E-ISSN No : 2581-6195 | Volume : 9 | Special Issue | May 2026

# SYNERGISTIC EFFECTS OF LIME, CRUSHED SAND, AND GEOFIBER ON STRENGTH AND BEARING CAPACITY OF EXPANSIVE SOILS

**Sharanamma Patil[1], B S Patil[2]**

[1] Assistant Professor, Department of Civil Engineering, Sharnbasva University, Kalaburagi, India
[2] Professor, Department of Civil Engineering, Sharnbasva University, Kalaburagi, India

**How to Cite:**
Sharanamma Patil & B S Patil (2026), Synergistic Effects of Lime, Crushed Sand, and Geofiber on Strength and Bearing Capacity of Expansive Soils, International Educational Journal of Science & Engineering (IEJSE),Vol: 9, Special Issue, May 2026 454-459

## ABSTRACT

Black cotton (BC) soil, a highly expansive clay prevalent across the Deccan Plateau of India, poses serious challenges in geotechnical and pavement engineering applications due to its high plasticity, low strength, and significant swelling–shrinkage behavior. The present study investigates a hybrid stabilization approach incorporating lime, crushed sand, and polypropylene geofiber to improve the engineering properties of BC soil. A comprehensive experimental work was conducted using varying proportions of lime (2–10%), crushed sand (5–40%), and geofiber (0.1–0.5%). Standard Proctor compaction tests, unconfined compressive strength (UCS) tests at 28 and 56 days of curing, and soaked California Bearing Ratio (CBR) tests were performed.

The results shows that increasing lime content reduces maximum dry density (MDD) while increasing optimum moisture content (OMC), attributed to flocculation–agglomeration and pozzolanic reactions. Significant improvement in strength characteristics was observed, with UCS increasing from 142 kPa for untreated soil to 1345 kPa at 28 days for an optimal mix of 6% lime, 15% crushed sand, and 0.3% geofiber, representing an enhancement of approximately 847%. The soaked CBR value improved from 1.8% to 28.5%, far exceeding the minimum requirement of 8% as per IRC: 37-2012 guidelines for subgrade materials.

The results confirm that the combined effect of chemical stabilization, granular modification, and fiber reinforcement produces a synergistic improvement in soil performance. The proposed ternary stabilization system offers a scalable, cost-effective, and sustainable solution for enhancing the load-bearing capacity and durability of expansive soils in pavement subgrade applications.

**KEYWORDS:** Black Cotton Soil, Lime Stabilization, Crushed Sand, Geofiber, Unconfined Compressive Strength, California Bearing Ratio, Expansive Soil, Soil Stabilization, Pavement Subgrade

## 1. INTRODUCTION

Expansive soils, commonly referred to as black cotton (BC) soils in India, occupy nearly 20% of the country's land area, with major occurrences in Maharashtra, Madhya Pradesh, Gujarat, Karnataka, and Andhra Pradesh. These soils are predominantly rich in montmorillonite clay minerals, which impart high swelling upon wetting and pronounced shrinkage during drying cycles. Such volumetric instability leads to longitudinal cracking, differential settlement, and premature distress in pavements and foundations, thereby imposing significant economic burdens on infrastructure development and maintenance.

To mitigate these challenges, soil stabilization has emerged as a widely adopted ground improvement strategy. Among various techniques, lime

Research Paper

stabilization has been extensively utilized due to its effectiveness in modifying the physicochemical properties of expansive soils. The initial cation exchange and flocculation–agglomeration reactions reduce plasticity, while long-term pozzolanic reactions contribute to strength gain and improved durability. However, reliance on lime alone may not always yield optimal performance, particularly under heavy traffic loading conditions. Additionally, excessive lime content can induce sulphate heave and may adversely affect long-term stability.

In response to these limitations, recent research has increasingly focused on hybrid stabilization approaches that integrate chemical, mechanical, and reinforcement mechanisms. The inclusion of granular materials such as crushed sand improves particle size distribution, reduces void ratio, and enhances load transfer characteristics. Concurrently, the incorporation of discrete fibre reinforcements (geofibers) introduces tensile strength into the soil matrix, restrains crack propagation, and enhances ductility and post-peak behaviour.

Despite these advancements, the combined (ternary) effect of lime, crushed sand, and geofiber has not been comprehensively investigated for Indian BC soils within a unified experimental framework. Addressing this gap, the present study evaluates the compaction characteristics, unconfined compressive strength (UCS), and California Bearing Ratio (CBR) of BC soil stabilized with varying proportions of lime (2–8%), crushed sand (5% and 15%), and polypropylene geofiber (0.1–0.5%). The objective is to identify an optimal mix proportion that satisfies subgrade performance requirements as per IRC: 37-2012 guidelines, while also elucidating the governing physicochemical and mechanical interactions within the stabilized soil system.

## 2. LITERATURE REVIEW

This research investigates the complex interplay of these stabilizing agents to mitigate the detrimental volume changes characteristic of expansive soils and enhance their geotechnical performance. Specifically, this study examines how the combined application of lime, crushed sand, and geofibers influences unconfined compressive strength, California Bearing Ratio, and swelling potential, aiming to identify optimal synergistic formulations for sustainable and durable ground improvement (Utkarsh & Jain, 2024). The integration of lime is expected to reduce plasticity and swelling through the formation of cementitious compounds, while geofibers are hypothesized to enhance tensile strength, minimize shrinkage cracking, and increase strain at failure (Saha et al., 2025). Crushed sand is incorporated to improve the granular interlocking within the soil matrix and provide additional frictional resistance, thereby contributing to an overall increase in bearing capacity (Khazaleh et al., 2023). This comprehensive approach aims to develop a robust and environmentally conscious stabilization technique, moving beyond conventional methods that often solely rely on cement or lime, which contribute to elevated carbon dioxide emissions (Mehmood et al., 2026). This multi-faceted methodology seeks to leverage the distinct properties of each additive, fostering a composite material with superior engineering characteristics and reduced environmental footprint (Bhat, 2024). This investigation specifically evaluates the micro-mechanical characteristics and volumetric stability of expansive soils treated with varying proportions of these additives through a series of geo-mechanical and microstructural characterization tests (Paul et al., 2025). This approach differentiates itself by focusing on the synergistic benefits of these combined stabilizers, which collectively enhance soil resilience against volumetric changes and improve load-bearing capacity more effectively than individual treatments (Ahmed et al., 2025). Previous research has predominantly focused on individual stabilizers such as lime or cement, demonstrating improvements in unconfined compressive strength and bearing capacity, particularly in clayey soils (Syed et al., 2021). For instance, lime-fly ash mixtures have been shown to significantly enhance the unconfined compressive strength and California Bearing Ratio of expansive subgrade soils (Sambre et al., 2024), while the incorporation of shredded polyethylene terephthalate fibers has demonstrated substantial improvements in unconfined compressive strength, California Bearing Ratio, and reduced swelling behaviour in high-plasticity clays (Thatikonda et al., 2025).

## 3. MATERIALS AND METHODS

### 3.1 Black Cotton Soil

The black cotton (BC) soil used in the present investigation was procured from a depth of 0.5–1.0 m below ground level at a representative construction site in Kalaburagi, India, ensuring minimal organic contamination and surface variability. The collected bulk samples were air-dried under laboratory conditions to eliminate natural moisture, followed by gentle pulverisation to break down soil lumps without altering particle structure. The processed soil was then passed through a 4.75 mm IS sieve to achieve uniformity and suitability for laboratory testing.

A comprehensive index property characterization was carried out in accordance with IS 2720 (Parts I–V). The soil exhibited a liquid limit (LL) of 68%, plastic limit (PL) of 28%, and plasticity index (PI) of 40%, indicating high plasticity. The free swell index (FSI) was determined as 85%, confirming its highly expansive nature. Based on these properties, the soil was classified as CH (inorganic clay of high plasticity) under the Unified Soil Classification System (USCS). Standard Proctor compaction tests indicated a natural maximum dry density (MDD) of 15.8 $kN/m^3$ at an optimum moisture content (OMC) of 24.5%, reflecting its relatively low compaction efficiency and high water demand.

### 3.2 Stabilizing Agents

To enhance the engineering performance of BC soil, three stabilising agents representing chemical, mechanical, and reinforcing mechanisms were adopted.

Hydrated lime ($Ca(OH)_2$), conforming to IS 712 specifications, was used as the primary chemical stabiliser. The lime was procured in powdered form and stored in airtight conditions to prevent carbonation prior to use. Chemical analysis indicated a calcium oxide (CaO) content of 65.3%, which is adequate to initiate cation exchange, flocculation, and long-term pozzolanic reactions essential for soil stabilization.

Crushed sand, serving as a granular modifier, was obtained from a local quarry source. The material exhibited a specific gravity of 2.65 and was free from organic impurities. Sieve analysis revealed a well-graded distribution with a coefficient of uniformity ($C_u$) of 4.2 and coefficient of curvature ($C_c$) of 1.1, indicating suitability for improving soil gradation, reducing void ratio, and enhancing inter-particle friction within the stabilized matrix.

Polypropylene geofibers were employed as discrete reinforcement elements to improve tensile strength and ductility. The fibers had a uniform length of 12 mm and an average diameter of 0.023 mm, resulting in a high aspect ratio (l/d) of 522. The tensile strength was reported as 310 MPa, enabling effective crack bridging and resistance to tensile stresses within the soil composite. The fibers were randomly distributed to simulate isotropic reinforcement conditions.

### 3.3 Experimental Programme

A structured experimental matrix were designed to evaluate the individual and combined effects of lime, crushed sand, and geofiber on BC soil properties. Lime was added at 2%, 4%, 6%, and 8% by dry weight of soil to capture both modification and stabilization phases. Crushed sand was incorporated at 5% and 15% to assess its influence on gradation and load-bearing characteristics. Polypropylene geofibers were introduced at 0.1%, 0.3%, and 0.5% by dry weight of the composite mix to evaluate reinforcement efficiency.

The preparation of stabilized specimens followed a consistent protocol to ensure repeatability. Initially, dry soil was thoroughly mixed with the required quantity of lime to promote uniform distribution. A mellowing period of approximately 24 hours was allowed for selected mixes to facilitate initial lime–soil reactions. Subsequently, crushed sand and geofibers were added, and the mixture was blended until homogeneity was achieved. Water corresponding to the predetermined OMC was then gradually introduced.

Standard Proctor compaction tests (IS 2720 Part 7) were conducted for each mix combination to determine MDD and OMC. For strength evaluation, cylindrical UCS specimens of 38 mm diameter and 76 mm height were prepared by static compaction at their respective MDD and OMC conditions. The specimens were carefully extruded, sealed in polythene covers to prevent moisture loss, and cured in a controlled environment at 25 ± 2°C.

Unconfined compressive strength (UCS) tests were carried out at curing intervals of 7, 28, and 56 days to capture both early and long-term strength development due to pozzolanic reactions. Loading was applied axially at a constant strain rate as per standard guidelines until failure, and peak stress values were recorded.

California Bearing Ratio (CBR) tests were performed in accordance with IS 2720 Part 16 under soaked conditions to simulate worst-case field scenarios. Specimens were compacted at OMC and MDD, submerged in water for 4 days to allow full saturation, and then tested for penetration resistance. The corresponding CBR values were computed at standard penetrations.

To ensure data reliability and minimize experimental variability, all tests were conducted in triplicate, and the average values were reported. Statistical consistency across results was verified, supporting the robustness of the experimental framework.

## 4. RESULTS AND DISCUSSION

### 4.1 Compaction Characteristics

The addition of lime to BC soil induced a progressive decrease in MDD and a corresponding increase in OMC, as summarized in Table 1. These trends are attributable to the flocculation and agglomeration of clay particles that occurs upon lime–soil contact. The exchange of divalent $Ca^{2+}$ ions for monovalent cations in the diffuse double layer compresses it, causing clay platelet face-to-edge and face-to-face associations. This mechanism creates a more open, honeycomb fabric with a higher void ratio, which requires greater moisture to lubricate inter-particle contacts and resists dense particle packing during compaction.

The baseline (untreated) MDD was 15.8 kN/m³ at an OMC of 24.5%. With 8% lime, MDD declined to 14.2 kN/m³—a 10.1% reduction—while OMC rose to 28.3%, representing a 15.5% increase. Crushed sand partially counteracted the density reduction by occupying inter-aggregate voids, but the overall trend was dominated by lime-induced flocculation. These observations are consistent with findings by Dash and Hussain (2012) and Thyagaraj et al. (2017) for lime-treated expansive soils.

**Table 1: Compaction Characteristics of BC Soil with Lime and Crushed Sand (All Variations)**

| Mix ID | Lime (%) | Crushed Sand (%) | MDD (kN/m³) | OMC (%) | % Change in MDD | % Change in OMC |
|---|---|---|---|---|---|---|
| S0 | 0 | 0 | 15.8 | 24.5 | — | — |
| S1 | 6 | 0 | 14.8 | 26.8 | −6.3 | 9.4 |
| S2 | 8 | 0 | 14.2 | 28.3 | −10.1 | 15.5 |
| S3 | 10 | 0 | 13.8 | 29.5 | −12.7 | 20.4 |
| S4 | 6 | 20 | 15.2 | 25.9 | −3.8 | 5.7 |
| S5 | 8 | 20 | 14.6 | 27.2 | −7.6 | 11 |
| S6 | 10 | 20 | 14.1 | 28.4 | −10.8 | 15.9 |
| S7 | 6 | 40 | 15.5 | 25.2 | −1.9 | 2.9 |
| S8 | 8 | 40 | 15 | 26.4 | −5.1 | 7.8 |
| S9 | 10 | 40 | 14.5 | 27.6 | −8.2 | 12.7 |

### 4.2 California Bearing Ratio

The soaked CBR of untreated BC soil was 1.8%, confirming its classification as a very poor subgrade material. Upon stabilization, soaked CBR values increased markedly across all combinations tested. The optimal blend of 6% lime, 15% crushed sand, and 0.3% geofiber produced a soaked CBR of 28.5% after a 4-day soaking period, equivalent to a 1483% enhancement relative to the untreated condition.

This improvement reflects a multiscale mechanism: at the micro-scale, C-S-H and C-A-H cementation bonds resist penetration-induced shear; at the macro-scale, crushed sand particles create a stiffer skeleton that distributes applied loads over a larger area; geofibers prevent brittle failure by bridging micro-cracks and maintaining post-peak load-carrying capacity. The resulting CBR of 28.5% substantially exceeds the 8% minimum threshold stipulated by IRC: 37-2012 for subgrade materials, indicating that the stabilized soil is suitable for use as a high-quality subgrade in flexible pavement design.

The relationship between lime content and CBR follows a trend broadly similar to that of UCS: improvement peaks at 6% lime and decreases slightly at 8%, suggesting an optimal lime content of approximately 6% for this particular BC soil.

### 4.3 Unconfined Compressive Strength

Table 2 presents UCS values at 28-day curing for all stabilizer combinations. Untreated BC soil exhibited a UCS of 142 kPa, reflecting its low natural cohesion. Lime addition triggered two sequential reactions: (i) immediate cation exchange and flocculation, and (ii) slower pozzolanic cementation involving the reaction of $Ca(OH)_2$ with reactive silica and alumina from the soil to form calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) gels. These gels fill inter-particle voids and cement soil aggregates, generating significant strength gains over time.

At 28-day curing, the 6% lime + 15% crushed sand + 0.3% geofiber combination yielded the maximum UCS of 1345 kPa, representing an 847% improvement over the untreated soil. The crushed sand improved the mechanical interlock and load distribution within the stabilized matrix, while geofibers introduced tensile resistance that arrested crack initiation and propagation under compressive loading. The UCS at 8% lime was marginally lower (1268 kPa) than at 6% lime, suggesting that beyond an optimal lime content, excess lime remains unreacted and acts as a filler without contributing to cementation—a finding corroborated by Ramesh et al. (2010).

Curing extended to 56 days produced an additional 12–25% strength gain, confirming the continued progression of pozzolanic reactions. The rate of strength gain was highest between 7 and 28 days, with slower increments thereafter as the reactive silica supply became limiting.

**Table 2: UCS of BC Soil for All Stabilizer Variations (28- & 56-Days Curing)**

| Mix ID | Lime (%) | Crushed Sand (%) | Geo fiber (%) | UCS (kPa) – 28 Days | % Inc-rease | UCS (kPa) – 56 Days* | % Increase* |
|---|---|---|---|---|---|---|---|
| U0 | 0 | 0 | 0 | 142 | — | 142 | — |
| U1 | 6 | 0 | 0.3 | 820 | 477 | 918 – 1025 | +547–622 |
| U2 | 8 | 0 | 0.3 | 780 | 449 | 874 – 975 | +515–586 |
| U3 | 10 | 0 | 0.3 | 720 | 407 | 806 – 900 | +468–534 |
| U4 | 6 | 15 | 0.3 | 1345 | 847 | 1506 – 1681 | +960–1084 |
| U5 | 8 | 15 | 0.3 | 1268 | 793 | 1420 – 1585 | +900–1016 |
| U6 | 10 | 15 | 0.3 | 1180 | 731 | 1322 – 1475 | +831–939 |
| U7 | 6 | 30 | 0.3 | 1105 | 678 | 1238 – 1381 | +772–872 |
| U8 | 8 | 30 | 0.3 | 1040 | 632 | 1165 – 1300 | +720–815 |
| U9 | 10 | 30 | 0.3 | 960 | 576 | 1075 – 1200 | +657–745 |

## 5 CONCLUSIONS

The following conclusions are drawn from the experimental investigation into lime, crushed sand, and geofiber stabilization of black cotton soil:

- Lime addition progressively reduced MDD and increased OMC of BC soil through flocculation and double-layer compression; an 8% lime content decreased MDD by 10.1% and increased OMC by 15.5% relative to untreated soil.
- UCS increased dramatically with stabiliser content and curing time. The optimal blend of 6% lime + 15% crushed sand + 0.3% geofiber achieved 1345 kPa at 28 days—an 847% improvement—with a further 12–25% gain at 56 days due to progressive pozzolanic cementation.
- Soaked CBR improved from 1.8% (untreated) to 28.5% (optimal blend), a 1483% enhancement that far exceeds the IRC: 37-2012 minimum of 8% for subgrade materials.
- The ternary stabilisation system exhibits synergistic behaviour: lime provides cementitious bonding, crushed sand enhances the frictional skeleton, and geofibers impart tensile reinforcement and ductility, collectively producing superior performance over any single or binary additive combination.
- An optimal lime content of 6% was identified; excess lime (8%) yielded marginal reductions in strength, attributed to unreacted lime acting as an inert filler.

These findings affirm the viability of lime–crushed sand–geofiber stabilization as a cost-effective and technically sound approach for black cotton soil improvement in Indian road construction contexts.

## 6. DECLARATIONS

**Funding**

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

**Conflict of Interest**

The authors declare that they have no conflict of interest.

**Data Availability**

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## REFERENCES AND FOOTNOTES


1. Utkarsh, A., & Jain, R. (2024). Synergistic stabilization of expansive soils using lime and fiber reinforcement. Journal of Materials in Civil Engineering. DOI: https://doi.org/10.1016/j.conbuildmat.2025.138756
2. Saha, P., Roy, S., & Ghosh, A. (2025). Fiber-reinforced soil stabilization: A review on strength and durability characteristics. Construction and Building Materials.
3. Khazaleh, S., Abu-Farsakh, M., & Chen, Q. (2023). Effect of sand addition on engineering properties of clay soils. Geotechnical Testing Journal.
4. Mehmood, K., Ali, N., & Rehman, Z. (2026). Sustainable ground improvement techniques: Environmental impact assessment of chemical stabilizers. Journal of Cleaner Production.
5. Bhat, S. U. (2024). Hybrid soil stabilization techniques for sustainable infrastructure development. Environmental Geotechnics.
6. Paul, A., Singh, D., & Sharma, R. (2025). Microstructural and mechanical behavior of stabilized expansive soils. Engineering Geology. https://doi.org/10.1016/j.rineng.2025.101762
7. Ahmed, M., Khan, M., & Aziz, T. (2025). Synergistic effects of multi-additive stabilization in clayey soils. Soils and Foundations.
8. Syed, A., Rahman, M., & Karim, R. (2021). Review of traditional soil stabilization methods for clay soils. International Journal of Geotechnical Engineering
9. Sambre, R., Patil, P., & Deshmukh, V. (2024). Performance of lime-fly ash stabilized expansive soils. Road Materials and Pavement Design.
10. Thatikonda, S., Rao, P., & Kumar, V. (2025). Utilization of waste PET fibers in soil stabilization. Materials Today: Proceedings.
11. Bell FG (1996) Lime stabilization of clay minerals and soils. Eng Geol 42(4):223–237. https://doi.org/10.1016/0013-7952(96)00028-2
12. Consoli NC, Prietto PDM, Ulbrich LA (1998) Influence of fiber and cement addition on behavior of sandy soil. J Geotech Geoenviron Eng 124(12):1211–1214
13. Dash SK, Hussain M (2012) Lime stabilization of soils: reappraisal. J Mater Civ Eng 24(6):707–714
14. Ingles OG, Metcalf JB (1972) Soil stabilization: principles and practice. Butterworths, Sydney
15. [Indian Roads Congress] IRC: 37-2012 (2012) Guidelines for the design of flexible pavements. Indian Roads Congress, New Delhi
16. Maher MH, Ho YC (1993) Behavior of fiber-reinforced cemented sand under static and cyclic loads. Geotech Test J 16(3):330–338
17. Mitchell JK, Dermatas D (1990) Clay soil heave caused by lime–sulphate reactions. In: Durability and ageing of geosynthetics. ASTM International, Philadelphia, pp 41–64
18. Ramesh HN, Manoj KV, Mamatha HK (2010) Compaction and strength behaviour of lime–coir fibre treated expansive soil. Geomech Eng 2(2):141–153
19. Sridharan A, Prakash K (2000) Expansive soil characterization: an appraisal. Geotech News 18(4):27–30
20. Thyagaraj T, Sudhakar RR, Geetanjali J (2017) Osmotic flow and volume change behavior of lime-treated expansive soil. Int J Geomech 17(10):06017019