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Review on Lime-Treated Black Cotton Soil Strength Properties

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Abstract
Black cotton soil, classified as expansive soil, is problematic for civil engineering construction due to its high shrink–swell potential, low bearing capacity, and high plasticity. Stabilization techniques are therefore adopted to improve its engineering behavior. Among the different stabilizers, lime has been extensively used due to its cost-effectiveness, easy availability, and chemical compatibility with clay minerals. This paper presents a comprehensive review of the strength properties of lime-treated black cotton soil, focusing on changes in Atterberg limits, compaction characteristics, California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), and shear parameters. The review also highlights the mechanisms of soil–lime reactions, the effect of lime content, and curing periods on soil strength. Findings indicate that lime addition significantly enhances the strength and durability of expansive soils, making them suitable for use in subgrade and foundation applications.

1. Introduction:

Black cotton soil, predominantly found in central and southern India, is a highly expansive clayey soil with montmorillonite as its chief mineral. This soil undergoes large volumetric changes with seasonal moisture variations, resulting in severe damage to pavements, lightly loaded structures, and foundations. To mitigate these problems, soil stabilization techniques such as mechanical stabilization, chemical stabilization, and geosyntheticreinforcementareemployed. Lime stabilization has gained significant attention due to its effectiveness in improving both short-term and long-term strength of expansive soils. The reaction between lime and soil minerals results in cation exchange, pozzolanic reactions, and formation of cementitious compounds like calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), which improve soil strength and durability. This review focuses on experimental findings from previous studies on lime-treated black cotton soil, analyzing the influence on compaction, strength, and durability characteristics.

2. Mechanism of Lime Stabilization

The improvement in strength of black cotton soil upon lime treatment is attributed to:

- Cation Exchange & Flocculation: Replacement of monovalent cations (Na^+, K^+) by Ca^{2+} ions reduce plasticity and improves workability.
- Pozzolanic Reactions: Lime reacts with amorphous silica and alumina in clay to form CSH and CAH gels.
- Carbonation: Excess lime reacts with atmospheric CO_2 forming $CaCO_3$, which further densifies soil.

3. Effect of Lime on Geotechnical Properties

3.1 Atterberg Limits

Studies reveal that with the addition of 2–8% lime, the liquid limit of black cotton soil decreases, while the plastic limit increases, thereby reducing the plasticity index. This indicates improvement in soil workability and reduction in swelling potential.

3.2 Compaction Characteristics

Lime-treated soils generally show a decrease in maximum dry density (MDD) and an increase in optimum moisture content (OMC). This is due to the flocculation and aggregation of clay particles, leading to a more open soil structure.

3.3 California Bearing Ratio (CBR)

CBR values of lime-treated black cotton soil increase significantly. For example, CBR may rise from 2–4% in untreated soil to 8–12% with 6–8% lime addition, depending on curing period. This makes the soil more suitable for use in road subgrades.

3.4 Unconfined Compressive Strength (UCS)

UCS tests indicate a significant improvement in strength after lime treatment. The optimum lime content (OLC) is usually found in the range of 4–8%. Strength gain continues with longer curing periods due to progressive pozzolanic reactions.

3.5 Shear Strength Parameters

Direct shear and triaxial tests have shown increased cohesion (c) and friction angle (φ) with lime stabilization. Cohesion may increase up to 200–300% depending on curing, while φ shows moderate improvement.

4. Review of Past Studies

- Kumar et al. (2016): Reported that UCS of black cotton soil increased up to 3–4 times with 6% lime addition and 28 days curing.
- Rao and Reddy (2018): Found that soaked CBR improved from 2% to 10% with lime stabilization, making it viable for highway subgrades.
- Patil et al. (2020): Highlighted that lime-treated black cotton soil showed reduced swell pressure by 60–70%.
- Recent trends: Combination of lime with other materials such as fly ash, GGBS, and cement has been explored to further enhance strength and reduce cost.

5. Applications and Practical Implications

- Highway Subgrades: Lime treatment enhances load-bearing capacity and reduces swelling, making it suitable for flexible and rigid pavements.
- Foundation Improvement: Lime-treated soil shows reduced settlement and improved shear strength.
- Rural Roads: Due to low cost and easy availability of lime, it is an economic stabilization method for village roads and low-volume traffic pavements.

6. Conclusions

1. Lime stabilization effectively improves the engineering properties of black cotton soil by reducing plasticity, increasing workability, and enhancing strength.
2. The optimum lime content is typically in the range of 4–8%, beyond which the strength gain is marginal.
3. Long-term curing significantly improves strength due to pozzolanic reactions.
4. Lime-treated black cotton soil is suitable for subgrades, embankments, and light foundation works.
5. Combination of lime with other industrial by-products can further enhance performance and sustainability.

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