1.453 g/cc at Moisture Content 18% and that of Blend S2 is 1.43 g/cc at Moisture Content 21%. Thus, S3 blend is denser due to the resistance of the flocculated structure to the compaction process providing the advantage of improved CBR value.

5. Free Swell Index values for Soil sample of Blend S2, S3, and S4 are 48.78%, 29.09%, and 21.61% respectively, when compared to Free Swell Index of 55.49% for Virgin Soil sample (S1). This is due to the process of flocculation of clay particles, reducing the attraction of moisture and thereby reducing the swelling activity of the soil.

6. Coefficient of Permeability for blended Soil sample S2, S3, and S4 reduces by 32.7%, 37.9%, and 36.2% respectively, when compared to Coefficient of Permeability of Virgin Soil sample (S1). This is due to of addition of Marble Dust and Bio-enzyme which reduces the porosity and it restricts the seepage of water through the soil.

7. It is observed from Direct Shear Strength test that as Marble Dust and Bio-enzyme content in the Blended Soil sample is increased, three times increase in the Angle of Internal Friction (φ) and 71.82% increase in Cohesion (C) is observed for Soil sample of Blend S4 as compared to Virgin Soil sample (S1). This is due to particle interlocking, providing a binding effect, and promoting improved compaction.

8. Unconfined Compression Strength for blended Soil sample S2, S3, and S4 increases by 2 times, 3.46 times, and 3.6 times, respectively when compared to Unconfined Compression Strength of Virgin Soil sample (S1). This significant increase in strength attributed to the chemical reactions that occur between the calcium content in Marble

Dust and Bio-enzyme and the silica and alumina present in the Soil. These reactions lead to the formation of cementitious compounds.

9. The CBR of Unsoaked Soil sample Blends S2, S3, and S4 increases by 2.2 times, 3 times, and 6.3 times respectively, when compared to CBR of Unsoaked Virgin Soil sample (S1) and the CBR of Soaked Soil sample Blends S2, S3, and S4 increases by 3.4 times, 5.4 times, and 11 times when compared to CBR of Soaked Virgin Soil sample (S1). This is due to formation of physical and chemical bonds between the soil particles and blend of bio-enzyme and marble dust. This binding effect reduces particle movement and sliding under loads leading to increased load-bearing capacity.

10. The estimation of pavement thickness was conducted based on the CBR values of the blended soil samples. Among the samples, Blend S2 with a 5% CBR value had a pavement thickness of 605mm, Blend S3 with a 7% CBR value had a thickness of 590mm, and Blend S4 with a 15% CBR value had a thickness of 555mm. A comparison of these samples revealed a reduction in pavement thickness. Specifically, Blend S3 showed a decrease of 15mm, while Blend S4 experienced a significant reduction of 50mm compared to the pavement thickness of Blend S2. These findings emphasize the potential advantages of using soil blends with higher CBR values, as they result in a reduced pavement thickness, potentially leading to cost savings in pavement construction.

11. The cost analysis of the designed flexible pavement clearly indicates that as the CBR value increases, the cost decreases. A thorough comparison of the cost for different CBR values reveals significant reductions. Specifically, when comparing the cost of the designed pavement for a 7% CBR of Blend S3 to the value to that of a 5% CBR value of Blend S2, a noticeable reduction of 5.4% is observed. Furthermore, the cost of the designed pavement for a 15% CBR of Blend S4 value shows a substantial reduction of 18.32% when compared to the cost for a 5% CBR value of Blend S2. These findings underscore the cost-effectiveness of higher CBR values in the design of flexible pavements.

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