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Taming the Expansive: Stabilizing Black Cotton Soil with Nano-Enhanced Waste Materials

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Abstract: Black cotton soil, with its high shrink-swell potential, poses significant challenges for highway construction. This research investigates a novel approach to stabilize black cotton soil for subgrade applications by combining a nano-engineered chemical (Terrasil) with industrial (fly ash) and agricultural (rice husk ash) waste products. The study aims to evaluate the influence of these additives on the geotechnical properties of black cotton soil, including index properties, compaction characteristics, and strength parameters. By leveraging the synergistic effects of these materials, the research seeks to develop a sustainable and cost-effective solution for improving the engineering performance of black cotton soil while promoting the utilization of waste materials. The findings of this study will contribute to the development of more resilient and environmentally friendly highway infrastructure.

I. INTRODUCTION

The construction of durable and reliable infrastructure is paramount for the sustainable development of any nation. However, the presence of problematic soils, such as black cotton soil, can pose significant challenges to civil engineers. Black cotton soil, characterized by its high shrink-swell potential, exhibits substantial volume changes in response to variations in moisture content. This inherent instability can lead to severe structural damage, including cracking, settlement, and even collapse, if not adequately addressed.

Traditional construction practices often involve extensive excavation and replacement of problematic soils, which can be both costly and environmentally disruptive. In recent years, soil stabilization techniques have emerged as viable and sustainable alternatives. These methods aim to improve the engineering properties of problematic soils, such as strength, stiffness, and durability, by incorporating suitable additives.

This research investigates the potential of a novel approach to stabilize black cotton soil for highway subgrade applications. The study focuses on a synergistic combination of materials:

1) Terrasil: A nano-engineered chemical additive known for its ability to modify soil microstructure and enhance strength.
2) Fly Ash: A byproduct of coal combustion in thermal power plants, rich in pozzolanic materials that contribute to cementation and strength development.
3) Rice Husk Ash (RHA): An agricultural waste product with pozzolanic properties and the potential to improve soil workability.

By combining these materials, the research aims to achieve a multi-pronged approach to soil stabilization, leveraging the unique properties of each component to address the specific challenges posed by black cotton soil. The study will systematically investigate the effects of varying proportions of these additives on the geotechnical properties of black cotton soil, including:

a) Index properties (liquid limit, plastic limit, plasticity index)
b) Compaction characteristics (maximum dry density, optimum moisture content)
c) Strength parameters (unconfined compressive strength, shear strength)
d) Permeability

II. LITERATURE REVIEW

A. Soil Stabilization

Soil stabilization is a crucial engineering practice aimed at improving the geotechnical properties of soils. This involves modifying soil characteristics such as strength, compressibility, and permeability to enhance their suitability for construction purposes. Traditional methods of soil stabilization include mechanical, chemical, and combined approaches. Chemical stabilization involves the addition of various substances to the soil, including cement, lime, fly ash, and other additives, to alter its physical and chemical properties.

B. Black Cotton Soil

Black cotton soil, also known as expansive soil, is a type of clay-rich soil that exhibits significant volume changes due to variations in moisture content. This characteristic poses significant challenges for construction, as it can lead to structural damage, such as cracking and heaving of foundations. The presence of expansive clays, particularly montmorillonite, contributes to this behavior. These soils are typically found in regions with distinct wet and dry seasons, where fluctuations in moisture content induce significant volume changes.

1) Conclusion

This study investigated the effectiveness of Terrasil, in combination with fly ash and rice husk ash, in improving the geotechnical properties of black cotton soil. The results of the experimental program demonstrated that the addition of Terrasil, within a specific optimal range, significantly improved the engineering characteristics of the soil.

2) Key Findings Include

a) *Improved Consistency Limits:* The addition of Terrasil generally resulted in a decrease in liquid limit and plastic limit, indicating a reduction in the soil's plasticity. This is beneficial as it can reduce the soil's susceptibility to volume changes due to moisture fluctuations.

b) *Enhanced Compaction Characteristics:* The optimal moisture content (OMC) and maximum dry density (MDD) were observed to vary with the addition of Terrasil. The results suggest that an optimal Terrasil content can be identified to achieve the desired compaction characteristics.

c) *Increased Strength:* The unconfined compressive strength and shear strength of the soil were observed to increase with the addition of Terrasil within a specific range. This indicates an improvement in the soil's load-bearing capacity and resistance to shear stresses.

d) *Reduced Permeability:* The permeability of the soil was observed to decrease with the addition of Terrasil. This is a significant finding as it can improve the soil's resistance to water infiltration and reduce the potential for erosion.

Overall, the results of this study demonstrate the potential of Terrasil, in combination with fly ash and rice husk ash, as an effective stabilizer for black cotton soil. The findings suggest that the addition of Terrasil can significantly improve the engineering properties of this challenging soil type, making it more suitable for various construction applications.

C. Future Scope

1) Further research is recommended to investigate the long-term performance of Terrasil-treated black cotton soil under different environmental conditions.
2) The effects of Terrasil on the swelling and shrinkage characteristics of black cotton soil should be further evaluated.
3) The economic feasibility of using Terrasil for soil stabilization should be thoroughly assessed.
4) The use of other nano-materials and their combinations with different stabilizers should be explored to further optimize soil stabilization techniques.

Fly ash, a byproduct of coal combustion in thermal power plants, and rice husk ash, a byproduct of rice milling, have been extensively studied as potential soil stabilizers. These industrial and agricultural waste products can be effectively utilized to improve the engineering properties of soils, including black cotton soil.

Fly Ash: Fly ash is a fine-grained, siliceous-aluminous material that exhibits pozzolanic properties. When mixed with lime or cement, it reacts to form compounds with cementitious properties, enhancing soil strength and stiffness.

Rice Husk Ash: Rice husk ash is a silica-rich material that can improve soil strength and reduce its plasticity. It also has the potential to improve the drainage characteristics of soils.

D. Previous Research

Several studies have investigated the use of fly ash and rice husk ash for stabilizing black cotton soil.

Prabhakar et al. (2020) explored the use of quarry dust and foundry sand for stabilizing expansive soils, demonstrating the potential of utilizing industrial waste materials.

Suresh. Kommu et al. (2018) focused on the use of fly ash alone for stabilizing expansive soils, analyzing its effects on various geotechnical properties.

Narsimha Rao et al. (2014) investigated the combined effects of lime and rice husk ash on the stabilization of expansive soils, observing improvements in strength and reduction in swelling potential.

SujitKawade et al. (2014) explored the combined effect of lime and geo-grid reinforcement on black cotton soil, demonstrating enhanced strength and stability.

These studies have provided valuable insights into the potential benefits and limitations of using fly ash and rice husk ash for soil stabilization. Further research is needed to optimize the use of these materials and explore their long-term performance in real-world applications

III. MATERIALS USED

This study utilized the following materials:

1) *Black Cotton Soil:* The soil samples were collected from a village near Ramgarh, Ujjain, Madhya Pradesh, India. As per IS 1498 (1970), it was classified as a compressible clay (CH). Black cotton soils are characterized by their high clay content, particularly montmorillonite, which exhibits significant swelling and shrinkage properties due to variations in moisture content. This characteristic poses significant challenges for construction as it can lead to structural damage, such as cracking and heaving of foundations.
2) *Fly Ash:* Fly ash is a fine-grained, siliceous-aluminous material generated as a byproduct of coal combustion in thermal power plants. It is typically composed of spherical particles with a high specific surface area. Fly ash exhibits pozzolanic properties, meaning it can react with calcium hydroxide in the presence of moisture to form compounds with cementitious properties. This characteristic makes it a suitable material for soil stabilization, as it can enhance soil strength and stiffness.
3) *Rice Husk Ash (RHA):* Rice husk ash is a byproduct of rice milling. It is a silica-rich material obtained by the controlled burning of rice husks. RHA possesses a high silica content and exhibits low specific gravity. It has been shown to improve soil strength, reduce plasticity, and enhance drainage characteristics.

Sample of Rice husk

4) *Terrasil:* Terrasil is a nano-chemical additive used for soil stabilization. It is a unique blend of nano-sized particles that interact with soil particles at the micro-level. Terrasil is known to enhance soil strength, reduce permeability, and improve overall soil stability.

Sample of Terrasil

IV. METHODOLOGY

This study employed experimental methods to investigate the effects of Terrasil, in combination with fly ash and rice husk ash, on the geotechnical properties of black cotton soil. The following tests were conducted on both untreated and treated soil samples:

A. *Index Properties*

1) Liquid Limit and Plastic Limit: These tests were performed according to IS 2720 (Part 5) to determine the Atterberg limits, which provide valuable insights into the soil's plasticity and consistency. The Casagrande's apparatus was used to determine the liquid limit, while the plastic limit was determined using the thread test.
2) Specific Gravity: The specific gravity of the soil was determined using the pycnometer method as per IS 2720 (Part 3).

B. *Compaction Characteristics*

1) Standard Proctor Compaction Test: The standard Proctor compaction test was conducted on both untreated and treated soil samples as per IS 2720 (Part 8). This test determined the optimum moisture content (OMC) and maximum dry density (MDD) of the soil, which are crucial parameters for assessing its compaction characteristics.

C. *Strength Characteristics*

1) Unconfined Compressive Strength (UCS) Test: The UCS test was performed on compacted soil specimens as per IS 2720 (Part 10). This test provides an indication of the soil's shear strength and its ability to resist compressive loads.

D. *Permeability Test*

1) Variable Head Permeability Test: The permeability of the soil was determined using a variable head permeameter as per IS 2720 (Part 19). This test measures the rate at which water flows through the soil, which is an important parameter for assessing its drainage characteristics.

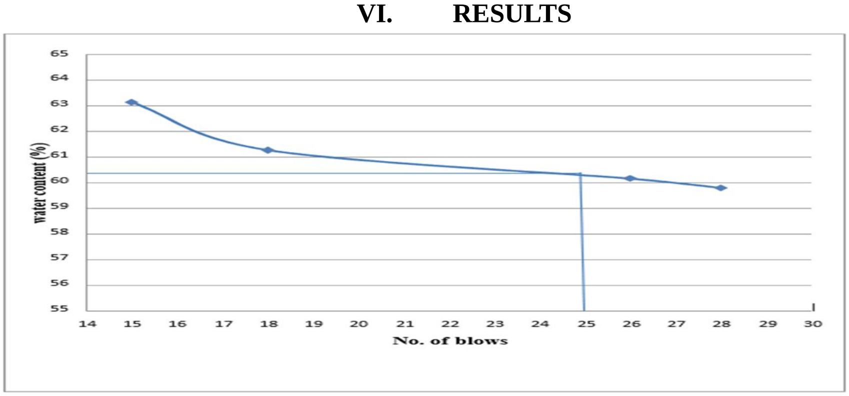
E. *Sample Preparation*

1) Soil samples were collected from a specific location and air-dried.
2) The soil was then oven-dried at 105-110°C to determine its moisture content.
3) The oven-dried soil was sieved to obtain a uniform particle size distribution.
4) The required amounts of fly ash, rice husk ash, and Terrasil were accurately weighed and mixed thoroughly with the soil using a mechanical mixer.
5) The treated soil samples were then prepared for the respective tests as per the relevant Indian Standards.

V. DATA ANALYSIS

The results of the various tests were recorded and analyzed to evaluate the effects of Terrasil, in combination with fly ash and rice husk ash, on the geotechnical properties of black cotton soil. The data was analyzed statistically to identify significant trends and draw meaningful conclusions.

VI. RESULTS



Liquid-Limit for Conventional Sample
Hence: Liquid Limit = 60.27%, Plastic Limit = 27.81

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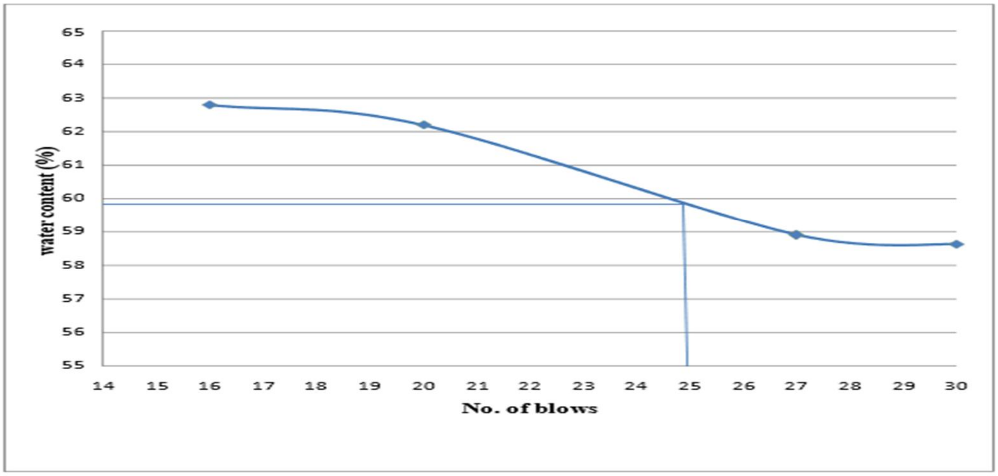
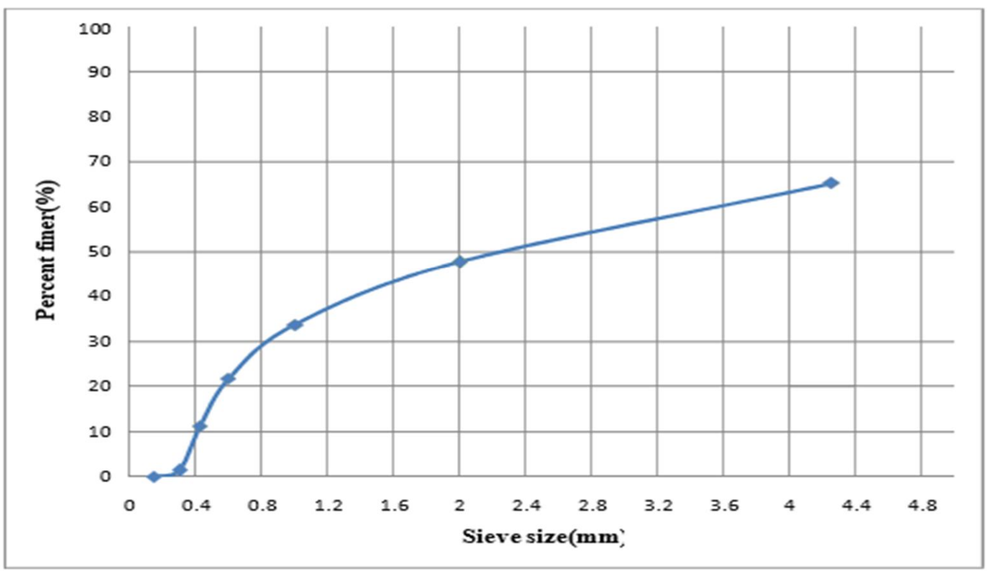


Liquid Limit for 0.02% of Terrasil,10% RHA and 20% FA
Hence: Liquid Limit = 59.82%, Plastic Limit = 27.52



Grain Size Distribution

Hence: Remarks

D_{10} = size at 10% finer by weight = 0.45mm

D_{30} = size at 30% finer by weight = 0.91mm

D_{60} = size at 60% finer by weight = 3.56mm

Result $Cu = \frac{D60}{D10} = \frac{3.56}{0.45} = 7.91$

$Cc = \frac{(D30)2}{D10 \times D6} = \frac{(0.91)2}{0.45 \times 3.56} = 0.52$

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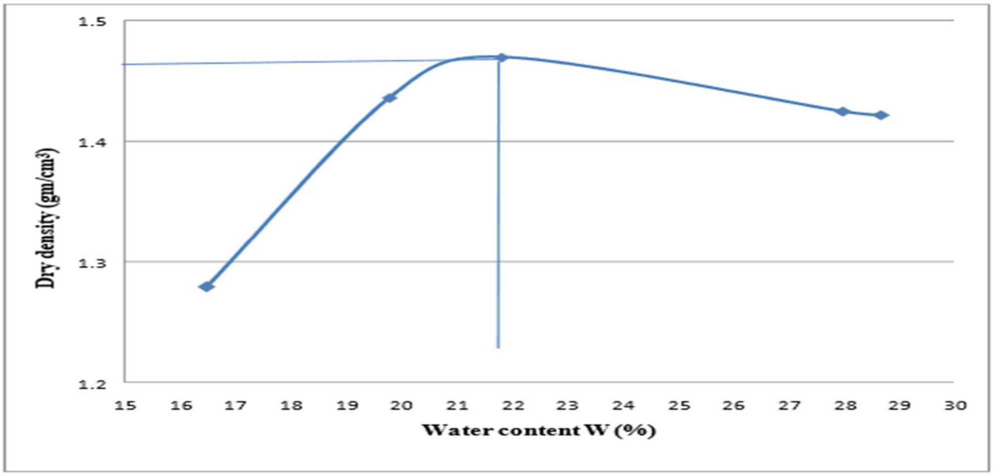
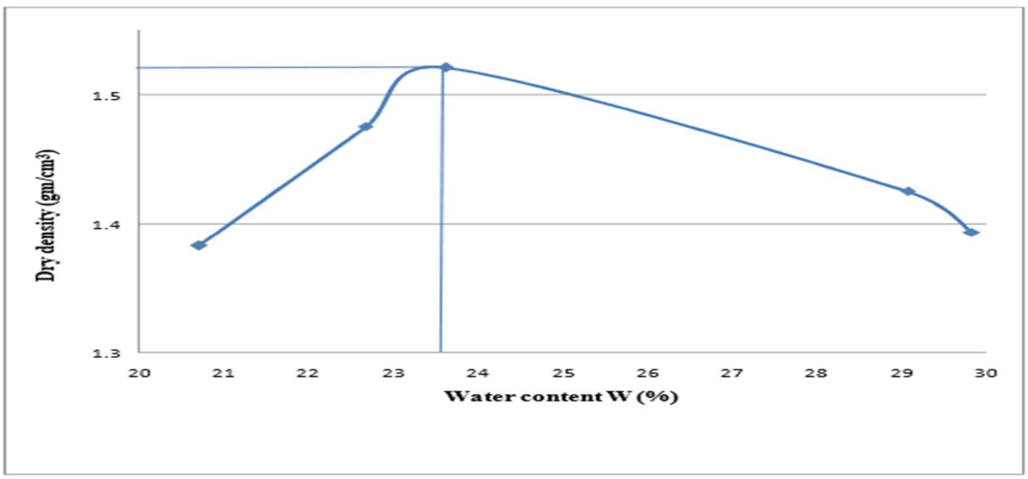
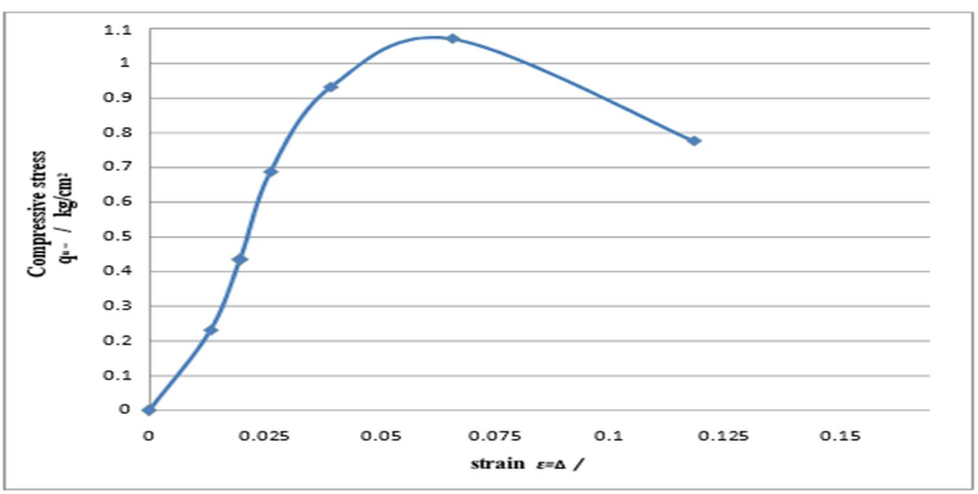


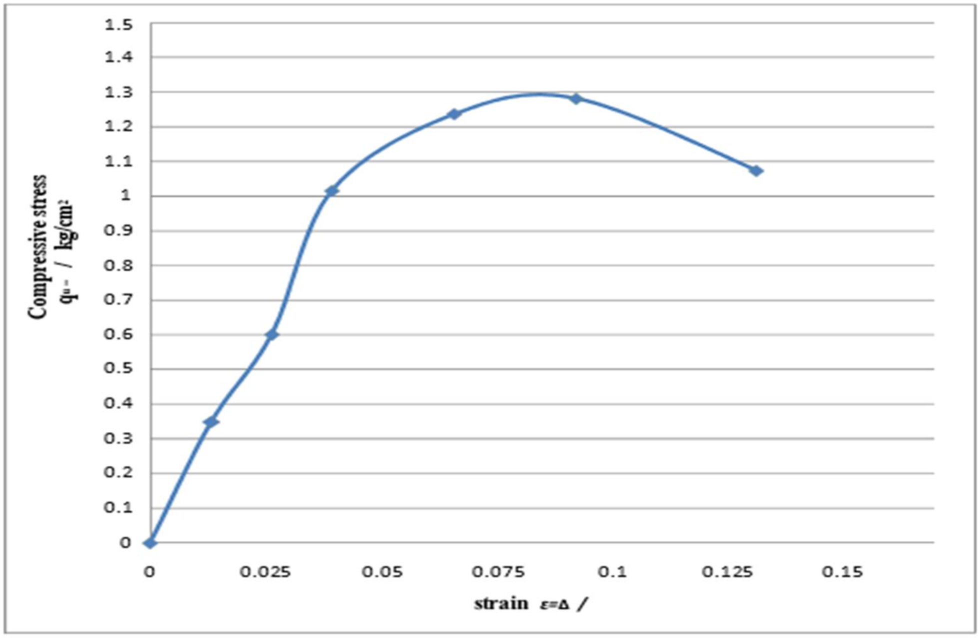
Standard Proctore Compaction test normal sample
Result: Max dry density (ρd) = 1.47 gm/cm3& Optimum moisture content = 21.85%



SPT test of sample with 0.02% Terrasil, 10% RHA and 20% FA
Result: Max dry density (ρd) = 1.53 gm./cm^3& Optimum moisture content = 23.6%



Unconfined compressive & shear strength test of normal sample



Unconfined compressive and shear strength test of sample with 0.02% Terrasil, 10% RHA and 20% FA

VII. CONCLUSION

This study investigated the effectiveness of Terrasil, in combination with fly ash and rice husk ash, in improving the geotechnical properties of black cotton soil. The results of the experimental program demonstrated that the addition of Terrasil, within a specific optimal range, significantly improved the engineering characteristics of the soil.

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