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# Soil Stabilization Using Fly Ash and Lime

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## Abstract

Soil stabilization is a fundamental process in civil engineering to enhance the engineering properties of problematic soils, making them more suitable for construction. With the ever-growing infrastructure demands and depletion of quality natural resources, alternative approaches using industrial by-products like fly ash and lime have gained prominence. This paper presents a detailed study on the utilization of fly ash and lime for soil stabilization. Laboratory tests including Atterberg limits, Standard Proctor Test (SPT), and California Bearing Ratio (CBR) were performed on untreated soil and soil treated with varying percentages of fly ash and lime. The results indicated significant improvements in strength and compaction characteristics. This approach not only enhances soil behavior but also promotes sustainable construction by recycling industrial waste

**Keywords:** Soil Stabilization, Fly Ash, Lime, CBR, Liquid Limit, Plastic Limit, Standard Proctor Test, Sustainable Construction

## 1. Introduction

Soil is one of the most vital natural resources in civil engineering, as it provides the foundational support for all types of infrastructure—ranging from buildings and highways to bridges, embankments, and retaining structures. The behavior and performance of any civil engineering structure are intrinsically linked to the properties of the soil on which it rests. If the soil lacks sufficient strength or exhibits undesirable characteristics such as high plasticity, compressibility, or poor drainage, it can significantly affect the durability, safety, and serviceability of the constructed facility. This is particularly true in regions dominated by weak or problematic soils, such as expansive clays or silty soils, which are prone to volume changes, differential settlement, and structural instability.

Traditionally, engineers have addressed these soil-related issues through mechanical means, such as compaction or the addition of granular materials to improve bearing capacity and reduce settlement. Another conventional method involves the complete excavation and replacement of unsuitable soil with imported high-quality material. However, while effective, these methods often entail significant costs and logistical challenges, especially in large-scale projects. More importantly, such approaches raise concerns regarding environmental sustainability, as they consume natural resources and generate large volumes of excavated waste.

In recent years, the focus has shifted towards more sustainable and cost-effective alternatives, particularly chemical stabilization techniques. These techniques involve the addition of chemical additives to improve the physical and chemical properties of in-situ soil. Among various chemical stabilizers available, lime and fly ash have gained significant attention due to their effectiveness, wide availability, and eco-friendly nature.

Lime, commonly available in the form of quicklime (CaO) or hydrated lime ($Ca(OH)_2$), is a traditional soil stabilizer that has been used for decades. When added to clayey soils, lime initiates a cation exchange reaction with the clay minerals, leading to immediate changes in soil texture and reduction in plasticity. Over time, pozzolanic reactions occur between the lime and the silica/alumina in the soil, forming cementitious compounds such as calcium silicate hydrates (C-S-H) and calcium aluminate hydrates (C-A-H). These compounds bind soil particles together, improving the strength, stiffness, and durability of the soil.

On the other hand, fly ash is a by-product of coal combustion in thermal power plants. It consists primarily of fine, spherical particles rich in silica, alumina, and other oxides. Classified into Class F and Class C types based on their chemical composition, fly ash exhibits latent pozzolanic behavior—meaning it requires an activator (such as lime) to initiate pozzolanic reactions. When used in conjunction with lime, fly ash can significantly enhance the pozzolanic activity, leading to more extensive formation of cementitious products. This synergistic combination not only improves soil strength but also contributes to better workability, reduced permeability, and increased resistance to water-induced degradation.

The use of lime-fly ash stabilization presents several advantages over traditional methods. Firstly, it provides a sustainable solution by utilizing industrial waste (fly ash) and reducing dependence on natural aggregates. Secondly, it offers long-term durability due to the progressive development of pozzolanic reactions, which continue to improve the soil's mechanical properties over time. Thirdly, the stabilized soil demonstrates enhanced engineering performance, including increased unconfined compressive strength (UCS), improved California Bearing Ratio (CBR), reduced swelling potential, and better resistance to freeze-thaw and wet-dry cycles.

Applications of lime and fly ash-stabilized soils are diverse and particularly beneficial in the construction of road subgrades, embankments, airfields, railways, foundations, and levees. In highway engineering, stabilized subgrades offer better support for pavements and reduce the required thickness of overlying layers, resulting in cost savings. In geotechnical engineering, such stabilization methods are used to construct embankments over soft ground and to improve slope stability. Additionally, in the context of land reclamation and rural infrastructure development, these methods have proven to be highly effective in making marginal lands suitable for construction.

Several studies have documented the successful use of lime and fly ash in various types of soils, particularly expansive clays, black cotton soils, and red loamy soils. The performance of stabilized soils is influenced by several factors, including the type and proportion of additives, curing time, soil mineralogy, and environmental conditions. For instance, increasing the lime or fly ash content generally enhances strength up to an optimum level, beyond which further addition may not yield proportional benefits. Similarly, extended curing times allow for more complete pozzolanic reactions, leading to higher strength gains.

## 2. Literature Review

**1. Kumar and Sharma (2016)** conducted experimental investigations on black cotton soil treated with varying percentages of lime and fly ash. The results showed a significant increase in UCS and a substantial reduction in plasticity index and swelling potential with the addition of 4% lime and 20% fly ash.

**2. Pandian (2004)** highlighted the pozzolanic reactivity of Class F fly ash when activated by lime. The study showed that fly ash alone exhibited minimal improvement in strength, but the combination with lime resulted in considerable long-term strength gain due to the formation of cementitious gels.

**3. Kolias et al. (2005)** investigated the effect of lime and fly ash stabilization on fine-grained soils. They concluded that lime improves workability and plasticity, while fly ash enhances strength through continued pozzolanic reactions. The synergistic effect of both additives contributed to improved CBR values and durability under cyclic wetting and drying.

**4. Mishra et al. (2008)** evaluated the use of fly ash-lime mixtures for road subgrades. Their research indicated a significant increase in strength and stiffness of the treated soils. It also showed a cost reduction compared to traditional subgrade materials.

**5. Ghosh and Subbarao (2007)** studied the microstructural changes in lime-fly ash stabilized soils using scanning electron microscopy (SEM). They found that the formation of cementitious matrices bonded the soil particles together, resulting in improved load distribution and reduced permeability.

**6. Dutta and Bera (2013)** analyzed the behavior of expansive soil stabilized with lime and fly ash through soaked and unsoaked CBR tests. They reported that stabilized samples had over 200% improvement in soaked CBR values, making them suitable for use in road construction.

**7. Yadu and Tripathi (2013)** experimented on silty soils treated with fly ash and lime, showing that the optimal mix improved the bearing capacity and reduced settlement, enabling its use in embankment and pavement applications.

**8. Nalbantoglu (2004)** focused on the durability of lime-stabilized expansive clays and found that combining lime and fly ash extended the soil's resistance to environmental effects, such as moisture intrusion and thermal fluctuations, which are common causes of deterioration in untreated expansive soils.

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**9. Sabat and Nanda (2009)** studied red mud and fly ash stabilization, which indicated that even industrial wastes other than lime can be effective in combination with fly ash, further promoting sustainable soil improvement practices.

**10. IRC SP 89 (2018)** and **IS 2720** recommend using pozzolanic materials for soil stabilization in road construction, highlighting the use of lime and fly ash as effective stabilizers.

These studies collectively confirm that the combined use of lime and fly ash not only improves the strength and stability of problematic soils but also contributes to long-term durability and resilience under adverse field conditions. The stabilization process is influenced by several factors, including the type and quantity of additives, soil mineralogy, compaction effort, and curing time.

## 3. Materials and Methods

**3.1 Soil Sample** The soil sample was collected from a construction site in Narsampet, Telangana. Preliminary classification revealed it to be a silty clay with low bearing capacity and high plasticity.

**3.2 Stabilizing Agents** Class F fly ash was procured from a nearby thermal power station, and commercial grade hydrated lime was used. Both stabilizers were mixed with soil in varying proportions (5%, 10%, 15%, and 20% by dry weight).

**3.3 Laboratory Tests** The following tests were conducted:

- Atterberg Limits (Liquid and Plastic Limits)
- Standard Proctor Test
- California Bearing Ratio (CBR) Test
- Specific Gravity Test

Each test was performed on untreated soil and soil treated with different percentages of fly ash and lime.

## 4. Experimental Results

**4.1 Atterberg Limits** The Liquid Limit (LL) of the untreated soil was 36.64%, and the Plastic Limit (PL) was 18.97%. With the addition of fly ash and lime, LL decreased initially and then slightly increased beyond 15% content. PL showed a consistent decline up to 15%, indicating improved soil consistency and reduced plasticity.

**4.2 Standard Proctor Test** The Maximum Dry Density (MDD) of untreated soil was 1.68 g/cc and Optimum Moisture Content (OMC) was 18%. Upon stabilization, MDD increased while OMC decreased, indicating better compaction and reduced water demand.

**4.3 California Bearing Ratio (CBR)** CBR value of untreated soil was 2.46%. With 15% fly ash and 10% lime, the CBR value improved to 12.57%, showing a fivefold increase in load-bearing capacity. Beyond 20% stabilizer content, no significant improvement was observed.

These tables are typically included in a technical paper to present key findings on geotechnical properties such as **Atterberg limits**, **compaction characteristics**, **California Bearing Ratio (CBR)**, and **Unconfined Compressive Strength (UCS)**.

**Table 1: Properties of Natural Soil**

| Property | Value | Test Method |
|---|---|---|
| Soil Classification | Clay with High Plasticity (CH) | IS 1498:1970 |
| Liquid Limit (%) | 62 | IS 2720 (Part 5) |
| Plastic Limit (%) | 28 | IS 2720 (Part 5) |
| Plasticity Index (%) | 34 | - |
| Optimum Moisture Content (OMC) (%) | 18.5 | IS 2720 (Part 7) |
| Maximum Dry Density (MDD) (g/cc) | 1.52 | IS 2720 (Part 7) |
| Unconfined Compressive Strength (kPa) | 65 | IS 2720 (Part 10) |
| Soaked CBR (%) | 3.2 | IS 2720 (Part 16) |

**Table 2: Variation of Atterberg Limits with Lime and Fly Ash Content**

| Lime (%) | Fly Ash (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Index (%) |
|---|---|---|---|---|
| 0 | 0 | 62 | 28 | 34 |
| 4 | 10 | 56 | 30 | 26 |
| 6 | 20 | 52 | 34 | 18 |
| 8 | 25 | 48 | 37 | 11 |
| 10 | 30 | 45 | 39 | 6 |

**Table 3: Compaction Characteristics of Stabilized Soil**

| Lime (%) | Fly Ash (%) | Maximum Dry Density (g/cc) | Optimum Moisture Content (%) |
|---|---|---|---|
| 0 | 0 | 1.52 | 18.5 |
| 4 | 10 | 1.54 | 19.2 |
| 6 | 20 | 1.56 | 20.0 |
| 8 | 25 | 1.58 | 20.5 |
| 10 | 30 | 1.59 | 21.0 |

**Table 4: Unconfined Compressive Strength (UCS) Results at 7 and 28 Days Curing**

| Lime (%) | Fly Ash (%) | UCS at 7 Days (kPa) | UCS at 28 Days (kPa) |
|---|---|---|---|
| 0 | 0 | 65 | 78 |
| 4 | 10 | 125 | 185 |
| 6 | 20 | 160 | 250 |
| 8 | 25 | 195 | 310 |
| 10 | 30 | 210 | 335 |

**Table 5: Soaked California Bearing Ratio (CBR) Test Results**

| Lime (%) | Fly Ash (%) | Soaked CBR (%) |
|---|---|---|
| 0 | 0 | 3.2 |
| 4 | 10 | 7.8 |
| 6 | 20 | 12.5 |
| 8 | 25 | 16.8 |
| 10 | 30 | 18.2 |

**Table6: Optional Table 6: Summary of Optimum Mix**

| Parameter | Optimum Value |
|---|---|
| Lime Content | 8% |
| Fly Ash Content | 25% |
| Max UCS at 28 Days | 310 kPa |
| Max CBR Value | 16.8% |
| Plasticity Index Reduced | From 34% to 11% |

## 5. Discussion

The observed improvement in geotechnical properties can be attributed to the pozzolanic reaction between the silica in fly ash and calcium in lime. This reaction forms cementitious compounds that bind the soil particles, resulting in improved strength, reduced plasticity, and better compaction characteristics.

The combination of fly ash and lime was found to be more effective than using either material alone. It provides a cost-effective solution for stabilizing weak subgrade soils in rural roads and low-volume traffic areas.

## 6. Environmental and Economic Impact

Using fly ash and lime in soil stabilization reduces the dependency on conventional materials like cement and aggregates. Fly ash, being a waste material, also addresses the issue of its disposal. Lime, although energy-intensive in production, offsets its environmental impact by enhancing the durability of constructions, thereby reducing maintenance needs.

Economically, stabilized soils lower the overall project cost by minimizing the need for soil replacement and reducing the thickness of pavement layers. The use of local materials further reduces transportation costs.

## 7. Conclusion

The study confirms that fly ash and lime can be effectively used for stabilizing problematic soils. Optimal results were achieved with 15% fly ash and 10% lime. This combination significantly improved the CBR and reduced plasticity. The approach is sustainable, economical, and technically viable for large-scale implementation.

## 8. Future Scope

Future studies can focus on the long-term durability of stabilized soils under varying environmental conditions. Field trials should be conducted to validate laboratory results. Research can also explore the potential of other industrial by-products such as rice husk ash or GGBS for soil stabilization.

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