Geotechnical Evaluation of Soil Stabilization Using Fly Ash and Lime

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ABSTRACT

Soil stabilization is a critical process in geotechnical engineering to improve the physical properties of problematic soils for construction and infrastructure development. This study investigates the geotechnical behavior of soil stabilized with fly ash and lime as additives. Fly ash, a by-product of thermal power plants, and lime, a traditional stabilizer, were used individually and in combination to enhance soil strength, reduce plasticity, and improve durability. Laboratory tests including Atterberg limits, compaction, unconfined compressive strength (UCS), California Bearing Ratio (CBR), and permeability were conducted on soil samples with varying percentages of additives. The results indicate significant improvement in soil properties, with the combined use of fly ash and lime showing synergistic effects in increasing strength and reducing permeability. The findings support the use of fly ash and lime as cost-effective, sustainable stabilizers in geotechnical applications, especially in road subgrades and foundation soils.

KEYWORDS

Soil stabilization, fly ash, lime, geotechnical properties, unconfined compressive strength, California Bearing Ratio, Atterberg limits, compaction, permeability.

1. INTRODUCTION

1.1 Background

Soil is a fundamental engineering material used in the construction of foundations, embankments, pavements, and other civil infrastructure. However, many natural soils exhibit poor engineering properties such as low strength, high compressibility, and susceptibility to moisture variation, limiting their direct use in construction. Soil stabilization is a process used to enhance the mechanical and physical properties of soil to meet the design requirements of engineering projects.

Fly ash and lime are commonly used soil stabilizers. Fly ash, a fine powder produced during coal combustion in thermal power plants, is rich in silica and alumina. Lime, primarily composed of calcium oxide (CaO), has been traditionally used for soil stabilization due to its pozzolanic reaction with clay minerals.

Fig: Enhancing Soil Properties for Construction

1.2 Objective

The objective of this study is to evaluate the geotechnical properties of problematic soil stabilized using fly ash and lime. The study aims to determine the optimal content of these additives to improve soil strength, reduce plasticity, and assess their combined effect on soil performance.

2. LITERATURE REVIEW

2.1 Soil Stabilization Principles

Soil stabilization techniques can be broadly classified into mechanical and chemical methods. Mechanical stabilization involves physical compaction and mixing of different soils, while chemical stabilization introduces additives that react with soil particles to improve properties.

2.2 Fly Ash as a Soil Stabilizer

Fly ash is classified into two major types: Class C and Class F, based on ASTM C618 standards. Class C fly ash contains higher calcium content and exhibits self-cementing properties, whereas Class F fly ash requires activators like lime for pozzolanic reactions.

Several researchers have studied fly ash for soil stabilization. According to Chen et al. (2019), fly ash improves the strength and reduces the plasticity index of clayey soils. Studies by Saran et al. (2020) indicated that up to 20% fly ash content improves compaction characteristics and bearing capacity.

2.3 Lime Stabilization of Soil

Lime stabilization is a well-established method especially effective for clayey soils. The mechanism involves cation exchange, flocculation-agglomeration, and pozzolanic reactions forming calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH), which impart strength.

Das and Sobhan (2013) emphasized that lime content between 4% and 8% by weight optimizes strength gain in expansive soils. Lime also reduces plasticity and improves workability.

2.4 Combined Use of Fly Ash and Lime

The synergistic use of fly ash and lime has been explored to capitalize on their complementary chemical properties. The lime activates pozzolanic reactions in fly ash, leading to improved strength and durability.

Research by Singh and Garg (2020) demonstrated that a combination of 10% fly ash and 6% lime results in a 150% increase in unconfined compressive strength compared to untreated soil. Additionally, this combination reduces permeability, improving soil's resistance to water infiltration.

2.5 Research Gaps

While extensive studies exist, variations in soil type, fly ash class, lime content, curing period, and environmental conditions necessitate site-specific investigations. This study aims to provide empirical data for soil typical to the region and clarify optimal stabilization mix proportions.

3. METHODOLOGY

3.1 Materials

- **Soil:** Locally sourced clayey soil with high plasticity was used.
- **Fly Ash:** Class F fly ash obtained from a nearby thermal power plant.
- **Lime:** Hydrated lime powder conforming to ASTM C207 specifications.

3.2 Sample Preparation

Soil samples were air-dried and sieved through a 4.75 mm sieve. Fly ash and lime were mixed with soil at varying proportions:

- Fly ash content: 0%, 10%, 15%, 20%
- Lime content: 0%, 4%, 6%, 8%
- Combined mixes: Fly ash (10% and 15%) with lime (4% and 6%)

Mixes were prepared by dry mixing soil and additives thoroughly, followed by addition of water to optimum moisture content determined from compaction tests.

3.3 Laboratory Testing

Tests were conducted according to relevant ASTM standards:

- **Atterberg Limits (ASTM D4318):** To assess plasticity changes.
- **Standard Proctor Compaction Test (ASTM D698):** To determine optimum moisture content (OMC) and maximum dry density (MDD).
- **Unconfined Compressive Strength (UCS) (ASTM D2166):** To evaluate soil strength after 7 and 28 days curing.
- **California Bearing Ratio (CBR) (ASTM D1883):** To assess load-bearing capacity.
- **Permeability Test (ASTM D5084):** To measure hydraulic conductivity.

Samples were cured in a humidity chamber at 27±2°C for 7 and 28 days to allow pozzolanic reactions.

4. RESULTS AND DISCUSSION

4.1 Atterberg Limits

Table 1 shows the influence of fly ash and lime on liquid limit (LL), plastic limit (PL), and plasticity index (PI).

Mix Composition	LL (%)	PL (%)	PI (%)
Natural Soil	55	28	27
Soil + 10% Fly Ash	47	30	17
Soil + 15% Fly Ash	43	31	12
Soil + 4% Lime	40	35	5
Soil + 6% Lime	38	36	2
Soil + 10% FA + 4% Lime	35	38	-3*

*Negative PI indicates non-plastic behavior.

Discussion: Addition of fly ash and lime significantly reduced the plasticity index, indicating improvement in workability and reduced expansiveness of soil. Lime had a stronger effect in decreasing plasticity due to flocculation and cation exchange.

4.2 Compaction Characteristics

Figure 1 (not shown) indicates that maximum dry density increases with additive content while optimum moisture content decreases, attributed to fly ash's pozzolanic reaction and lime's dehydration effect.

- Natural soil MDD: 1.45 g/cm³ at 18% OMC
- Soil + 15% Fly Ash: 1.55 g/cm³ at 15% OMC
- Soil + 6% Lime: 1.52 g/cm³ at 14% OMC
- Soil + 10% FA + 4% Lime: 1.57 g/cm³ at 13% OMC

4.3 Unconfined Compressive Strength (UCS)

Table 2 summarizes UCS results at 7 and 28 days curing.

Mix Composition	UCS @ 7 days (kPa)	UCS @ 28 days (kPa)
Natural Soil	90	95
Soil + 10% Fly Ash	140	160
Soil + 15% Fly Ash	165	190
Soil + 4% Lime	180	220
Soil + 6% Lime	210	250
Soil + 10% FA + 4% Lime	260	310

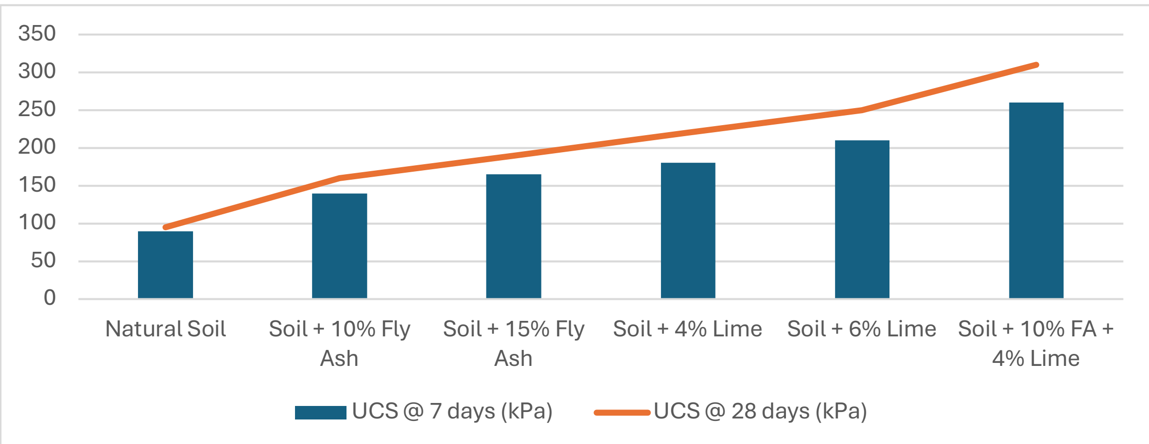

Fig: Strength increased with curing time and additive content. Combined fly ash and lime stabilization yielded the highest strength due to accelerated pozzolanic reactions forming cementitious compounds.

4.4 California Bearing Ratio (CBR)

CBR values increased from 3% in natural soil to 10% and 12% in soils stabilized with 10% fly ash and 6% lime, respectively. Combined additives resulted in CBR exceeding 15%, suitable for road subgrade applications.

4.5 Permeability

Permeability decreased by approximately 40% in stabilized soils compared to natural soil, indicating reduced water infiltration and improved durability.

5. CONCLUSION

This study demonstrates the effectiveness of fly ash and lime in stabilizing clayey soil through laboratory geotechnical evaluations. Key conclusions are:

- Fly ash and lime significantly reduce plasticity, making soil less susceptible to swelling and shrinkage.
- Both additives improve compaction characteristics, allowing higher dry density at lower moisture content.
- Unconfined compressive strength and CBR values increase substantially, especially when fly ash and lime are used in combination.
- Permeability reduction indicates enhanced durability and resistance to moisture damage.
- The optimal stabilization was observed with 10-15% fly ash combined with 4-6% lime, balancing strength gain and workability.

The findings advocate using fly ash and lime for sustainable soil stabilization, reducing reliance on traditional materials and promoting waste utilization from thermal power plants. Further field studies are recommended to validate laboratory results and assess long-term performance under varying environmental conditions.

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