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Performance Evaluation of Soil Stabilization Using Lime & Fly Ash

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ABSTRACT: The improvement of weak subgrade soils remains a critical challenge in geotechnical engineering, particularly for infrastructure development in developing regions. This study presents a detailed experimental investigation on the stabilization of soil using lime and fly ash as chemical additives. Soil samples were treated with varying percentages (0%, 5%, 10%, 15%, and 20%) of stabilizers and tested for key engineering properties including California Bearing Ratio (CBR), Maximum Dry Density (MDD), and Atterberg limits.

The results reveal that both stabilizers significantly enhance soil strength due to pozzolanic reactions and physicochemical modifications. The maximum improvement in CBR was observed at 15% stabilizer content, with lime exhibiting slightly superior performance (12.57%) compared to fly ash (10.71%). However, fly ash demonstrates better sustainability potential due to its industrial waste origin. The study concludes that optimum stabilization improves subgrade performance while reducing environmental impact and construction costs.

Keywords: Soil Stabilization, Fly Ash, Lime Stabilization, California Bearing Ratio (CBR), Bearing Capacity, Optimum Moisture Content (OMC), Maximum Dry Density (MDD), Geotechnical Engineering

I. INTRODUCTION

Rapid urbanization and infrastructure growth demand the utilization of locally available soils, which are often weak and unsuitable for direct construction. Expansive and low-strength soils pose serious challenges such as excessive settlement, low bearing capacity, and volumetric instability.

Soil stabilization is a well-established technique to enhance soil performance by modifying its physical and chemical properties. Among various stabilizers, lime and fly ash have gained widespread acceptance due to their effectiveness, availability, and economic viability.

Lime stabilization primarily involves cation exchange, flocculation, and pozzolanic reactions, leading to improved strength and reduced plasticity. Fly ash, a by-product of thermal power plants, contains silica and alumina that react with calcium in the presence of water to form cementitious compounds.

This study focuses on evaluating and comparing the performance of lime and fly ash in improving soil properties, with emphasis on strength behavior and practical applicability in pavement construction.

II. LITERATURE REVIEW

Previous research highlights the effectiveness of chemical stabilization:

Saleh and Hussein (2020) demonstrated improved subgrade performance using lime fly ash blends.

Andavan and Pagadala (2019) reported increased CBR and reduced plasticity index.

Chen et al. (2022) showed enhanced durability of stabilized soils in adverse environmental conditions.

Renjith et al. (2021) emphasized optimization of fly ash content for sustainable construction.

Despite extensive research, there remains a need to identify optimum stabilizer content for specific soil types and evaluate comparative performance under controlled conditions.

III. SOIL STABILIZATION AND ITS NEED

The role of soil is crucial part in the design and construction of a building, a bridge, or a road, a runway, or a railway track. This is due to the fact that it functions as a medium for the successful burden transfer into the dirt. This implies that a poor dirt foundation will ultimately compel the structure to collapse resulting in failure. The practise of improving the technical properties of the dirt prior to construction is known as stabilisation. It is a procedure that transforms a dirt's physical properties to offer long-term irreversible strength benefits.

Stabilisation is done to improve dirt capacity and shrink swelling potential are increased, hence improving the load-bearing ability and overall safety of dirt. Dirt stabilisation is a process for refining and improving dirt technical features. These properties include mechanical strength, permeability etc.

Stabilized dirt provide a stable working platform that serves as the basis for all other project components. Weak dirt can be improved after stabilisation measures by the establishment of permanent pozzolanic reactions. That is, soils are not prone to leaching and have significantly reduced permeability, resulting in less shrink and higher freeze-thaw resilience. Furthermore, dirts that have been stabilised have undergone some alteration. In other words, the soil has altered physically, making compaction simpler and decreasing flexibility. Easier compaction facilitates reaching maximal dry density. The plasticity index is a fundamental geotechnicalstatistic that takes into account the critical water content of dirts. When their sturdiness is reduced they become more soft and practical. The following are the reasons for soil stabilisation:

- In the case of low-cost highways, to strengthen sub-bases, bases, and sometimes surface courses.
- To reduce the cost of road and building construction.
- Using lesser grade locally available soils/materials. (Whenever if the required or mandated power cannot be found in the local material dirt stabilisation treatments can be utilised)
- To ameliorate unfavourable dirt qualities such as excessive swell or shrinkage, high plasticity, compaction issues, and so forth.
- Increased carrying capability and settling.
- Reduce settlement and, hence, compressibility.

IV. METHODOLOGY

This study focuses on evaluating the effects of chemical stabilisers, specifically fly ash and lime, on the geotechnical properties of soil to improve its load bearing capacity for construction purposes. The methodology consists of several key phases, including sample collection, preparation, stabiliser application, laboratory testing, and analysis of results.

A. Sample Collection

Soil samples were collected from the playground area of the Oriental Institute of Science and Technology, Bhopal, where the soil was identified as being in poor condition. The soil was crushed to remove lumps, and all extraneous materials were carefully removed to ensure homogeneity.

B. Application of Stabilisers

Two chemical stabilisers, fly ash and lime, were used. Both were added to the soil in varying percentages by dry weight: 5%, 10%, 15%, 20%, and 25%. Each mixture was thoroughly blended to ensure uniform distribution of the stabilising agents.

FLY ASH

Fly ash is a tiny grey dust made up mostly of oval, shiny parts generated by coal-fired power stations. Because fly ash has pozzolanic properties, it reacts with lime to produce cementitious compounds. Fly ash is a burn byproduct made up of fine particles that rise with the flue gases.

Bottom ash is ash that does not rise to the surface.

LIME

It comes in the form of a white powder made largely of oxides and hydroxide which has been satisfied with water. Lime is widely utilised in construction and engineering products. It is obtained from rocks and minerals, most notably limestone or chalk.

Lime, often known as consumable lime or quicklime, is a white, burning, crystalline powerful substance that comprises calcium oxide (CaO).

Table 1. Composition of fly Ashand lime

CHEMICAL COMPOSITION	FLY ASH (%)	LIME (%)
Carbon	23.29	0
Calcium Oxide	3.10	91.99

Silicon Dioxide	36.10	3.75
Aluminium Oxide	25.03	2.09
Ferrous Oxide	8.66	0.50
Magnesium Oxide	1.24	1.19
Sodium Oxide	0	0.43
Sulfur Trioxide	0.59	0.05
Titanium Dioxide	0.91	0
Potassium Oxide	1.08	0
TOTAL	**100.00**	**100**

Laboratory Testing

The following tests were conducted on untreated soil and soil treated with different percentages of fly ash and lime to assess changes in soil properties:

Sieve Analysis: To determine the particle size distribution of the soil.

- Specific Gravity Test: To measure the density of soil particles.
- Liquid Limit Test: To determine the water content at which soil changes from plastic to liquid state.
- Plastic Limit Test: To find the water content at which soil begins to crumble when rolled into a thread.
- Standard Proctor Test: To identify the optimum moisture content (OMC) and maximum dry density (MDD) of the soil.
- California Bearing Ratio (CBR) Test: To evaluate the load-bearing capacity of the soil.

C. Sample Preparation for Testing

For each stabiliser percentage, soil samples were prepared at their optimum moisture content and compacted to maximum dry density using the Standard Proctor method. Samples were then subjected to the above tests to measure the influence of fly ash and lime.

V. RESULTS & DISCUSSION

Results from all tests were tabulated and graphed to observe trends in soil properties with increasing stabiliser content. Comparisons between fly ash and lime treatments were made to identify the optimal stabiliser type and concentration for improving soil strength and durability

Table 2. CBR Values

% Stabilizer	Fly Ash CBR	Lime CBR
0%	0.89	0.89
5%	3.87	2.46
10%	4.16	3.91
15%	10.71	12.57
20%	4.39	3.98

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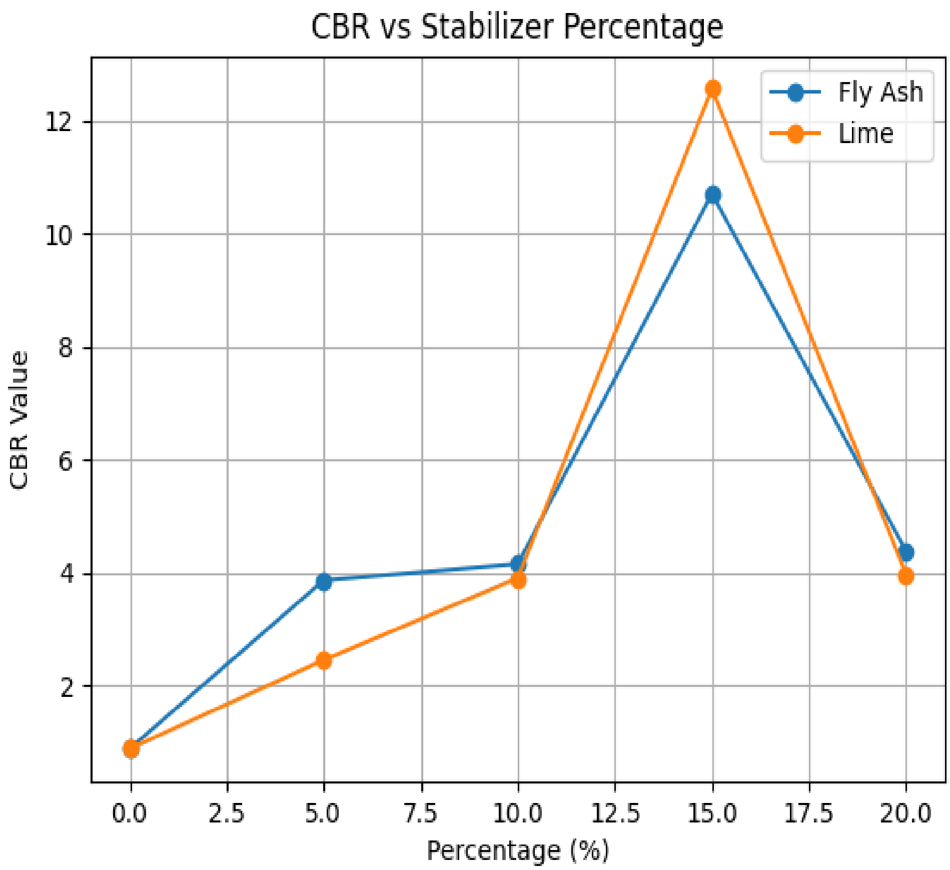

Fig.1 CBR Value

Table 3. Limit Variation Liquid

%	Fly Ash	Lime
0	33.64	33.64
5	27.45	29.87
10	30.78	32.43
15	36.64	35.51
20	40.81	42.75

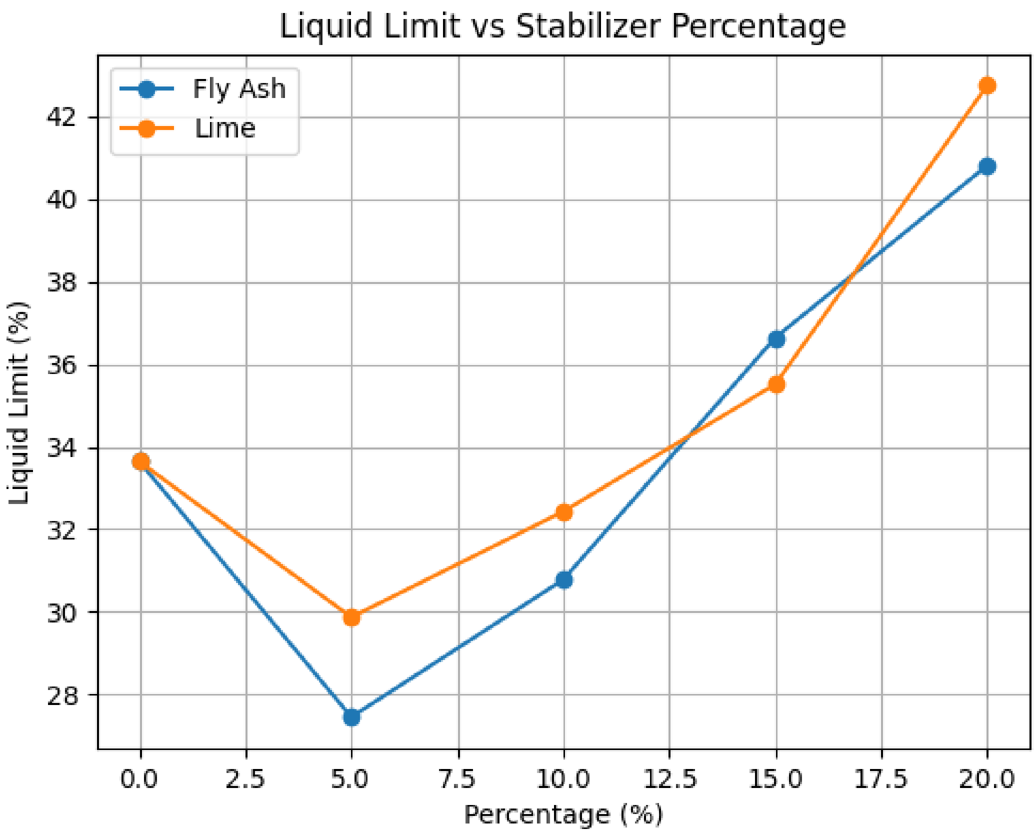

Fig. 2 Liquid Limit

Observation:

- Decreases initially
- Increases after 10%

Table 4. Maximum Dry Density (MDD)

%	Fly Ash	Lime
0	2.01	2.01
5	1.99	1.96
10	1.94	1.92
15	1.95	1.94
20	1.97	1.95

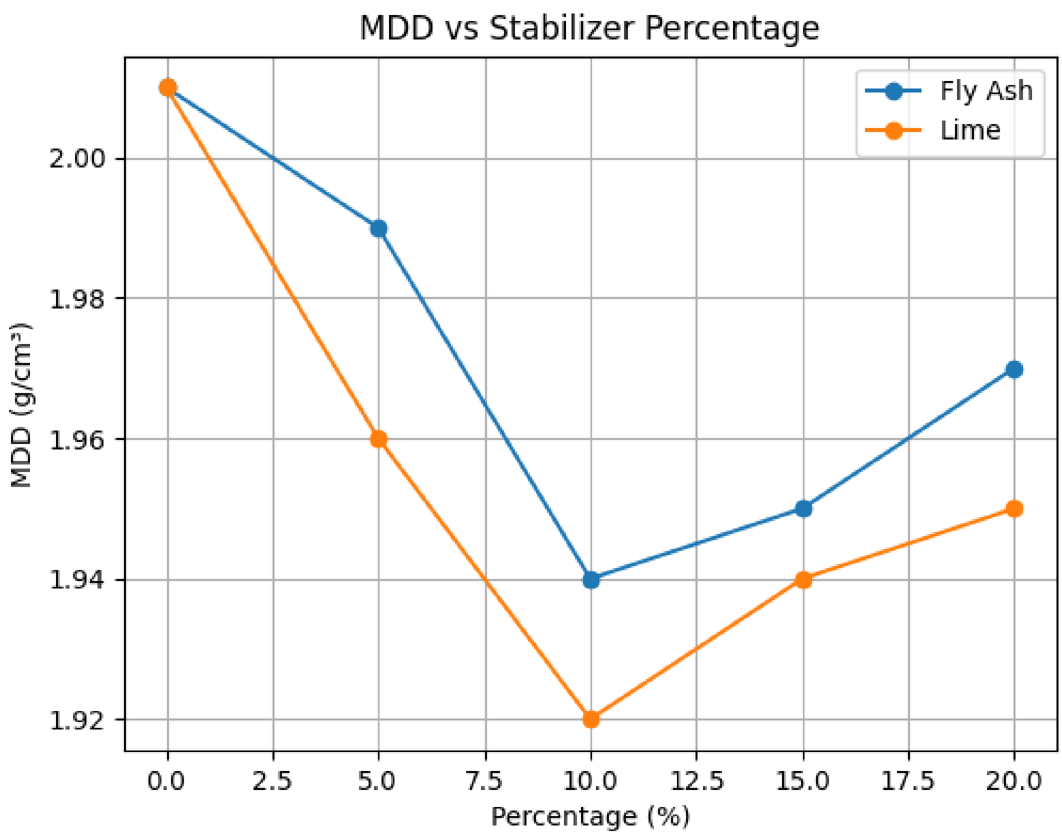

Fig. 3 MDD

Observation:

- Decreases up to 10–15%
- Slight increase afterward

VI. CONCLUSION

The following conclusions can be drawn from the experimental work on soil stabilisation with fly ash and lime:

Specific gravity was shown to drop up to 15% as the proportion of fly ash in soil increased, but it slightly increased after that. A similar pattern was observed with lime addition.

The effect of fly ash on soil liquid limit was unusual, with addition up to 5% resulting in a fall in liquid limit and a progressive increase on additional addition up to 20%, which was even bigger than the original liquid limit of the soil utilised. The same was true with lime.

The soil plastic limit was 25%, and it gradually decreased with the addition of fly ash and lime up to 10%, after which it marginally increased.

OMC decreased by 2% with the addition of fly ash and by 3% with the addition of lime.

Soil MDD was 2.01g/cm3, which dropped to 1.92g/cm3 after 10% fly ash addition and increased slightly to 1.95g/cm3 with additional addition. In the case of lime, the MDD decreased but not as much as in the case of fly ash, with a minimal decrease of 1.94g/cm3 followed by a tiny increase to 1.97g/cm3.

CBR @ 2.5mm for soil was 0.49, increasing to 4.16 with 10% fly ash addition, then a massive rise to 10.71 with 15% addition, although it dropped with additional addition. In the case of lime, there was a linear increase up to 10%, but at 15%, the value increased even more than in the case of fly ash, to 12.57.

As a result, soil with an optimal amount of fly ash and lime (15-20%) is most suited and cost-effective for highway construction.

VII. FUTURE SCOPE

Lime and Fly Ash are both agricultural and industrial waste. Both of them contain a significant proportion of siliceous substance. The lime manufacturing method is based on a chemical reaction caused by heating calcium carbonate (CaCO3), which produces quicklime (CaO). This process will inevitably produce CO2. These CO2 emissions, which are inherent in the lime production process, are referred to as process emissions. These process emissions alone account for 70% of overall CO2 emissions from the lime production process and are unavoidable. Coal-fired power facilities in India generate around 196 million tonnes of fly ash each year. The management of fly ash has thus been a source of worry, given the vast amount of land required for disposal and the potential for pollution of air and water. Although the cement business is heavily utilising, it has hit its utilisation level. As a result, a new region for its disposal is urgently required. One of the finest options for soil stabilisation is to use fly ash. The use of fly ash in bulk in building and soil stabilisation has a lot of potential. NHAI is now utilising 100 lakh Tone fly ash in construction on various NH projects across India, with plans to double it in the future. The application of fly ash in road building includes the following:

- Embankment stabilisation and roadway backfill
- Pavement subgrade stabilisation
- Railway embankment stabilisation.

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