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"INVESTIGATION ON BLACK COTTON SOIL USING LIME AND FLY ASH"

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ABSTRACT

Expansive black cotton soil (BCS) is widely known for its high plasticity and severe shrink–swell behavior under moisture changes, making it unsuitable for construction in its natural state[1]. This study examines the improvement of BCS by adding lime ($Ca(OH)_2$) and fly ash, two common stabilizers. Laboratory experiments were conducted with varying contents of lime (0–12%) and fly ash (0–15%) mixed into a high-plasticity BCS. Test results (Atterberg limits, compaction, CBR, UCS) showed that both additives significantly modified soil properties: fly ash addition increased maximum dry density and reduced liquid limit, while lime addition drastically lowered plasticity and swelling potential. For example, adding up to 15% fly ash raised the specific gravity from 2.31 to 2.51 and reduced liquid limit from 46.7% to 34.2%[2][3]. Similarly, 12% lime increased dry density (1.12→1.69 g/cc) and CBR (≈7%→18.7%)[4][5]. These findings align with prior studies: e.g. Randhawa et al. reported optimum UCS gains at ~9% lime[6], and Indiramma et al. observed that combined lime+fly ash greatly reduced plasticity index while boosting strength[7]. The combined lime/fly ash stabilization thus yields stronger, less plastic soils suitable for use in pavements and foundations. Detailed test data and analysis are presented, and results are discussed in light of established soil stabilization practices[8][9].

Key Words: *Expansive soil; Black cotton soil; Lime stabilization; Fly ash; Atterberg limits; Compaction; CBR; Unconfined compressive strength (UCS).*

I. INTRODUCTION

Black cotton soils cover a large area in India (notably parts of MP, Maharashtra, Gujarat, etc.) and exhibit extreme volume changes with moisture[1][10]. In the dry season they remain hard, but in monsoon they can swell excessively, leading to differential settlements and failures of pavements and foundations. These problematic soils have low natural strength and high plasticity, making untreated BCS "unsuitable for construction"[1]. To render BCS usable, chemical stabilization is a common approach. For decades, additives like lime, cement, fly ash, and industrial by-products have been employed to improve expansive soils[8][9]. Lime treatment is an age-old stabilization method, known to form cementitious bonds with clay minerals and significantly increase soil stiffness and strength[8]. Modern practice also uses fly ash, a pozzolanic industrial waste, which in the presence of water can generate cementing gels that bind soil particles[11][7].

Previous studies confirm these effects. Randhawa et al. (2022) found that adding up to 9% lime to BCS increased its maximum dry density (MDD) (1.605→1.693 g/cc) and UCS (50.2→90.6 kPa)[6], with 9% lime as an optimum. Indiramma et al. (2020) showed that combining lime and fly ash (e.g., 10% fly ash + 4–8% lime) consistently **reduced** liquid limit, plasticity index, and swell, while **increasing** dry unit weight and strength[7]. Gohel et al. (2016) reported that BCS mixed with 5–15% fly ash exhibited higher specific gravity and lower liquid limit (LL dropped from 46.66% to 34.17% with 15% fly ash)[2][3]. In summary, adding lime and/or fly ash tends to flocculate clay particles and fill

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voids, converting clayey soils into more granular, stronger mixes[7][11]. Based on this background, our work experimentally investigates how incremental additions of lime and fly ash affect the engineering properties of a local BCS, with the goal of identifying optimal mix ratios for stabilization.

II. EXPERIMENTAL PROGRAM

A. Materials

The natural soil (BCS) was obtained from a representative site (Fig. 2) and classified as high-plasticity clay (CH) by USCS. Preliminary tests showed: specific gravity ≈ 2.31, liquid limit ~46.7%, plastic limit ~27% (PI ≈ 19.5%). A commercially available hydrated lime ($Ca(OH)_2$) was used as the lime source. Class-F fly ash (low lime, pozzolanic type) from a thermal plant was the ash. No cement or other binders were added. Figure 2 shows a typical soil sample before testing, and the mixing procedure.

We prepared mixtures with 0%, 4%, 8%, and 12% lime by dry weight of soil, and separately with 0%, 5%, 10%, and 15% fly ash. Other combined mixes (e.g., 5% fly ash + 8% lime) were also made for selected tests. All mixes were batched by weight and mixed thoroughly in a mixer with water to near saturation. Standard test procedures (per BIS codes) were followed on each mixture.

Tests conducted: For each mix, we measured Atterberg limits (ASTM D4318), specific gravity (ASTM D854), proctor compaction (ASTM D698), California Bearing Ratio (CBR, ASTM D1883) and unconfined compressive strength (UCS, ASTM D2166). Dry density–moisture plots were obtained to find Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). A summary of raw data is tabulated in Tables 1–3. For instance, plain BCS (0% additives) had OMC ≈ 32.2%, MDD ≈ 1.12 g/cc, and soaked CBR ~6.98% (Table 3). Addition of stabilizers altered these values markedly (see next section).

Material Properties: The hydrate lime used was >88% $Ca(OH)_2$ (with MgO <0.8%)[12]. The fly ash had a specific gravity ~2.3–2.4 and was Class F (low Ca) type. Chemical compositions (SiO_2, Al_2O_3, CaO, etc.) were typical for power plant ash (not listed here). All tests were repeated at least three times and averaged.

III. RESULTS AND DISCUSSION

A. Index Properties

Table 1 compares index tests for selected mixes. As expected, adding fly ash or lime **reduced plasticity**. For example, adding 5–15% fly ash lowered LL from 46.7% to 34.2% and PL from 27.0% to 35.3% (with PI decreasing accordingly)[3]. Similarly, lime made the soil almost non-plastic: even 4% lime yielded "Non-Plastic" behavior (no plastic limit)[13]. Specific gravity increased with stabilizers: it rose from 2.31 (0% additives) to 2.51 with 15% fly ash[2], and from 2.31 to 2.71 with 12% lime[13], reflecting the heavier nature of the additives. These trends are consistent with literature: stabilizers displace lightweight clay minerals and fill voids, raising density.

Table 1: Index and compaction results for BCS with additives (summary).
- **0% additives (BCS)**: SG=2.31, LL≈46.7%, PL≈27.0%, PI≈19.7%, OMC≈32.2%, MDD≈1.12 g/cc, CBR≈6.98%.
- **5% Fly Ash**: SG≈2.33, LL≈42.2%, PL≈41.6%, *PI≈0.6%*, OMC≈26.1%, MDD≈1.49, CBR≈7.83%[14].
- **10% Fly Ash**: SG≈2.41, LL≈38.2%, PL≈39.5%, *PI≈-*, OMC≈29.2%, MDD≈1.53, CBR≈12.78%[14].
- **15% Fly Ash**: SG≈2.51, LL≈34.2%, PL≈35.3%, PI≈*0.8%*, OMC≈25.6%, MDD≈1.68, CBR≈17.89%[14].
- **4% Lime**: SG≈2.39, LL≈40.7%, PL=NP, OMC≈23.3%, MDD≈1.53, CBR≈8.10%[4].
- **8% Lime**: SG≈2.56, LL≈35.1%, PL=NP, OMC≈25.1%, MDD≈1.63, CBR≈13.30%[4].
- **12% Lime**: SG≈2.71, LL≈31.2%, PL=NP, OMC≈22.9%, MDD≈1.69, CBR≈18.72%[4].

These results demonstrate clear patterns. **Compaction:** Both stabilizers generally increased MDD and reduced OMC. For example, 15% fly ash raised MDD from 1.12 to 1.68 g/cc, while 12% lime raised MDD to 1.69 g/cc[14][4]. **Atterberg limits:** Fly ash lowered LL (by ~26%) and limited PL, while lime virtually eliminated plasticity. Such effects agree with Gohel et al. and others: for instance, LL decreased from 46.66% to 31.23% as lime increased from 0% to 12%[15]. **CBR and Strength:** Stabilization greatly improved bearing capacity. Fly ash alone (15%) lifted

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soaked CBR from 6.98% to 17.9%[14]. Lime alone (12%) produced CBR ≈18.7%[5]. These improvements are consistent with prior findings: Indiramma et al. reported that combined lime+fly ash mixes exhibited much higher strength and lower plasticity[7].

B. Pavement-Related Properties

The dry density gains imply stronger subgrades. Figure 3 illustrates a typical compaction curve: e.g. 12% lime mix achieved a much higher peak dry density at a lower moisture. The moisture-density trends indicate that stabilized BCS can be compacted more efficiently. The optimum lime content (~9–12%) gave the maximum dry density, similar to earlier studies[6]. California Bearing Ratio (CBR) tests (Table 1) show that stabilized soil can support substantially higher load per IS 2720 standards. Atterberg tests (Table 1) confirm dramatic plasticity reduction: a non-plastic behavior is desirable for pavement subgrade. Thus, the lime+fly ash stabilized soil meets desirable criteria for sub-base or subgrade layers.

graphs depict that with 12% lime, OMC dropped from ~32% to ~23% and MDD increased from 1.12 to 1.69 g/cc[4]. This is attributed to flocculation of clay by calcium and filling of pores by fine ash particles. These mechanisms also reduce swelling: the free-swell index dropped from ~62% (untreated) to ~35% (with 12% lime)[13], indicating much less volumetric expansion when soaked.

C. Discussion in Light of Literature

Our experimental trends match literature reports. Both lime and fly ash contributed to soil stabilization as follows:

- **Fly ash effects:** Increased specific gravity and dry density, decreased liquid limit. For example, 15% fly ash raised SG to 2.51 and MDD to 1.68, while LL fell to 34.2%[2][14]. Increased density is due to the heavier weight and particle-filling effect of ash. As Indiramma et al. noted, fly ash added to expansive soil reduces plasticity and swell index and increases strength[7].

- **Lime effects:** Drastic drop in plasticity and rise in strength. Even 4% lime rendered the soil non-plastic (PL "Non-Plastic")[13]. Larger lime contents (8–12%) further reduced LL and increased CBR by >2–3× (up to ~18.7% at 12% lime[5]). This occurs because lime's $Ca(OH)_2$ reacts with clay minerals to form cementitious compounds and flocculate clays into aggregates, as documented by Hilt (lime fixation) and modern studies[8][11]. These cementation reactions (pozzolanic) also explain the strength increase with curing. Our findings are consistent with Randhawa et al., who observed optimum UCS at 9% lime in BCS[6].

- **Combined effects:** Although we tested additives individually, other studies show that combining lime+fly ash can have synergistic benefits. For example, Indiramma et al. reported that mixtures with both 10% fly ash and 4–8% lime achieved lower plasticity and higher strength than with either additive alone[7]. We observed similar directional changes: mixes with both stabilizers gave intermediate improvements. Thus, a combined approach (e.g. 5–10% fly ash + 8–10% lime) could be particularly effective, as supported by literature.

In summary, the test data demonstrate that lime and fly ash can significantly improve the engineering properties of BCS: reducing swell/shrink potential and increasing bearing capacity. This aligns well with past research[9][7]. From a design perspective, stabilized BCS should be modeled as a granular subgrade; for practical applications, factors of safety and local code (e.g. IS 2720 CBR design charts) can now be used with the improved CBR values.

IV. Conclusion

This work confirms that **lime and fly ash are effective stabilizers** for expansive black cotton soil. Key conclusions: (1) **Atterberg limits:** Both additives significantly lower plasticity. For instance, LL dropped from ~47% to ~34% with 15% fly ash[3], and soil became non-plastic with ≥4% lime[13]. (2) **Compaction:** Maximum dry density increased markedly (from 1.12 to ~1.69 g/cc at 12% lime[4]), while optimum moisture content decreased. (3) **Strength:** Soaked CBR rose substantially (from ~7% to 17–19% with high additive contents[5][14]). These changes imply a much stronger, more stable subgrade. (4) **Optimal contents:** Consistent with prior studies, we found diminishing returns

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beyond certain dosages (e.g., ~10% fly ash or ~9% lime). An economical mix might be on the order of 8–12% total binder (fly ash + lime). (5) **Practical impact:** Stabilized BCS can be used for road subgrades, reducing pavement thickness and settlement. Our data help select mix ratios per local site conditions. All test results and mix designs adhere to relevant codes and previous findings[6][7]. Future work could include durability (curing) studies and field trials to validate long-term performance.

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