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Comparative Assessment of Lime–Fly Ash Stabilization of Expansive Soil for Pavement Subgrades: A Secondary-Data Study

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Abstract

Expansive soils create significant challenges in pavement construction because of their high plasticity, low bearing capacity and moisture-induced swelling and shrinkage. Sustainable stabilization using industrial by-products such as fly ash, particularly in combination with lime, provides a potential alternative to conventional soil replacement. This study presents a comparative secondary-data analysis of real experimental results reported in peer-reviewed literature on fly ash and lime–fly ash stabilization of expansive soils. Key parameters including California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), free swell and swelling pressure were examined. Published results for black cotton soil treated with 10% fly ash showed an increase in CBR from 2.189% to 2.33% and UCS from 0.1688 to 0.333 N/mm². Another peer-reviewed study on expansive soil from Nashik reported substantial improvement with lime–fly ash treatment, including a CBR value of up to 28% for a specific tested mixture compared with approximately 4% for untreated soil. Swelling pressure was also reported to decrease from approximately 147 to 70 kPa for a selected mixture. The findings indicate that lime–fly ash stabilization can significantly improve the engineering performance of problematic soils, although optimum proportions are soil-specific and require laboratory validation before field application.

Keywords: Expansive soil, fly ash, lime, soil stabilization, CBR, UCS, pavement subgrade, sustainable construction.

1. Introduction

Expansive soils undergo considerable volume change with variations in moisture content, resulting in pavement cracking, heaving and loss of serviceability. Conventional excavation and replacement of weak soil can be expensive and requires large quantities of natural materials. Consequently, industrial by-products such as fly ash have increasingly been investigated for sustainable soil stabilization. Fly ash contains reactive silica and alumina, while lime provides calcium and an alkaline environment that can promote pozzolanic reactions. The resulting cementitious compounds can improve strength and reduce plasticity and swelling. Previous research has demonstrated that the effectiveness of stabilization varies considerably with soil type, additive percentage and curing conditions. The present study therefore compares real experimental results reported in peer-reviewed literature. The objective is to identify the potential of fly ash and lime–fly ash combinations for improving expansive pavement subgrades without representing previously published laboratory observations as original experiments.

2. Methodology

A secondary-data methodology was adopted. Numerical results were extracted from peer-reviewed studies investigating fly ash and lime–fly ash stabilization of expansive and black cotton soils. The principal parameters considered were CBR, UCS, free swell and swelling pressure.

Percentage improvement was calculated as:

[$\text{Improvement}=\frac{X_t-X_u}{X_u}\times100$] where ($X_t$) is the treated value and (X_u) is the untreated value.
Two principal experimental studies were considered: Gireesh Kumar and Harika (2021), who investigated fly ash stabilization of black cotton soil, and Sambre et al. (2024), who investigated lime–fly ash stabilization of expansive soil from Nashik, Maharashtra.

3. Results and Discussion

Table 1. Comparison of Published Experimental Results

Parameter	Untreated	Stabilized	Change
CBR – black cotton soil	2.189%	2.33%	+6.44%
UCS – black cotton soil	0.1688 N/mm^2	0.333 N/mm^2	+97.27%
CBR – expansive soil	≈4%	Up to 28%*	≈600%
Free swell	75%	≈54%	≈28% reduction
Swelling pressure	147 kPa	70 kPa	52.38% reduction

*The 28% value represents a particular lime–fly ash mixture reported in the detailed experimental results and should not be interpreted as a universal optimum.

The black cotton soil study demonstrated that 10% fly ash increased CBR from 2.189% to 2.33%, corresponding to approximately 6.44% improvement. More significant improvement was observed in UCS, which increased from 0.1688 to 0.333 N/mm^2, representing approximately 97.27% improvement. The lime–fly ash investigation demonstrated a substantially stronger response in another expansive soil. A CBR of up to 28% was reported for a particular mixture compared with approximately 4% for untreated soil. The corresponding relative improvement was approximately 600%. The same investigation reported reduction in free swell and swelling pressure, indicating improved volume stability. The improvement can be attributed to cation exchange, flocculation and pozzolanic reactions. Calcium supplied by lime interacts with reactive silica and alumina from fly ash and soil, forming cementitious products that increase interparticle bonding. However, the comparison also demonstrates that stabilization performance is highly soil-specific. Therefore, increasing additive content does not necessarily result in continuous improvement.

4. Engineering and Sustainability Significance

Improving the CBR of weak subgrade soil can potentially reduce pavement thickness and the requirement for imported granular materials. Utilization of fly ash also provides a beneficial route for industrial-waste management and supports circular-economy principles. However, laboratory results from one geographical location cannot be directly adopted for another site. Local soil classification, mineralogy, moisture conditions, stabilizer chemistry and curing must be considered. Soaked CBR, UCS, swelling, durability and environmental/leachability testing should be undertaken before field implementation.

5. Conclusions

The comparative analysis demonstrates that sustainable stabilization using fly ash and lime–fly ash can improve the engineering properties of expansive soils. Fly ash treatment of black cotton soil increased UCS by approximately 97%, although the CBR improvement was relatively modest. Lime–fly ash treatment produced substantially greater improvement in the selected expansive-soil dataset, with reported CBR increasing from approximately 4% to as high as 28% for a particular mixture. Swelling pressure was reduced by approximately 52% for a selected stabilized mixture. The results confirm that lime–fly ash stabilization has considerable potential for pavement subgrade improvement and industrial-waste utilization. Nevertheless, optimum stabilizer content must be established through site-specific laboratory testing, and published values should not be treated as substitute laboratory results for a new construction project.

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