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Stabilization of Expansive Soil Using Marble Dust and Bagasse Ash

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Abstract: *The problem of expansive black cotton soil is one of the most severe problems associated with construction activities because of the nature of swell and shrink properties of this soil that lead to pavement distress and foundation settlement. The current research focuses on the stabilization of such soil using waste industrial materials like marble dust and bagasse ash. The purpose of the study is to develop engineering properties of the soil by using sustainable waste resources.*

The soil samples collected in the Nashik region were subjected to laboratory testing using the Specific Gravity test, Atterberg's limits, Free Swell Index, Standard Proctor Compaction Test, and Unconfined Compressive Strength (UCS) test by adding various quantities of marble dust and bagasse ash. As a result of the performed testing, it is possible to observe improvements in the soil properties. The samples showed decreased swelling capacity, plasticity, better compaction and higher strengths. The UCS test results revealed the increase of strength with the curing period because of cementation by pozzolanic reactions.

Out of all the blends examined, the SBM05 blend demonstrated superior performance by displaying lower swelling properties along with higher UCS values after curing. The study has thus established that the use of marble dust along with bagasse ash improves the stability and durability of expansive soils.

This study also emphasizes the environmental and economic aspects associated with the application of waste materials for stabilization of soils. The application of marble dust along with bagasse ash is a sustainable, economical, and environmentally friendly method compared to traditional stabilizers and also helps to dispose of wastes in an effective manner. Thus, the proposed method of stabilization can be efficiently applied for subgrade pavements, embankments, foundation, and other geotechnical engineering applications in areas having expansive soils.

Keywords: Expansive Soil, Black Cotton Soil, Soil Stabilization, Marble Dust, Bagasse Ash, Unconfined Compressive Strength, Free Swell Index, Sustainable Construction, Waste Utilization

I. INTRODUCTION

Thus, soil is one of the most vital natural materials in civil engineering because the entire structure depends upon the soil. It is safe to say that the stability, strength, and durability of any civil engineering project are all based on the qualities of the soil that are providing support to the building structures. Thus, knowledge about the behaviour of soil and soil improvement are necessary for constructing the required civil structures. Black cotton soil can be termed one of the worst soil types in India due to its very expansive quality.

The black cotton soil is mostly present in the Deccan Plateau region, which comprises parts of Maharashtra, Madhya Pradesh, Gujarat, Karnataka, Andhra Pradesh, and Telangana. The black cotton soil is basically made by the weathering of the basalts and consists of a large amount of clay minerals, specifically the montmorillonite type. The montmorillonite mineral has a greater affinity towards water, and therefore, absorbs moisture from it and expands during wet weather conditions and shrinks during dry weather conditions.

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With respect to the rise in population and urbanization in developing countries like India, there is a greater need for the development of infrastructures. There are many construction sites where the presence of black cotton soil has been noticed. Due to low bearing capacity, high compressibility, poor drainage, and swelling and shrinking, the black cotton soil is not suitable for construction purposes without any modifications. In this way, there is a need to study the improvements of engineering properties of black cotton soil in geotechnical engineering.

The soil stabilization is one of the most common methods that are employed in ground improvement in order to improve the engineering properties of soil. It includes the modification of the soil properties by adding certain stabilizers or adopting any mechanical method to improve strength, decrease plasticity, bearing capacity, and volume change of soil. The conventional soil stabilizers, i.e., lime and cement have been frequently used for soil stabilization. However, these are quite expensive and cause the emission of carbon into the environment. Besides enhancing engineering properties, this study aims at promoting sustainability in construction by using industrial and agricultural waste products in an advantageous manner. The results of this study will be instrumental in creating cost-effective, environment-friendly, and sustainable solutions for stabilizing expansive soils in constructions such as pavements and foundations.

STUDY AREA

It can be concluded from the research that the combination of marble dust and bagasse ash works efficiently in improving the properties of expansive soil, in terms of increasing their strength and stability and reducing their expansion potential. Also, the use of these inexpensive waste materials offers an economically efficient and sustainable way of soil stabilization instead of conventional soil stabilizers. The current study has been performed on expansive black cotton soil obtained from different sites in and around Nashik city of Maharashtra state of India. Black cotton soil is extensively available in Maharashtra state, characterized with high swelling and shrinkage characteristics because of the presence of montmorillonite clay minerals in it. This soil undergoes considerable volume change with changes in the moisture content, resulting in problems like foundation settlement, pavement crackings, and damages to the structures. Soil samples from representative locations have been collected at a depth of 1.0 to 1.5 meters underground from different selected locations. These soil samples have been collected and brought to the geotechnical laboratory for analysis and testing purposes. Some preliminary testing of soil samples including sieve analysis, specific gravity, Atterberg limits, free swell index, compaction, and unconfined compressive strength tests have been done.

The research was done in relation to the improvement in the engineering properties of the expansive soil by using the marble dust, which is an industrial waste from marble processing industries, and bagasse ash, which is an agricultural waste from sugar industries. Various amounts of these two materials have been used in combination with the soil and the resulting effects in terms of strength, compaction, plasticity, and swelling of the soil have been analysed. The study area chosen for this particular project is a representative area of a black cotton soil region, where soil stabilization is very important for construction of civil engineering structures.

II. LITERATURE REVIEW

Stabilization of black cotton soil using waste materials has received significant attention owing to the necessity for environmentally-friendly and cost-effective construction methods. Amongst all stabilizers, marble dust and bagasse ash are found to be effective material to improve the engineering properties of expansive soils. Marble dust, being the waste product from marble production industry, is rich in calcium content and reduces the plasticity, swell and shrink properties of the soil. On the other hand, bagasse ash, being the waste material from agriculture, is rich in reactive silica and leads to pozzolanic reactions leading to improved strength of soil. Various researchers have also found out that there is significant improvement in MDD, CBR, and UCS properties of the soil when it is mixed with marble dust and bagasse ash. In addition, reduction in swelling property and moisture susceptibility of the soil makes it more suitable for paving and founding purposes.

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The main benefit of employing these materials in the construction process lies in their ecological and economic advantages. Industrial and agricultural waste helps to save natural resources, decreases cost of construction and solves the problem of disposing of the waste material. Hence, marble dust and bagasse ash can be regarded as efficient materials for the stabilization of expansive black cotton soil.

However, there is a lack of research related to the combined use of the materials mentioned above. This is why the purpose of the current paper is to find out the impact of their combined use on the soil properties and to find the optimum ratio of mixing.

III. METHEDOLOGY

PROBLEM STATEMENT

Black Cotton Soil is one of the soils that causes great engineering problems to civil engineers because of its shrink-swell behavior and poses great damage to the construction through cracks and differential settlements. This soil is mainly prevalent in the state of Maharashtra and is the dominant soil type in that area. From the geographical point of view, this soil exists in a land area of 5.46 lakh square kilometers, comprising almost 16.6% of the total land area of India. The engineering problems caused by the black cotton soil can be effectively handled by the technique of soil stabilization

Materials Used

The materials utilized for this investigation are black cotton soil, marble dust, and bagasse ash. Black cotton soil is taken from the Trimbakeshwar–Nashik Road area, Maharashtra. Marble dust is sourced from marble production plants situated at Satpur MIDC, Nashik, whereas bagasse ash is taken from Ranwad Sugar Factory, Niphad, Nashik. The collected materials are air-dried, pulverized, and sieved through the necessary IS sieves before conducting tests in the laboratory.

Figure 1 Marble Dust

Figure 2 Bagasse Ash

Soil Sample Collection and Preparation

Samples of disturbed black cotton soil were taken from a depth of about 0.5-1.0 meters below ground level after stripping off the top organic layer. These samples were then brought to the laboratory where they were air-dried, pulverized, and sieved through a 4.75mm IS sieve. The prepared soil samples were used to determine the properties of unstabilized and stabilized soil

Preparation of Stabilized Soil Mixes

The soil was mixed with varying percentages of marble dust (MD) and bagasse ash (BA) by dry weight of soil. The mix proportions adopted for the study were:

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Mix ID	Marble Dust (%)	Bagasse Ash (%)
SBM-0	0	0
SBM-1	5	5
SBM-2	7.5	7.5
SBM-3	10	10
SBM-4	15	15

Various laboratory tests were conducted on the stabilized soil mixes using different amounts of marble dust and bagasse ash in order to investigate the effects of the same on the engineering properties of black cotton soil. The Atterberg limits test was done in order to determine the Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) of the stabilized soil mixes and to investigate how the consistency properties have changed as a result of the stabilization process. Standard Proctor Compaction test was done in order to determine the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for each of the mixes in order to examine the compaction properties of the soil. Free Swell Index tests were done in order to determine how much the swelling capacity of the soil has been reduced as a result of the stabilization process. In addition, UCS tests were conducted on the stabilized soil samples after 7, 14, and 28 days.

The adopted method gives an organized way of checking whether the use of marble dust and bagasse ash is suitable for the stabilization of expansive black cotton soil. Results from the research were utilized in identifying the most appropriate stabilization mixture and assessing its application in the construction of subbases, foundation layers, embankments, and other geotechnical engineering works.

III. RESULTS AND DISCUSSIONS

ENGINEERING AND PHYSICAL PROPERTIES OF THE SOIL

The soil type from the field sample is Black Cotton Soil categorized as CH type (High Plasticity Clay). The Liquid Limit is 62.30% and Plasticity Index is 36.29%. This soil has a high-volume change characteristic and compressibility. The Shrinkage Limit is 9.15% and this denotes that the soil is highly sensitive to changes in moisture leading to swelling and shrinkage. The Specific Gravity is 2.59 and this is normal for clayey soils.

From the compaction test, the Maximum Dry Density is 1.89 g/cm³ and Optimum Moisture Content is 26.90%. From this, we note that the soil needs high moisture for efficient compaction. The UCS value is 0.323 kg/cm² (31.7 kPa). This denotes low shear strength. Generally, the soil has high plasticity, high swelling-shrinkage characteristic and low strength. This implies that stabilization is mandatory before using it in any project

Properties	Values
Liquid Limit	62.30%
Plasticity Index	36.29%
Shrinkage Limit	9.15%
Specific Gravity	2.59
Colour	Black
Classification	CH
MDD	1.89
OMC	26.90%
UCS	0.323 kg/cm² (or) 31.7 kPa

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Sieve Analysis

The particle size distribution curve shows that the percentage passing increases with increasing sieve size. A sharp rise in the curve between 7 mm and 10 mm indicates that most of the particles are concentrated within this size range. The curve is relatively steep, suggesting that the soil is poorly graded or uniformly graded, with limited variation in particle sizes. Therefore, the sample contains a higher proportion of medium-sized particles and a comparatively smaller amount of fine particles.

Specific Gravity Test

The specific gravity of the natural soil (SBM00) was found to be 2.59. With the addition of marble dust and bagasse ash, the specific gravity initially decreased to 2.25 for SBM05 due to the lightweight nature of bagasse ash. The value then increased to 2.90 for SBM7.5, indicating improved particle packing and densification of the soil. Further increases in stabilizer content resulted in lower specific gravity values of 2.40 and 2.35 for SBM10 and SBM15, respectively, which may be attributed to the higher proportion of porous bagasse ash. Overall, the SBM7.5 mix exhibited the highest specific gravity, suggesting it as the optimum proportion for improving the density characteristics of black cotton soil.

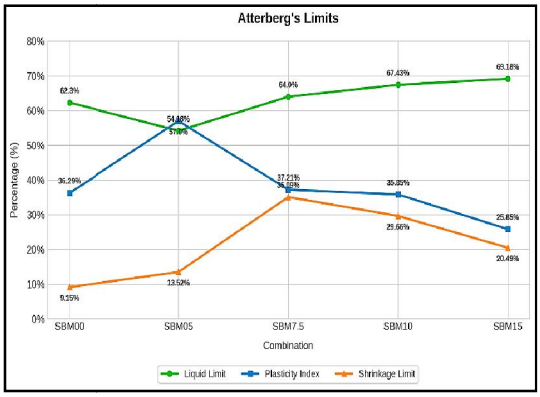
Atterberg's Limits Test

The Atterberg's Limits test results indicate that the addition of marble dust and bagasse ash significantly influenced the consistency characteristics of black cotton soil. The natural soil sample (SBM00) exhibited a high liquid limit of 62.30% and a plasticity index of 36.29%, indicating high plasticity and expansive behaviour. Upon stabilization, the liquid limit generally decreased, reflecting reduced water absorption capacity of the soil. The shrinkage limit increased from 9.15% for untreated soil to higher values in the stabilized mixes, indicating improved dimensional stability and reduced shrinkage potential.

Among the tested combinations, SBM7.5 showed the most favorable performance, with a substantial increase in shrinkage limit to 35.09% and a reduction in plasticity characteristics compared to the untreated soil. These results suggest that the combined use of marble dust and bagasse ash effectively modifies the soil structure, reduces its expansive nature, and improves its overall engineering behavior.

From the result of the Atterberg's Limits test, it is clear that the use of marble dust and bagasse ash has affected the consistency characteristics of the black cotton soil. The untreated soil (SBM00) had a liquid limit of 62.30%, plasticity index of 36.29%, and shrinkage limit of 9.15%. This indicates that the untreated soil has a very high plasticity and expansivity characteristic. As more stabilizers were used, the value of the liquid limit and shrinkage limit of the soil increases, whereas the plasticity index decreases.

The best mix is observed in SBM7.5 which had a plasticity index of 37.21% and the highest shrinkage limit of 35.09%. As more stabilizers are added in the soil, the plasticity index decreases as is evident in the mixes of SBM10 and SBM15 having plasticity indexes of 35.85% and 25.85%, respectively. Therefore, from this analysis, it can be concluded that the marble dust and bagasse ash have helped improve the consistency of expansive soil, and SBM7.5 is the optimum mix.



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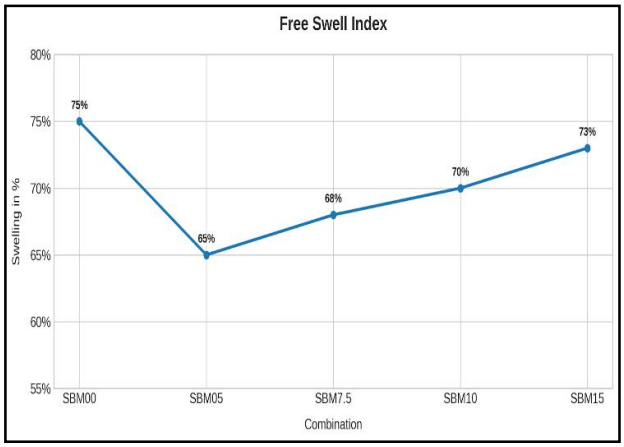
Free Swell Index Test

From the results obtained from the Free Swell Index (FSI) test, one can conclude how marble dust and bagasse ash affect the swelling characteristics of black cotton soil. The FSI value of the untreated soil sample is quite high, as it amounted to 75%. The addition of materials led to the reduction of FSI value to 65% in the case of SBM05 sample, which means that there is a significant reduction of swelling potential.

The value of FSI became a little bit higher in SBM7.5 and SBM10 samples, namely, it increased up to 68% and 70% correspondingly, though still it was lower compared to that of the untreated soil. At the same time, in the case of SBM15, the FSI was even higher – it equaled 73%, which was almost equal to the value of natural soil due to the inefficiency of stabilization at such content of additives.

Thus, it could be stated that marble dust and bagasse ash successfully decreased the swelling features of soil. In general, the least value of Free Swell Index was in SBM05 soil sample



Standard Proctor Test (IS 2720 Part VII: 1965)

The Standard Proctor Test was done in order to study the compaction characteristics of black cotton soil which is mixed with varying amounts of marble dust and bagasse ash. The outcomes were studied based on their Maximum Dry Density (MDD) and Optimum Moisture Content (OMC).

Maximum Dry Density (MDD)

Maximum dry density showed a decreasing pattern when the stabilizer amount increased. The highest MDD was shown by the soil without any treatment (SBM00) with 1.89 g/cc whereas the lowest MDD was obtained by SBM15 soil sample with 1.38 g/cc. This could be due to the lower specific gravity and low weight of bagasse ash. It clearly shows that stabilized soil has lower density as the percentage of stabilizers increases.

Optimum Moisture Content (OMC)

Optimum moisture content decreased from 26.90% in untreated soil to 18.14% in SBM05. When more stabilizers are added to the mixture, the optimum moisture content decreases but there were some changes at SBM7.5, SBM10, and SBM15 soils which show 19.53%, 23.38%, and 19.53% values respectively.

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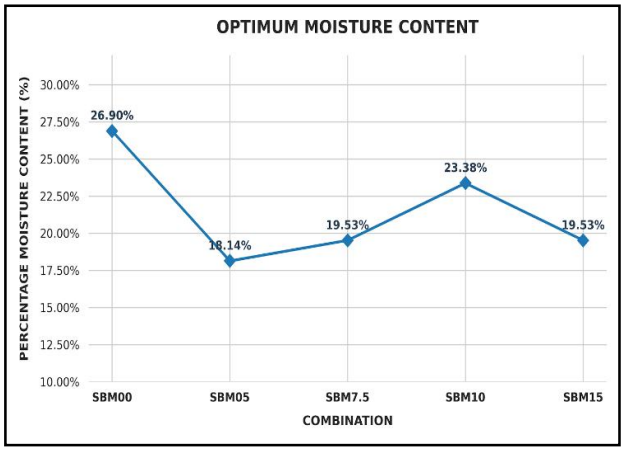

Unconfined Compressive Strength (UCS) Test

In an unconfined compressive strength (UCS) test, the effect of using marble dust and bagasse ash in enhancing the strength of black cotton soil was determined at various curing ages. The specimen of untreated soil (SBM00) had the least UCS values at 7, 14, and 28 days, showing poor strength characteristics of natural soil.The application of stabilizers led to increased compressive strength of soil. In the case of all the mixtures, SBM05 showed the highest UCS values of 5.21 kg/cm², 5.01 kg/cm², and 5.03 kg/cm² at 7, 14, and 28 days, respectively. This indicates that the mixture had optimum strength. SBM7.5 and SBM10 also had improved strength compared to untreated soil; however, they did not have UCS values as high as those of SBM05.

An increase in stabilizer to SBM15 caused a decrease in UCS values, meaning that too much stabilizers can have an adverse effect on particle bonding and stabilization of soil. The stabilized soil samples retained their strength throughout the curing age due to formation of cementitious compounds.

Mix Proportion	UCS at 7 Days (kg/cm²)	UCS at 14 Days (kg/cm²)	UCS at 28 Days (kg/cm²)
SBM00	0.323	0.323	0.323
SBM05	5.210	5.010	5.030
SBM7.5	2.382	3.360	4.520
SBM10	2.382	2.563	2.367
SBM15	1.736	1.425	1.660

Engineering Properties of Stabilized Soil

There has been an appreciable improvement in the engineering properties of the black cotton soil due to stabilization through marble dust and bagasse ash. The untreated soil had shown a great deal of plasticity, high swelling potential and weak compressive strength, which made the soil unfavorable for any type of construction work. The stabilization process reduced the liquid limit, plasticity, free swell index and optimum moisture content, while the strength properties increased significantly.

Out of all the stabilized soils, the performance of SBM05 was the best with regard to minimum swelling potential and maximum UCS. The SBM7.5 and SBM10 have also shown better performance compared to the untreated soil; however, it is still inferior to SBM05. However, the performance of SBM15 is less than both SBM7.5 and SBM10, which means that more stabilizers make the soil perform badly.

In summary, it can be said that the mixture of marble dust and bagasse ash is quite effective in improving the properties of expansive black cotton soil with optimum mix proportion of SBM05.

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IV. CONCLUSION

This research project aimed at stabilizing the expansive black cotton soil through the use of sustainable stabilizing agents such as marble dust and bagasse ash. In order to determine the effect of the proportions of the stabilizers on the properties of the soil, experiments such as Specific Gravity, Atterberg's Limits, Free Swell Index, Standard Proctor Compaction and Unconfined Compressive Strength (UCS) were carried out in the laboratory.

From the experimental findings, the effect of adding marble dust and bagasse ash on black cotton soil was significant. The properties of the soil improved in terms of swell ability, consistency characteristics and strength as compared to the untreated soil. The Free Swell Index showed a significant decrease, signifying efficient control of the expansive nature of the soil. Besides, there was an increase in the UCS value after stabilization, showing the formation of cementitious bonds in the soil structure.

Out of all the combinations, the mix SBM05 performed optimally, with the lowest Free Swell Index (65%) and highest UCS value (5.03 kg/cm²) after 28 days of curing. Even though higher stabilizer contents improved the properties of the soil, too much quantity of stabilizers reduced the strength of the soil.

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