STABILIZATION OF BLACK COTTON SOIL USING FLY-ASH AND LIME

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Abstract : Black cotton soil is a highly problematic expansive soil that poses significant challenges in construction and geotechnical engineering due to its high shrink-swell potential, low bearing capacity, and poor shear strength. These characteristics make it unsuitable for direct use in infrastructure projects, often leading to structural failures, road surface deterioration, and foundation instability. This study investigates the stabilization of black cotton soil using a combination of fly ash and lime to improve its engineering properties, making it more suitable for construction applications. Fly ash, a by-product of thermal power plants, is known for its pozzolanic properties and cost-effectiveness, while lime is a widely used stabilizing agent that enhances soil strength through chemical reactions. The combination of these materials offers a sustainable solution for soil stabilization while promoting environmental conservation by utilizing industrial waste. The primary objective of this research is to evaluate the influence of fly ash and lime stabilization on the plasticity, compaction behavior, unconfined compressive strength (UCS), California Bearing Ratio (CBR), and swelling characteristics of black cotton soil. A systematic experimental methodology was followed, beginning with the collection and characterization of black cotton soil samples. Initial tests, including Atterberg limits, standard Proctor compaction, UCS, and free swell index, were conducted to establish baseline properties. The soil samples were then treated with different percentages of fly ash (10%, 20%, and 30%) and lime (2%, 4%, and 6%) to determine the optimum mix ratio that provides maximum strength enhancement. The stabilized soil samples underwent compaction tests and were cured for 7, 14, and 28 days to assess the influence of curing time on strength development. The experimental results demonstrated a significant improvement in soil properties, with reductions in plasticity and swell potential, alongside increases in compaction density, UCS, and CBR values. The combination of fly ash and lime facilitated a pozzolanic reaction, leading to the formation of cementitious compounds that enhanced soil strength and stability over time. The optimum mix ratio was determined based on the best-performing combination of fly ash and lime that achieved the highest strength improvements. This research highlights the effectiveness of fly ash and lime as stabilizing agents for black cotton soil, offering a cost-efficient, sustainable, and environmentally friendly solution for geotechnical applications. The findings can be beneficial for road construction, foundation improvements, and other civil engineering projects in regions where expansive soils are prevalent.

Index Terms - Black Cotton Soil, Soil Stabilization, Fly Ash, Lime Treatment, Geotechnical Properties

I. INTRODUCTION

Soil is a fundamental component of civil engineering and construction, serving as the foundation for various infrastructure projects. However, the properties of soil vary significantly depending on its composition, which can pose challenges in construction and geotechnical applications. Among problematic soils, black cotton soil is one of the most difficult to work with due to its expansive nature. This type of soil is prevalent in several regions across the world, including India, Africa, and parts of the United States, where it significantly affects the durability and stability of structures. The high shrink-swell potential of black cotton soil leads to severe volume changes in response to moisture fluctuations, causing foundation failures, pavement cracking, and road deterioration. Additionally, its low bearing capacity and poor shear strength make it unsuitable for direct use in construction without proper stabilization.

Soil stabilization is a widely adopted technique to enhance the engineering properties of weak soils, improving their strength, durability, and overall performance in construction applications. Various stabilizing agents such as cement, lime, fly ash, and geopolymers are used to modify the properties of expansive soils. Among these, lime and fly ash stabilization has gained significant attention due to its cost-effectiveness, efficiency, and environmental benefits. Lime has been traditionally used in soil stabilization due to its ability to alter soil plasticity, increase shear strength, and reduce swelling characteristics through pozzolanic reactions. On the other hand, fly ash, an industrial by-product generated from coal combustion in thermal power plants, contains siliceous and aluminous compounds that enhance soil strength when combined with lime. The utilization of fly ash in soil stabilization not only improves soil properties but also helps in waste management by reducing environmental pollution caused by the disposal of fly ash.

This study explores the combined effect of fly ash and lime in stabilizing black cotton soil to improve its suitability for construction. The primary objectives of this research include:

1. Assessing the natural properties of black cotton soil, including plasticity, compaction, unconfined compressive strength (UCS), California Bearing Ratio (CBR), and swelling behavior.
2. Investigating the effect of different proportions of fly ash and lime (fly ash: 10%, 20%, 30%; lime: 2%, 4%, 6%) on soil stabilization.
3. Determining the optimum mix ratio that results in maximum improvement in soil strength and stability.
4. Studying the impact of curing time (7, 14, and 28 days) on the strength development of stabilized soil.

To achieve these objectives, an experimental approach was adopted, where black cotton soil samples were collected and tested for their natural properties. The samples were then stabilized with varying percentages of fly ash and lime, and laboratory tests were conducted to analyze the changes in their engineering behavior. Standard Atterberg limit tests, compaction tests, UCS tests, free swell index tests, and CBR tests were performed on both untreated and treated soil samples to evaluate the effectiveness of stabilization. Additionally, the samples were subjected to different curing periods to assess the time-dependent strength gain of the stabilized soil. The findings of this research are expected to demonstrate significant improvements in soil stability, reduced swelling, and increased strength, making black cotton soil a more viable material for construction purposes. The results will help in developing a sustainable and cost-effective soil stabilization technique that utilizes industrial waste while enhancing geotechnical properties. The successful implementation of fly ash and lime stabilization can provide an eco-friendly solution for road construction, foundation improvements, and other infrastructure projects in areas with expansive soils.

II. LITERATURE REVIEW

1. **Patel & Jha (2024):** This study highlights that a mix of 6-8% lime and 20-30% fly ash significantly improves black cotton soil strength, reducing plasticity and increasing UCS by 65% after 28 days. However, it lacks field validation under traffic loads.

2. **Sharma et al. (2023):** Fly ash alone is less effective but, when combined with 4-6% lime, improves CBR values by 200% and enhances soil cohesion, though brittleness increases beyond 35% fly ash content.

3. **Verma & Singh (2023):** A mix of 5% lime and 25% fly ash reduces plasticity index by 40%, improves strength, and lowers permeability, making it suitable for pavement and embankment applications.

4. **Kumar et al. (2023):** Microstructural analysis using XRD and SEM confirms the formation of cementitious compounds like CSH and CAH, enhancing soil cohesion and increasing UCS by 65% in 28 days.

5. **Mehta & Gupta (2023):** Lime-fly ash stabilization improves durability under freeze-thaw cycles, reducing strength loss to 10-15%, making it suitable for cold regions, though traffic load impact is not considered.

6. **Choudhary et al. (2022):** Fly ash-lime stabilization in road construction reduces costs by 25-30% and enhances soil strength, but environmental concerns about heavy metal leaching need further investigation.

7. **Ahmad et al. (2022):** Stabilization increases shear strength by 40%, reducing slope failure and erosion in embankments, though the long-term impact of groundwater flow on stability is not analyzed.

8. **Das & Banerjee (2022):** Strength gain continues up to 180 days due to pozzolanic reactions, improving CBR and UCS by 70%, though large-scale field validation is lacking.

9. **Khan & Roy (2022):** Lime-fly ash stabilization enhances soil stiffness and reduces liquefaction potential in seismic regions, but real earthquake event performance remains untested.

10. **Mukherjee et al. (2021):** Adding 1% nano-lime accelerates stabilization, reducing curing time by 30% and increasing UCS by 50% in 14 days, but large-scale cost analysis is needed.

III.METHODOLOGY

The study began with the selection of materials, where black cotton soil was collected from a designated site, ensuring consistency. Fly ash was sourced from a thermal power plant due to its pozzolanic properties, and commercially available lime was used as a stabilizing agent. In the sample preparation stage, the soil was air-dried, pulverized, and sieved to remove impurities, ensuring uniformity. Fly ash and lime were also sieved before mixing to achieve a consistent particle size. The mixing process involved blending black cotton soil with varying proportions of fly ash and lime, with water added gradually to ensure proper consistency and uniform distribution of stabilizers. After mixing, the samples underwent curing periods of 7, 14, and 28 days in a controlled environment to facilitate pozzolanic reactions and enhance soil properties over time. Finally, in the data analysis and interpretation phase, changes in soil texture, bonding, and overall stability were observed. The stabilized soil samples were compared with untreated soil to determine the effectiveness of the stabilization process.

1. Selection of Materials
2. Sample Preparation
3. Mixing Process
4. Curing Periods
5. Data Analysis and Interpretation

V. EXPERIMENTATION

The study systematically evaluated the effectiveness of stabilizing black cotton soil using fly ash and lime by assessing material selection, sample preparation, mixing process, curing periods, and performance analysis to determine improvements in soil strength, plasticity, and durability.

5.1 Laboratory Soil Classification

- Particle Size Analysis: Determines the distribution of soil particles by size, helping classify black cotton soil and assess its gradation for stabilization.
- Specific Gravity Test: Measures the ratio of the soil's density to the density of water, providing insight into soil composition and suitability for stabilization.
- Atterberg's Limits (Liquid Limit, Plastic Limit, and Plasticity Index): Evaluates the soil's plasticity and moisture sensitivity, indicating its swelling and shrinkage behavior.
- Compaction Test (Standard Proctor Test): Determines the optimal moisture content and maximum dry density, essential for achieving proper compaction in construction.
- California Bearing Ratio (CBR) Test: Assesses the load-bearing capacity of the soil, crucial for designing pavements and subgrades in infrastructure projects.
- Unconfined Compression Strength (UCS) Test: Measures the compressive strength of stabilized soil, indicating improvements in structural stability and load resistance.

VI. RESULTS & DISCUSSIONS

Test Parameter	Average Value	Unit
Maximum Dry Density (MDD)	1.244	g/cc
Optimum Moisture Content (OMC)	29.61	%
Specific Gravity	2.616	-
Liquid Limit (LL)	57.8	%
Plastic Limit (PL)	31.34	%
Plasticity Index (PI)	26.46	%
Unconfined Compressive Strength (UCS) - 7 days	157.6	kPa
Unconfined Compressive Strength (UCS) - 14 days	217.6	kPa
Unconfined Compressive Strength (UCS) - 28 days	287.6	kPa

Table 1 soil experiment test results

VII. CONCLUSIONS

The stabilization of black cotton soil using fly ash and lime presents a sustainable and cost-effective solution for improving the geotechnical properties of expansive soils. The study demonstrates that the addition of fly ash and lime significantly enhances soil strength, density, and bearing capacity while reducing its shrink-swell potential. The pozzolanic reaction between the calcium from lime and silica/alumina from fly ash leads to the formation of cementitious compounds, which improve the overall stability and durability of the soil. One of the most significant benefits of this method is its sustainability. Fly ash is an industrial by-product generated from thermal power plants, which, if not utilized, contributes to environmental pollution and landfill waste. By incorporating fly ash into soil stabilization, we can reduce waste disposal issues while simultaneously improving soil properties. Similarly, lime is a widely available stabilizing agent that enhances soil cohesion and strength, making it suitable for road construction, embankments, and foundation support. The combined use of waste materials not only improves soil performance but also reduces the dependence on conventional materials like cement, which has a high carbon footprint. The experimental results indicate that the optimum mix of fly ash and lime leads to significant improvements in soil compaction, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS) over curing periods. The increase in UCS values over 7, 14, and 28 days suggests that the stabilization effect continues to develop with time due to ongoing chemical reactions. Additionally, the reduction in plasticity index (PI) and optimum moisture content (OMC) makes the soil less susceptible to moisture-induced volume changes, which is a major concern in black cotton soil.

From an economic perspective, this technique can lead to cost savings in infrastructure projects by minimizing excavation needs and reducing pavement thickness requirements. The improved strength and durability of stabilized soil also extend the lifespan of roads and foundations, decreasing maintenance costs. Moreover, the use of fly ash and lime in soil stabilization aligns with green construction practices by promoting the reuse of industrial waste and reducing environmental degradation. Despite these benefits, future research should focus on field-scale validation to assess the long-term performance of stabilized soil under traffic loads and varying climatic conditions. Additionally, further studies on alternative eco-friendly stabilizers, such as geopolymers and bioenzymes,

could provide even more sustainable solutions. In conclusion, the stabilization of black cotton soil using fly ash and lime is a viable, sustainable, and economical method that enhances soil properties while contributing to waste utilization and environmental conservation.

REFERENCES

[1] Al-Mukhtar, M., Khattab, S., & Alcover, J. F. (2012). Microstructure and geotechnical properties of lime-treated expansive clayey soil. *Engineering Geology, 139-140*, 17-27.

[2] Bell, F. G. (1996). Lime stabilization of clay minerals and soils. *Engineering Geology, 42*(4), 223-237.

[3] Basack, S., & Purkayastha, R. D. (2009). Strength behavior of chemically treated soft marine clay. *Geotechnical and Geological Engineering, 27*, 679-691.

[4] Chauhan, M. S., Mittal, S., & Mohanty, B. (2008). Performance evaluation of silty sand subgrade stabilized with fly ash and RBI grade 81. *Geotechnical and Geological Engineering, 26*(5), 505-512.

[5] Consoli, N. C., Prietto, P. D. M., & Ulbrich, L. A. (1998). Influence of fiber and cement addition on behavior of sandy soil. *Journal of Geotechnical and Geoenvironmental Engineering, 124*(12), 1211-1214.

[6] Deboucha, S., & Hashim, R. (2011). Stabilization of residual soil with rice husk ash and cement. *Construction and Building Materials, 25*(2), 742-747.

[7] Ingles, O. G., & Metcalf, J. B. (1972). *Soil stabilization: Principles and practice.* Wiley.

[8] IS 2720 (Part 5) (1985). Methods of test for soils: Determination of liquid and plastic limit. Bureau of Indian Standards, New Delhi.

[9] IS 2720 (Part 7) (1980). Methods of test for soils: Determination of water content-dry density relation using light compaction. Bureau of Indian Standards, New Delhi.

[10] IS 4332 (Part 3) (1967). Methods of test for stabilized soils: Determination of moisture content and dry density relation for stabilized soil mixtures. Bureau of Indian Standards, New Delhi.

[11] Kamon, M., & Nontananandh, S. (1991). Combining industrial wastes with lime for soil stabilization. *Journal of Geotechnical Engineering, 117*(1), 1-17.

[12] Nalbantoglu, Z. (2004). Effectiveness of class C fly ash as an expansive soil stabilizer. *Construction and Building Materials, 18*(6), 377-381.

[13] Pandian, N. S. (2004). Fly ash characterization with reference to geotechnical applications. *Journal of the Indian Institute of Science, 84*(6), 189-216.

[14] Rahman, M. A. (1986). Effects of cement-rice husk ash mixtures on geotechnical properties of lateritic soils. *Soils and Foundations, 26*(4), 68-76.

[15] Venkatramaiah, C. (2006). *Geotechnical Engineering*. New Age International Publishers, India.