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Research Article

Determination of Strength Parameters and Economic Analysis of Pavement Design by Treating Clay Soil with Fly Ash at Optimization Level

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Abstract

This experimental study investigates the improvement in strength and economic performance of clayey subgrade soil stabilised with varying percentages of fly ash. A 6.735 km flexible pavement stretch from Hastinapur to Makhdoompur, District Meerut (U.P.), was considered for design analysis. Laboratory tests, including specific gravity, Atterberg limits, sieve analysis, hydrometer analysis, standard Proctor compaction, and California Bearing Ratio (CBR) tests, were performed. Results indicated that the addition of fly ash significantly improved the engineering properties of the clay soil. The CBR value increased from 5.88 to 18.78, leading to an approximate 20% reduction in pavement thickness and construction cost. The study concludes that 22.5% fly ash addition is the optimal level for achieving desirable strength and cost-efficiency in pavement subgrade stabilisation.

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KEYWORDS: Clay soil, Fly ash, Soil stabilisation, Pavement design, Economic analysis, CBR, Resilient modulus.

1. INTRODUCTION

Flexible pavements are extensively used for road construction due to their economy and ease of maintenance. However, the strength and performance of flexible pavements depend largely on the quality of the subgrade soil. Clay soils, particularly those exhibiting high plasticity and significant volume change behaviour, pose major challenges in geotechnical engineering. These soils often suffer from low shear strength, high compressibility, and excessive swelling–shrinkage characteristics, making them unsuitable for use in pavement subgrades, embankments, foundations, and other load-bearing structures. With growing infrastructure demands, improving the engineering performance of such problematic soils has become essential for ensuring stability, durability, and cost-effective construction. Soil stabilization using industrial by-products has gained increasing attention due to its technical effectiveness, economic viability, and environmental advantages. Fly ash, a pozzolanic waste material generated from coal-based thermal power plants, has shown significant potential for stabilizing clay soils by improving workability, reducing plasticity, and enhancing long-term strength through pozzolanic reactions.

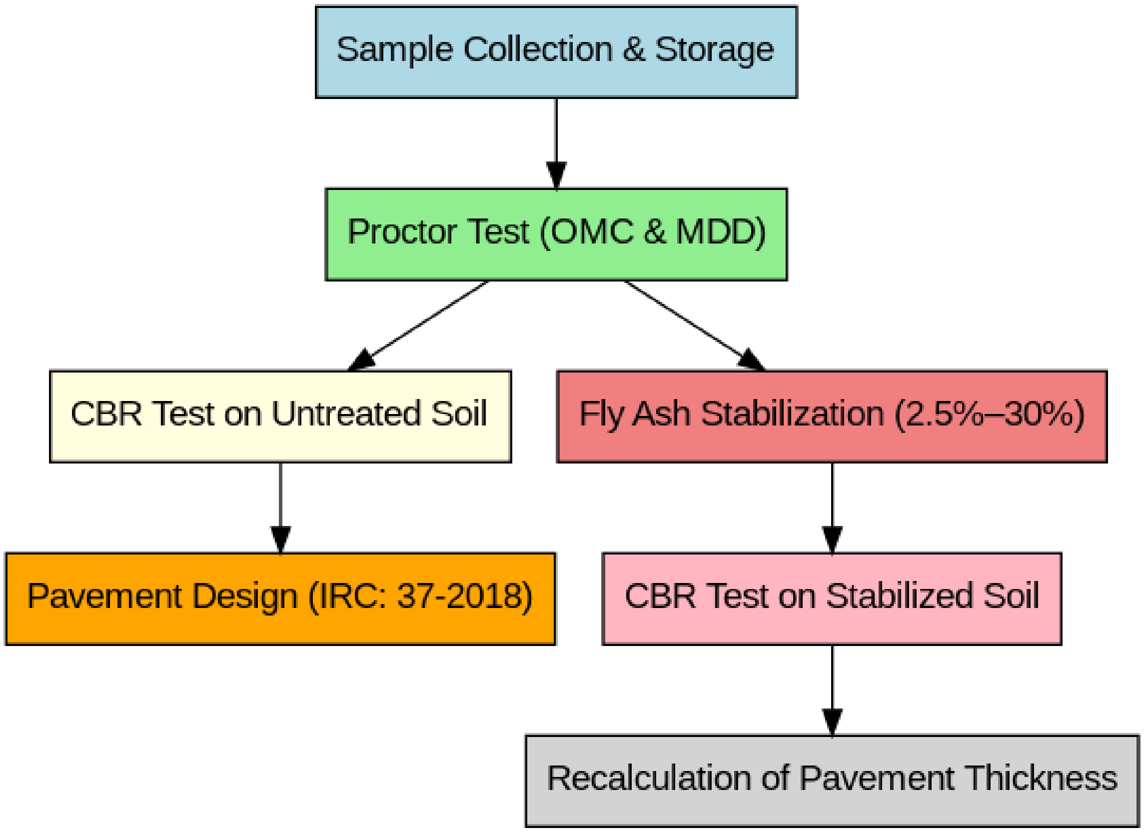
In many cases, naturally available clay soils have inadequate strength to support traffic loads, necessitating thicker pavement layers and higher construction costs. On the other hand, managing industrial waste such as fly ash has become a pressing environmental issue. The utilization of fly ash in soil stabilization offers a sustainable and cost-effective solution by improving subgrade strength and reducing environmental impact.

2. OBJECTIVES

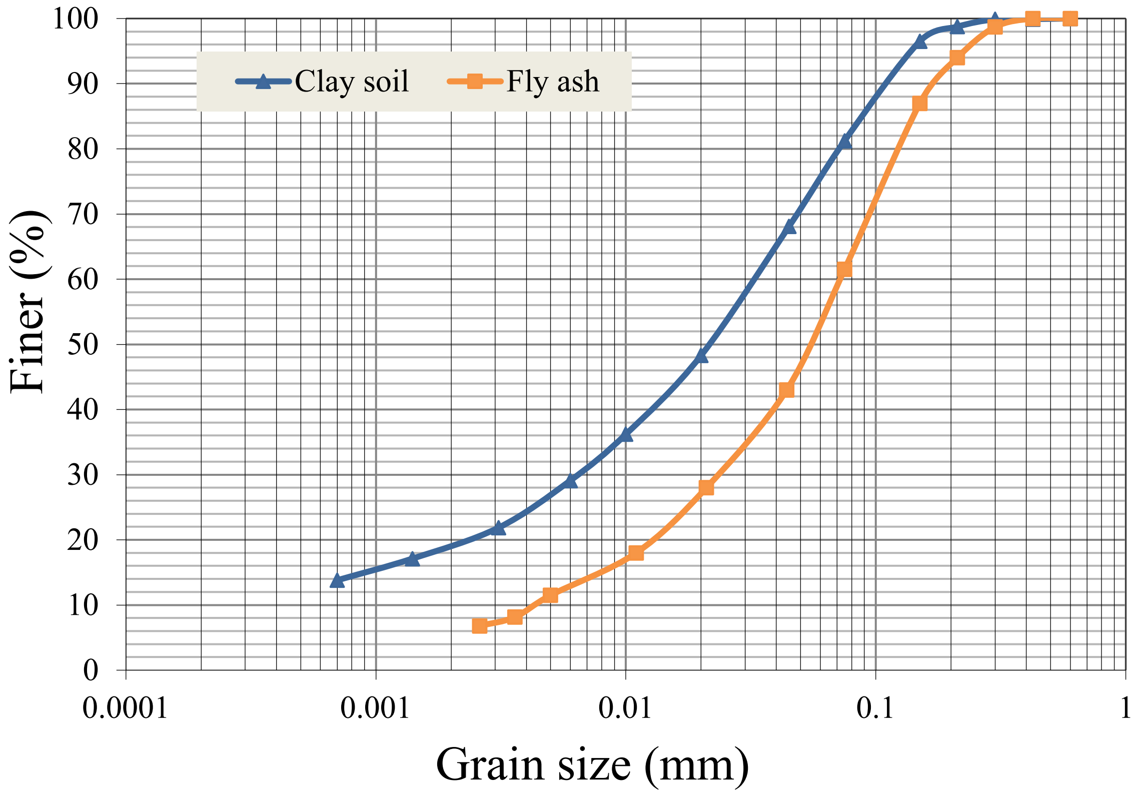
- To evaluate the engineering properties of natural clay subgrade soil through standard laboratory tests.
- To determine the CBR value of untreated and fly ash-treated soils.
- To identify the optimum fly ash content that provides the best improvement in CBR value.
- To design flexible pavement thickness based on improved subgrade properties.
- To perform economic analysis comparing untreated and treated subgrades.

3. MATERIALS AND METHODS

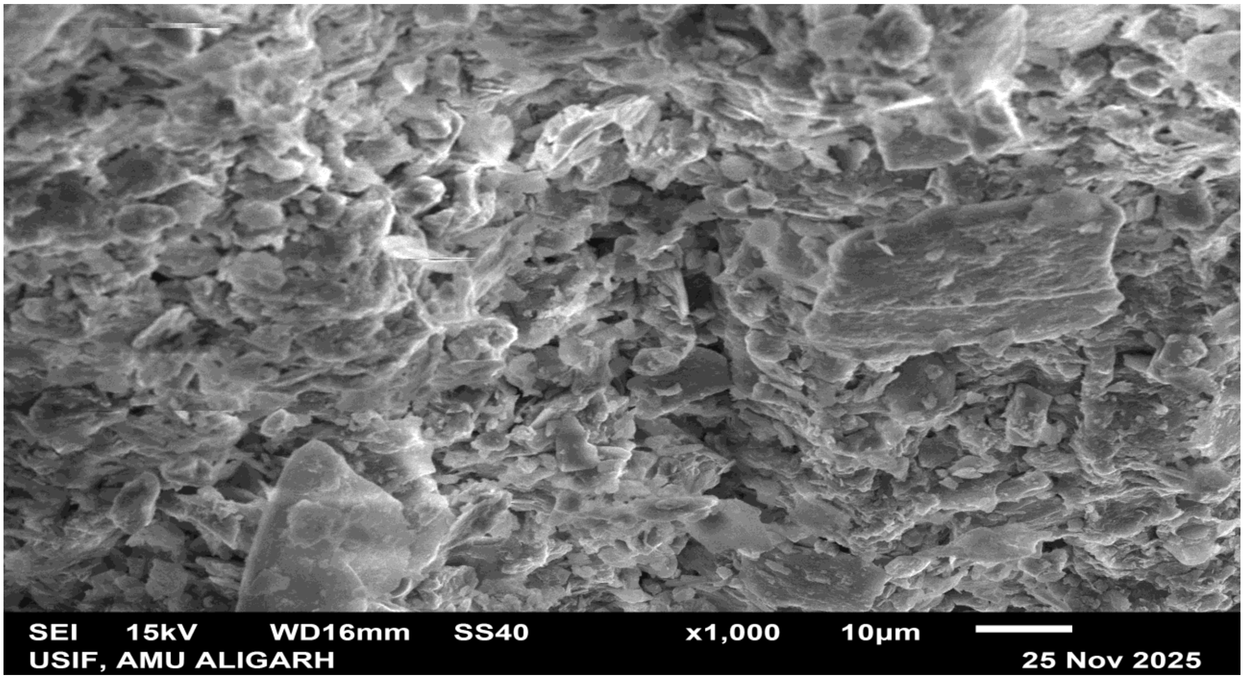
The experimental program involved collecting clay soil samples from the project site and treating them with varying percentages of fly ash (0%, 2.5%, 5%, 7.5%, 10%, 15%, 22.5%, and 30%). The laboratory investigations were performed as per IS codes. The tests conducted included specific gravity, Atterberg limits, sieve and hydrometer analysis, Standard Proctor compaction, and California Bearing Ratio (CBR) test. The resilient modulus (Mr) was estimated using IRC 37:2018 relations for different CBR values.



Particle size distribution curve



SEM of Clay



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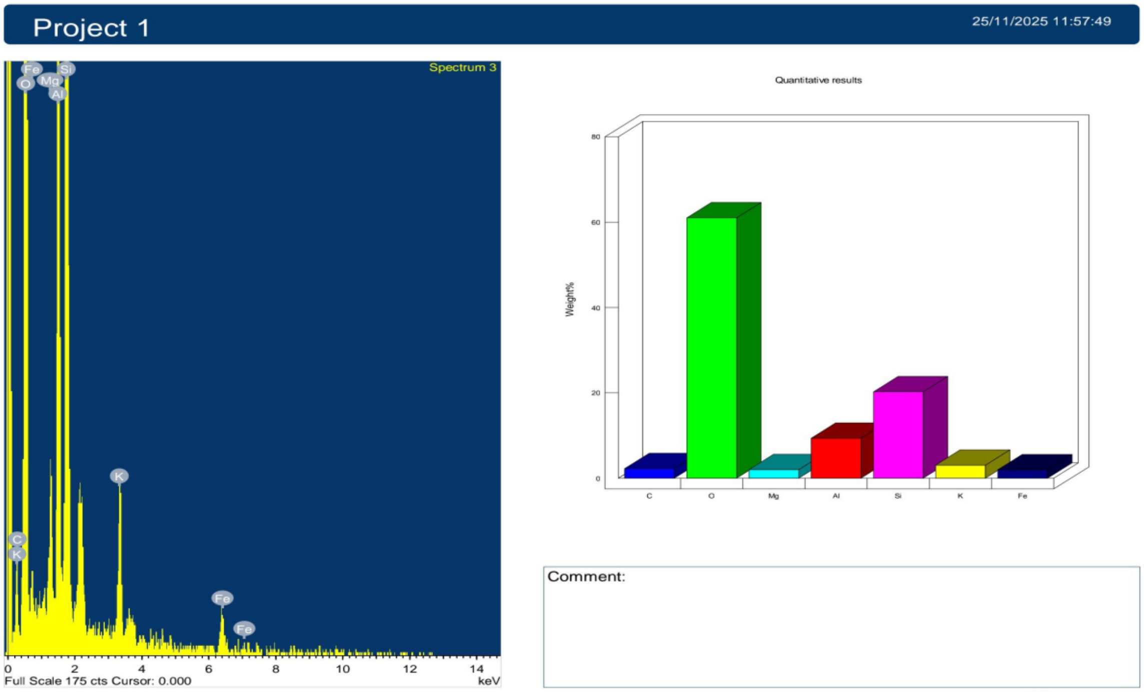
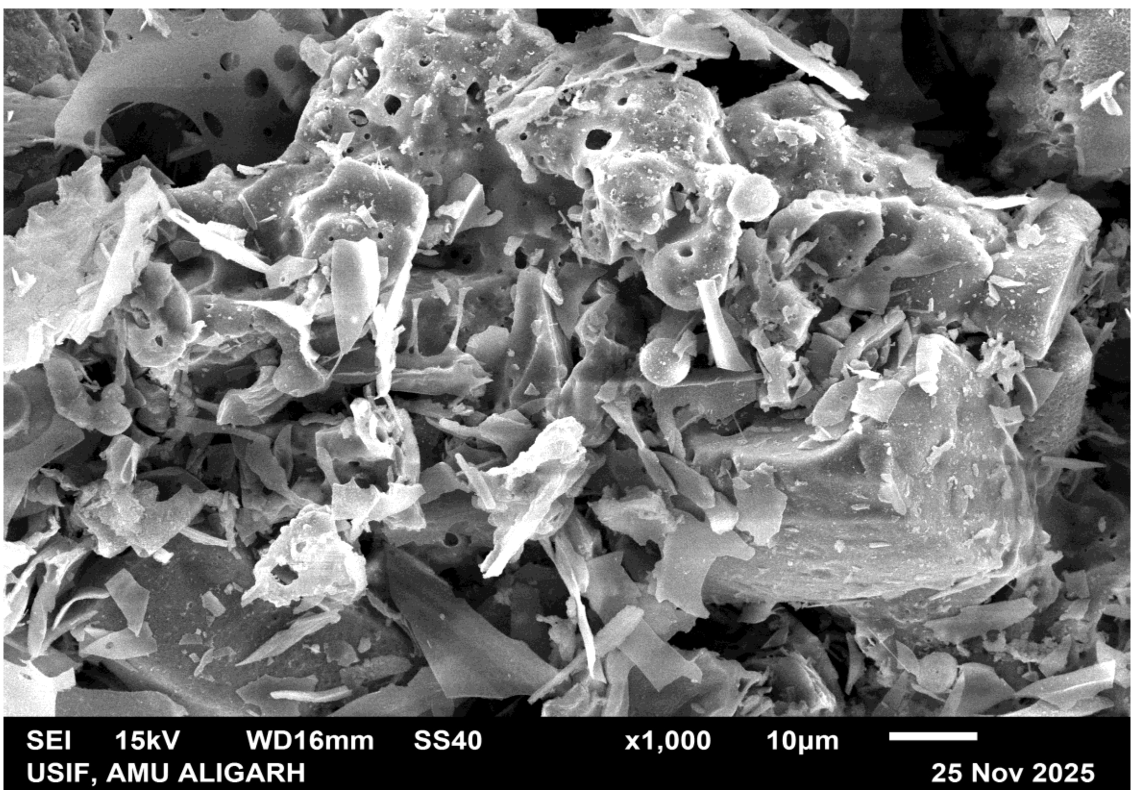
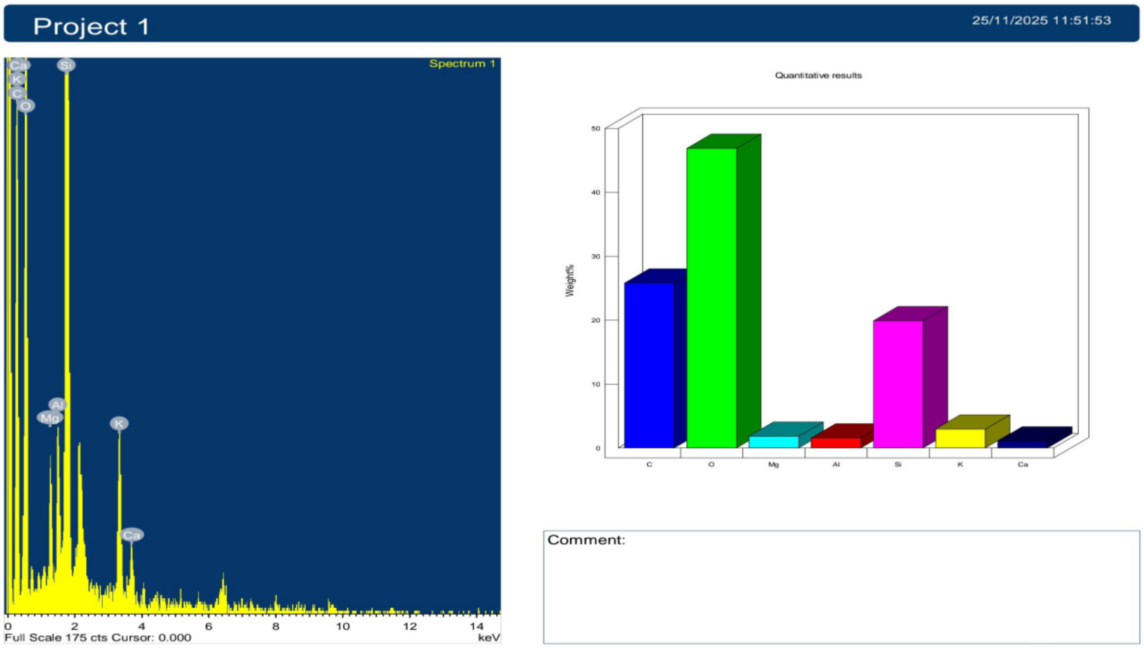


SEM of FLY ASH



EDX Of FLY ASH



4. RESULTS AND DISCUSSION

The specific gravity of the soil decreased from 2.67 (0% fly ash) to 2.58 (30% fly ash) due to the lower density of fly ash. The Optimum Moisture Content (OMC) increased from 17.2% to 21.63%, while the Maximum Dry Density (MDD) showed a decreasing trend. The Liquid Limit decreased, and the Plastic Limit increased with higher fly ash content, resulting in a reduction in Plasticity Index from 16% to 7.03%, indicating improved workability. The CBR value increased significantly from 5.88 to 18.78 with fly ash addition, showing that stabilization improved load-bearing capacity. The resilient modulus increased from 54.69 MPa to 115 MPa, reflecting improved elasticity of the subgrade soil.

Table 1: Variation of specific gravity with respect to different flyash content

Sample composition	Specific gravity
Clayey Soil+0% Fly ash	2.67
Fly ash + 0% Clayey Soil	2.34
Clay + 2.5% Fly ash	2.66
Clay + 5% Fly ash	2.63
Clay + 7.5% Fly ash	2.62
Clay + 15% Fly ash	2.61
Clay + 22.5% Fly ash	2.60
Clay + 30% Fly ash	2.58

Table 2: Variation of liquid limit with different fly ash content

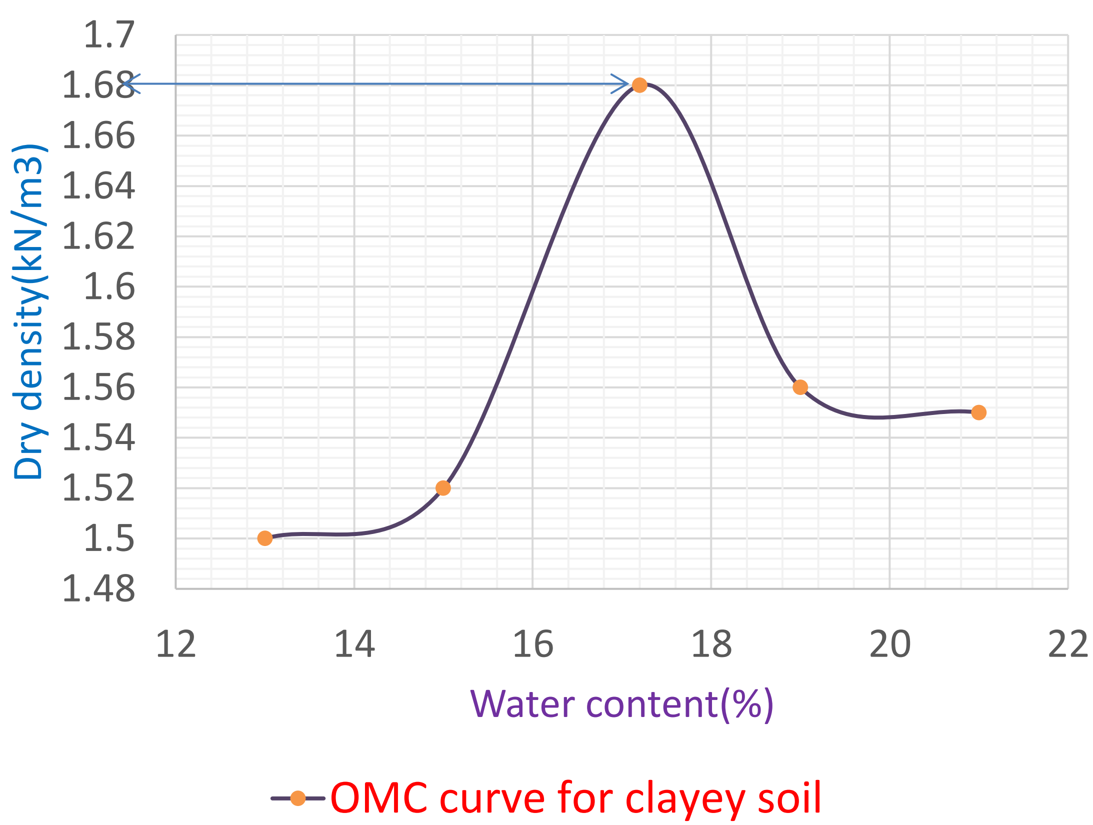
Sample composition	Liquid Limit
Clayey Soil+0% Fly ash	36.00
Fly ash + 0% Clayey Soil	31.06
Clay + 2.5% Fly ash	34.43
Clay + 5% Fly ash	33.58
Clay + 7.5% Fly ash	32.06
Clay + 15% Fly ash	31.72
Clay + 22.5% Fly ash	31.45
Clay + 30% Fly ash	30.90

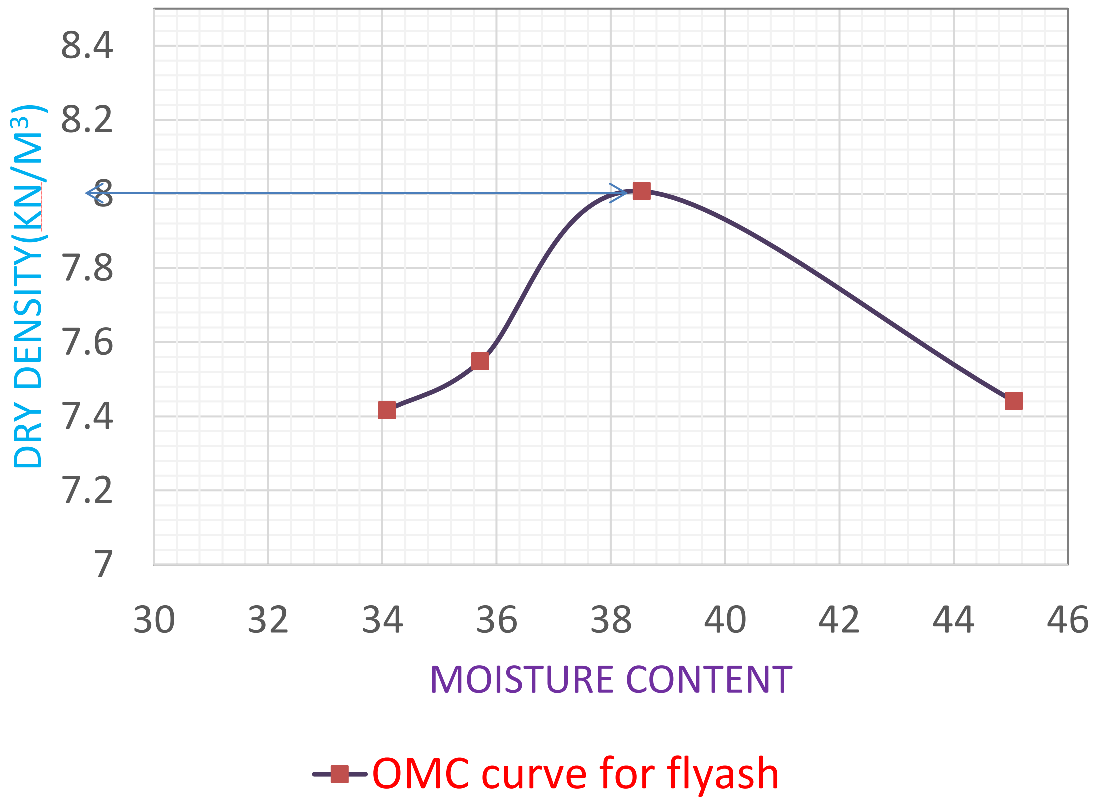
Table 3: Variation of Plastic limit with different fly ash content

Sample composition	Plastic Limit
Clayey Soil+0% Fly ash	20.00
Clay + 2.5% Fly ash	20.80
Clay + 5% Fly ash	21.50
Clay + 7.5% Fly ash	22.47
Clay + 15% Fly ash	23.05
Clay + 22.5% Fly ash	23.48
Clay + 30% Fly ash	23.87

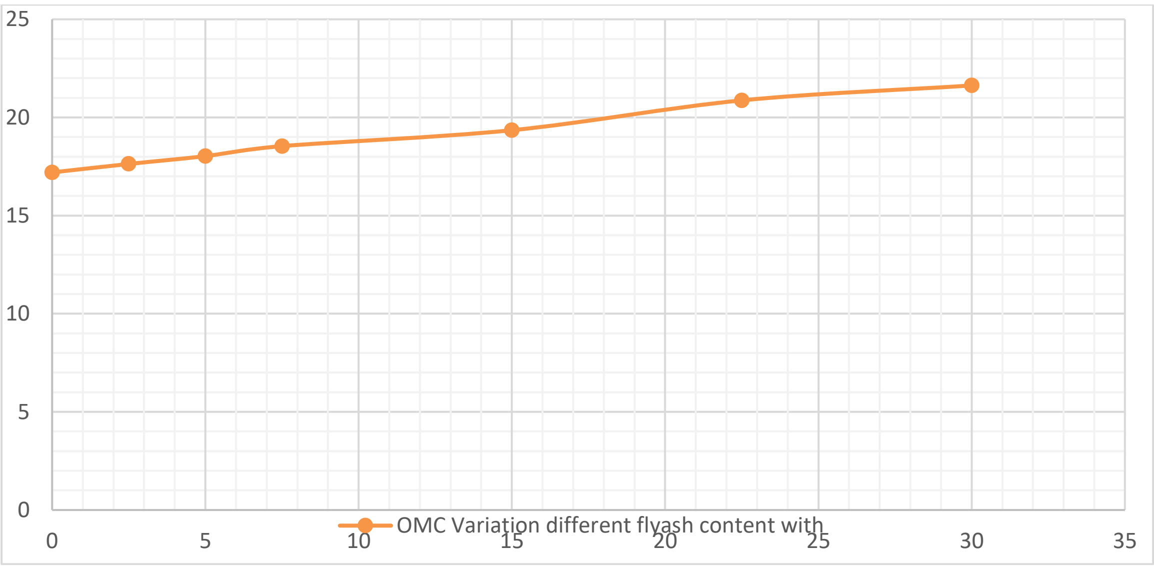
Table 4: Variation of Plasticity Index with different fly ash content

Sample composition	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
Clayey Soil+0% Fly ash	36.00	20.00	16.00
Clay + 2.5% Fly ash	34.43	20.80	13.63
Clay + 5% Fly ash	33.58	21.50	12.08
Clay + 7.5% Fly ash	32.06	22.47	9.59
Clay + 15% Fly ash	31.72	23.05	8.67
Clay + 22.5% Fly ash	31.45	23.48	7.97
Clay + 30% Fly ash	30.09	23.87	7.03





DRY DENSITY(KN/M3)
8.4
8.2
8
7.8
7.6
7.4
7.2
7
30
32
34
36
38
40
42
44
46
MOISTURE CONTENT
OMC curve for flyash



25
20
15
10
5
0
0
5
10
15
20
25
30
35
OMC Variation different flyash content with

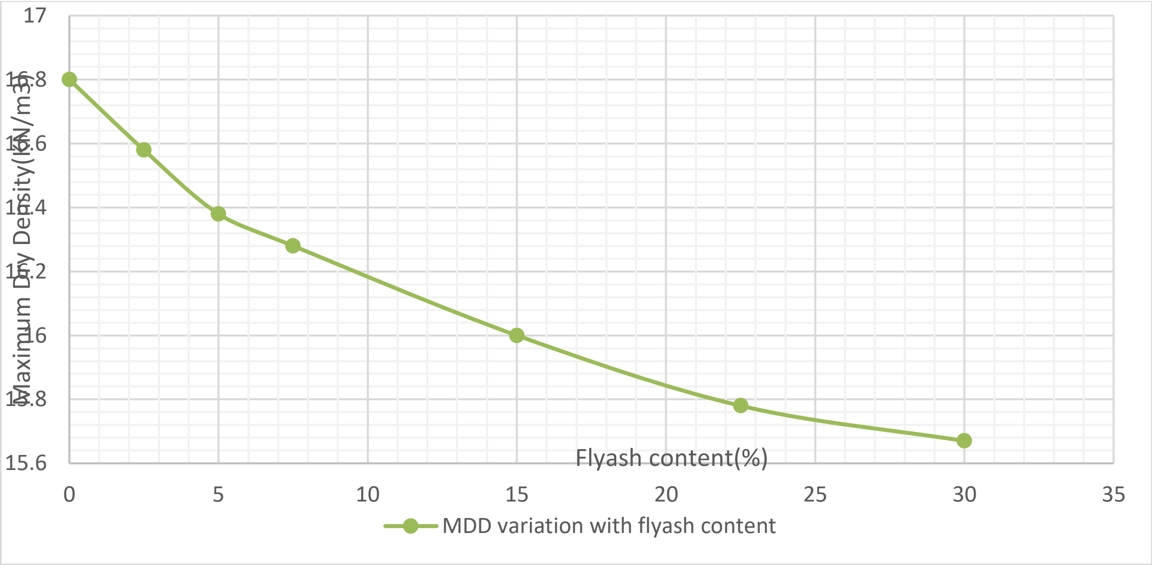
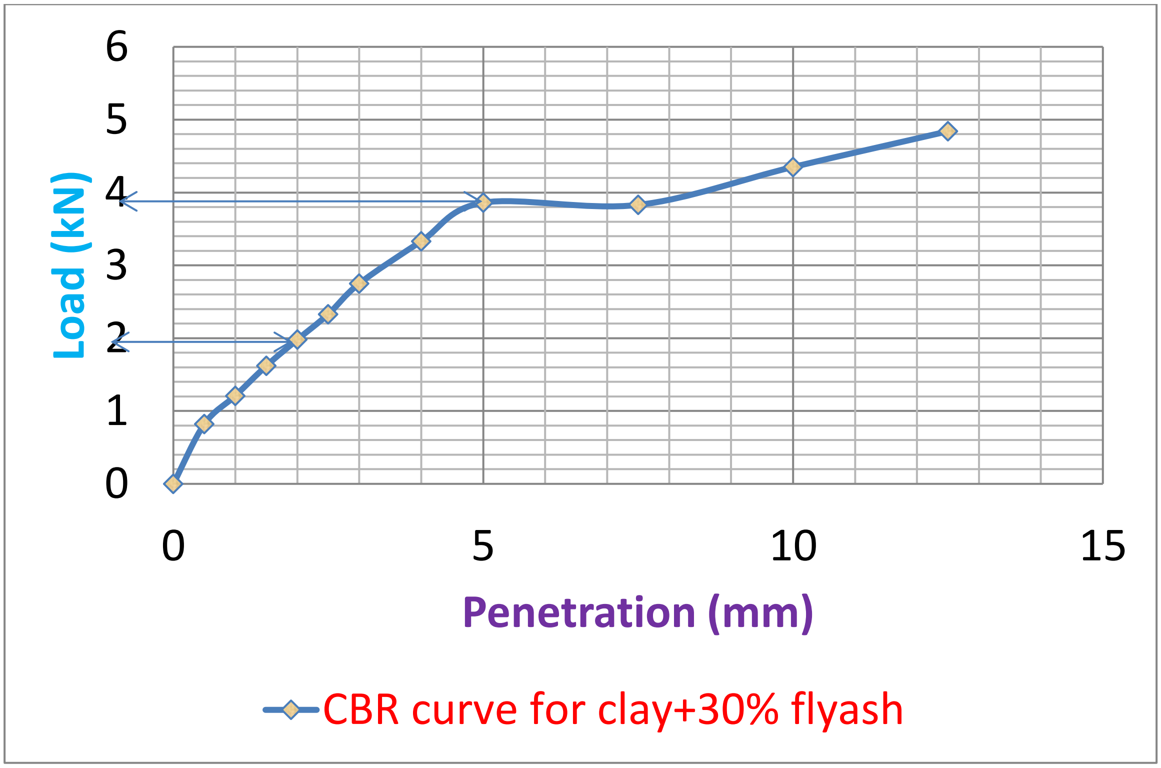


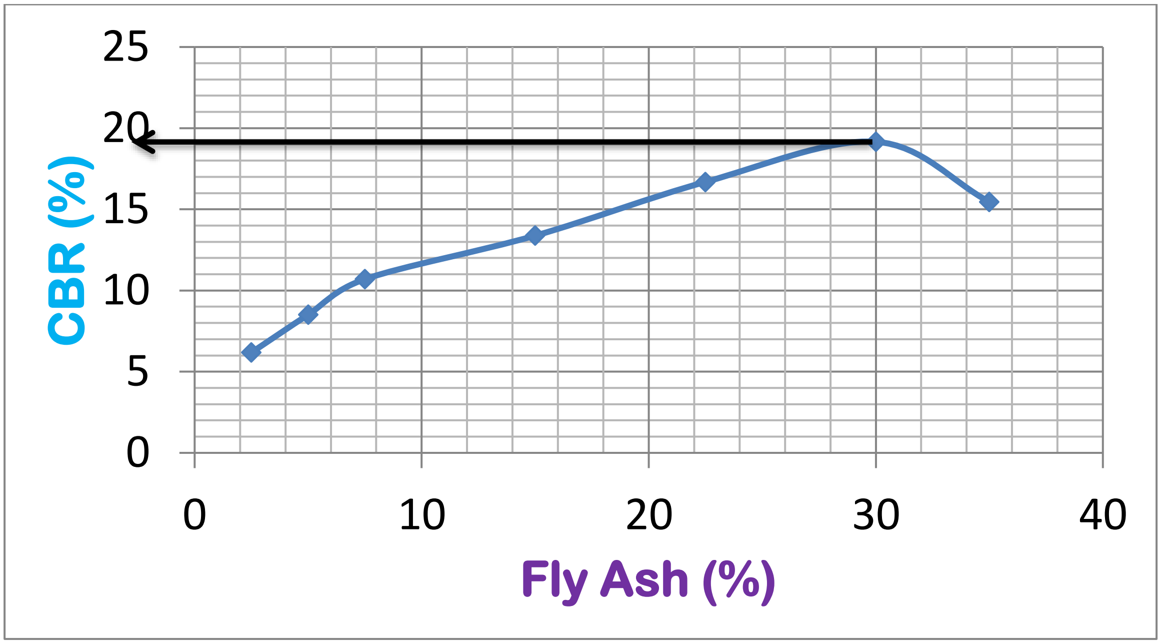
Table 5: Variation of CBR Values at different compositions

Sample composition	CBR Value
Clayey Soil+0% Fly ash	5.88
Flyash+0% Clayey Soil	10.90
Clay + 2.5% Fly ash	6.18
Clay + 5% Fly ash	8.51
Clay + 7.5% Fly ash	10.7
Clay + 15% Fly ash	13.38
Clay + 22.5% Fly ash	16.69
Clay + 30% Fly ash	18.78

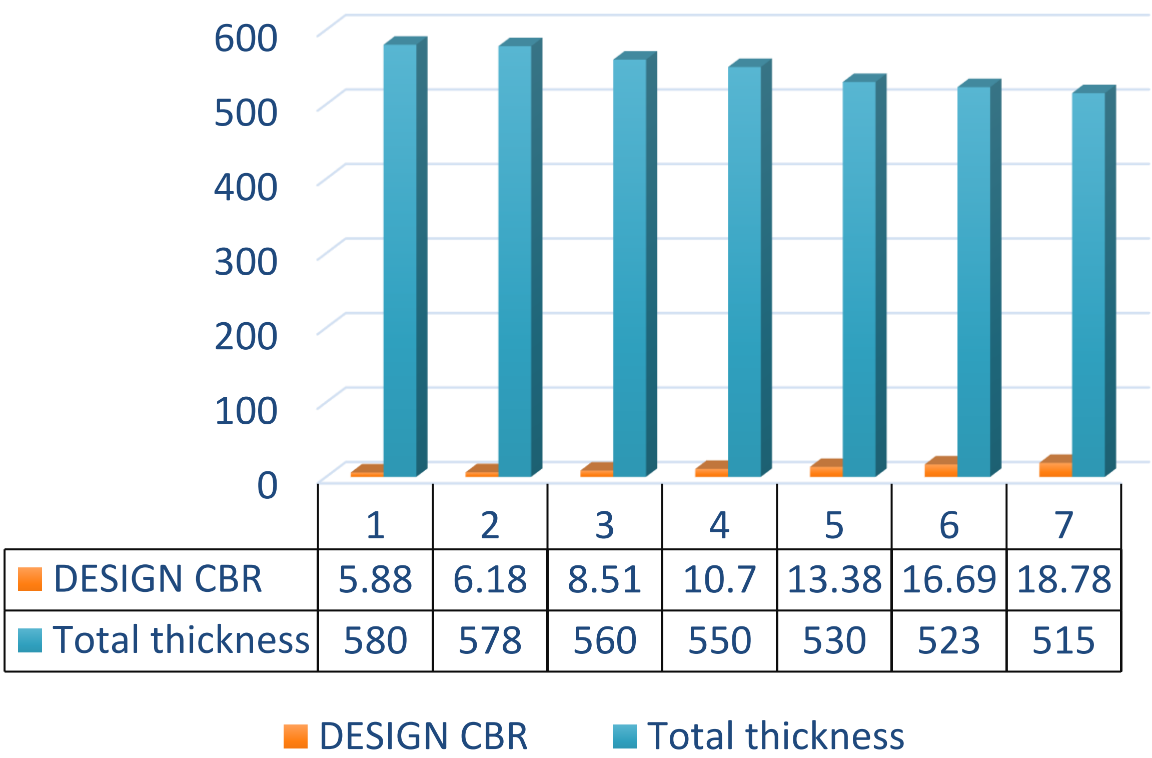
CBR CURVE FOR CLAY WITH 30% FLY ASH



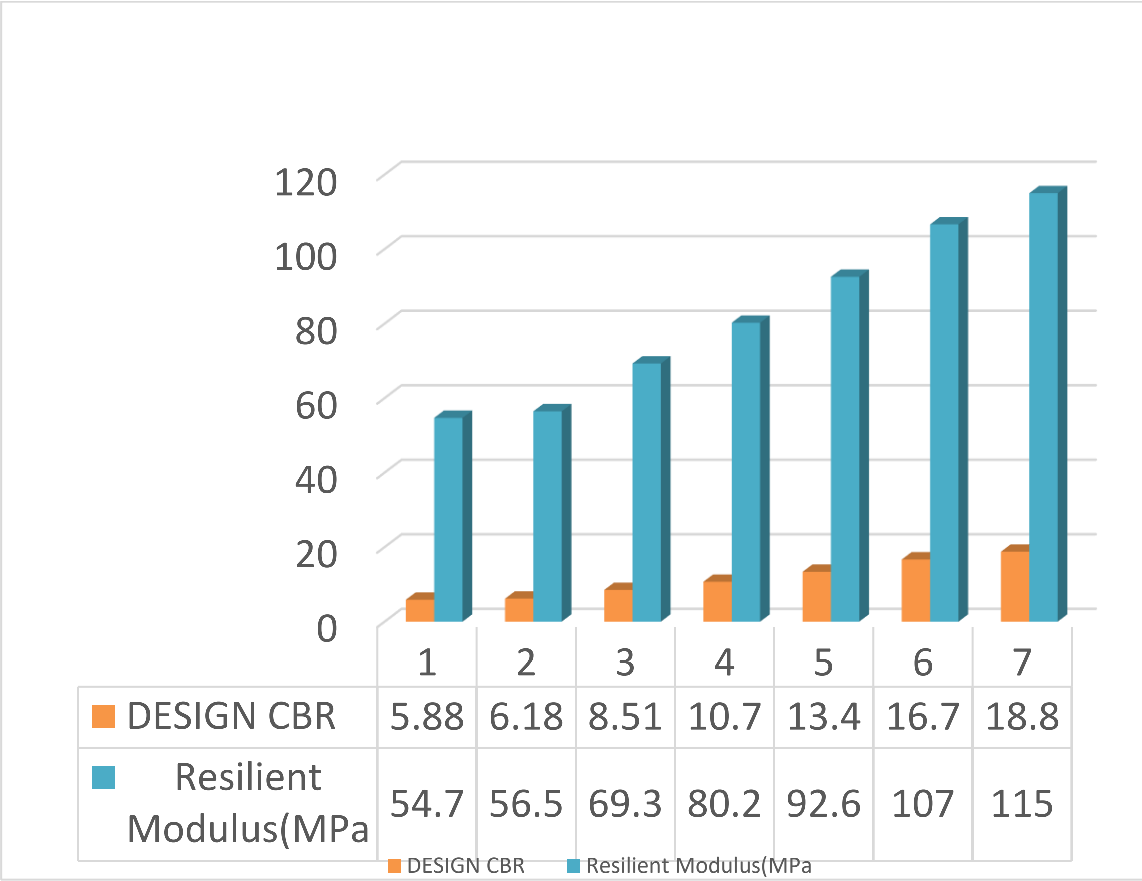
CBR VARIATION WITH FLY ASH CONTENT

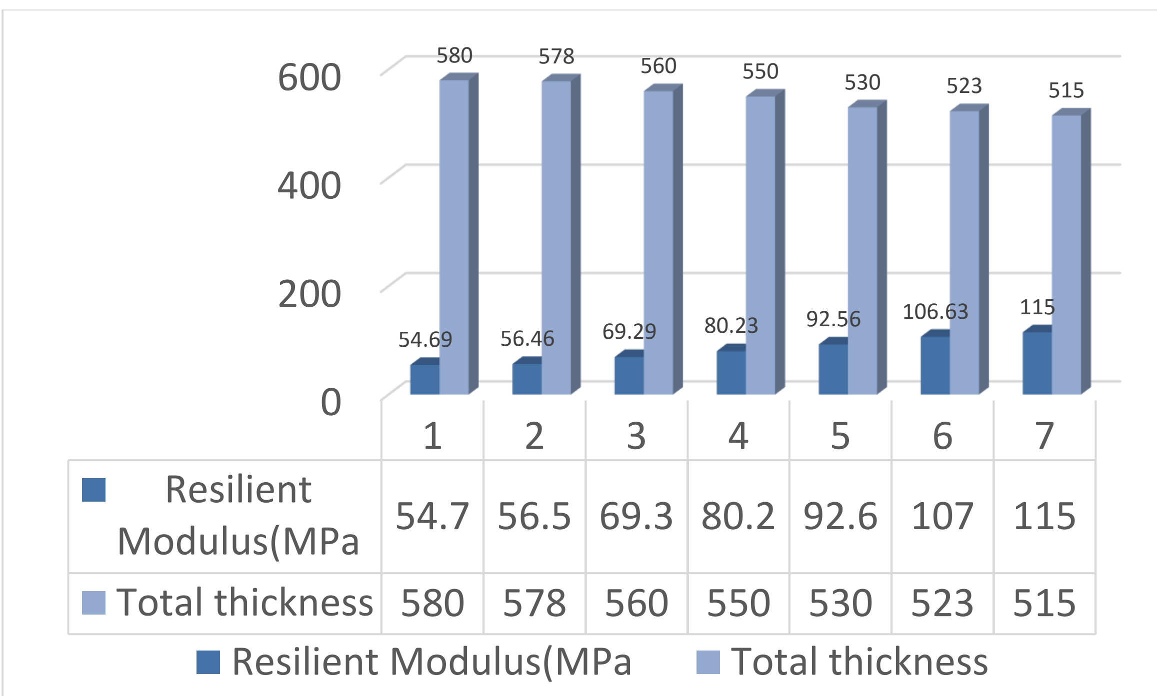


Variation Of Pavement thickness with different CBR



Variation of Resilient Modulus with different CBR





5. Economic Analysis

Cost Analysis for Clay Soil

Layer	Thickness(m)	Volume(m^3)	Rate (INR/m^3)	Cost (INR)
GSB	0.2	2800	3250	9100000
Granular Base	0.25	3500	3900	13650000
DBM	0.09	1260	10700	13482000
BC	0.04	560	13200	7392000
Total				43624000

Cost Analysis after optimisation (Clay soil + 22.5% Flyash)

Layer	Thickness(m)	Volume(m^3)	Rate (INR/m^3)	Cost (INR)
GSB	0.2	2800	3250	9100000
Granular Base	0.25	3500	3900	13650000
DBM	0.048	672	10700	7190400
BC	0.025	350	13200	4620000
Total				34560400

The improved subgrade properties resulted in a reduction of pavement crust thickness from 580 mm to 515 mm. This decrease led to a reduction in material quantities and overall construction cost by approximately 20%. Hence, fly ash stabilization not only enhanced the subgrade strength but also reduced pavement costs, making it a sustainable and economic solution.

6. CONCLUSIONS

Based on the laboratory results and design analysis, the following conclusions are drawn:

1. The specific gravity of the plain soil (0% fly ash) decreased from 2.67 to 2.58 (30% fly ash), primarily due to the lower specific gravity of fly ash (2.34) compared to natural clay.
2. The Optimum Moisture Content (OMC) increased from 17.20% to 21.63% with higher fly ash content, indicating increased water demand due to pozzolanic activity.
3. The Maximum Dry Density (MDD) showed a decreasing trend, which can be attributed to the lightweight nature of fly ash.
4. Liquid Limit decreased while Plastic Limit increased with increasing fly ash content.
5. The Plasticity Index (PI) reduced from 16% to 7.03%, reflecting improved soil workability and reduced shrink-swell potential.
6. Fly ash stabilization significantly enhances the strength and performance of clay subgrade soil.
7. The optimum fly ash content was found to be 22.5%, yielding a CBR value of approximately 16.69.
8. The resilient modulus and load-bearing capacity of the soil increased notably with fly ash addition.
9. Pavement thickness and construction cost reduced by nearly 20%, demonstrating economic viability.
10. Utilization of industrial waste such as fly ash in pavement construction promotes sustainability and environmental conservation.

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