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Stabilization of Various Soil Types using Egg Shell Powder and Fly Ash Composites

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KEYWORDS

Soil Stabilization, Egg Shell Powder (ESP), Fly Ash (FA), California Bearing Ratio (CBR), Waste Utilization.

ABSTRACT

This paper focuses on the stabilization of various soil types using a sustainable composite of Egg Shell Powder (ESP) and Fly Ash (FA). The soils selected for this study include Black Cotton Soil from Namburu, Alluvial Soil from Mangalagiri, and Red Soil from Acharya Nagarjuna University Campus. Stabilization was carried out by blending ESP and FA with the soils at varying percentages, 5%, 10%, 15%, and 20% by dry weight, to evaluate their effects on the geotechnical properties of the soil. A series of laboratory experiments was conducted, including Sieve Analysis, Specific Gravity, Water Content, Atterberg Limits (Liquid Limit, Plastic Limit, and Plasticity Index), Compaction, and California Bearing Ratio (CBR) tests. The results revealed significant improvements in the soil properties after stabilization. There was a notable reduction in plasticity and moisture sensitivity, along with enhanced strength and compaction characteristics, making the treated soils more suitable for construction applications. This study emphasizes the effective utilization of industrial and agricultural waste materials as sustainable solutions for enhancing weak soil properties.

1. INTRODUCTION

`Soil stabilization represents a cornerstone in geotechnical engineering practice, addressing the inadequacies of native soils through mechanical or chemical means to enhance their engineering performance. Soils exhibiting high plasticity, poor load-bearing capacity, and susceptibility to moisture fluctuations, such as expansive Black Cotton Soil, pose significant design and construction challenges. The demand for cost-effective and environmentally benign stabilization strategies has prompted increased exploration into sustainable alternatives to conventional additives like lime and cement.

In this context, Eggshell Powder (ESP), primarily composed of calcium carbonate ($CaCO_3$), offers substantial cementitious potential and is readily sourced from agro-industrial waste streams. Fly Ash (FA), a silica- and alumina-rich residue from coal combustion, is well-documented for its pozzolanic reactivity, which contributes to long-term strength development in soil systems. When employed synergistically, ESP and FA form a composite matrix that facilitates chemical bonding, reduces soil plasticity, and improves compactability and structural stability.

The present study investigates the influence of these materials on the strength characteristics of Black Cotton, Alluvial, and Red Soils. The goal is to quantify changes in critical parameters such as Atterberg limits, compaction characteristics, and CBR values, thereby elucidating the practical potential of ESP and FA in the domain of sustainable ground improvement.

STRUCTURE OF PAPER

The paper is organized as follows:

- Section I introduces the background and motivation for the study, defines the objectives, and presents a brief overview of the materials used.
- Section II reviews relevant literature on the use of Eggshell Powder (ESP) and Fly Ash (FA) for soil stabilization.
- Section III describes the materials selected for the study, including different soil types and stabilizers.
- Section IV outlines the mix proportions used in the experimental investigation.
- Section V details the experimental procedures followed, including the tests conducted as per Indian Standard codes.
- Section VI presents the results and analysis of geotechnical tests performed on untreated and treated soil samples, and discusses the observed trends.
- Section VII summarizes the key conclusions derived from the study and highlights the practical applicability of the stabilization method. The paper ends with Acknowledgment and References.

OBJECTIVES

The primary objectives of this study are outlined as follows:

- To study the behavior of three different types of soils.
- To compare the improvements in soil properties before and after the addition of Eggshell Powder (ESP) and Fly Ash (FA).
- To study the influence of ESP and FA on the overall strength and stability.
- To evaluate the extent of improvement in strength and stability parameters of Eggshell Powder (ESP) and Fly Ash (FA) for different soil types.

2. RELATED WORK

Numerous studies validate the potential of bio-waste and industrial by-products for soil stabilization.

- Khan et al. (2022) : [1] Multi-variable stabilization using ESP, FA, lime, and cement improved rural subgrade properties.
- Harikaran et al. (2018) : [2] Found that lime-ESP blends reduced swelling and enhanced compressive strength in expansive soils.
- Alzaidy (2019) : [3] Demonstrated that ESP combined with plastic fibers improved UCS and CBR in clayey soils, optimal at 5% ESP.
- Sunil Kumar Birkur (2016) : [4] Reported FA increased dry density and ESP reduced moisture sensitivity in Black Cotton Soil.
- Anu Paul et al. (2016) : [5] Partial substitution of lime with ESP improved CBR and plasticity index.
- Amu et al. (2005) : [6] Observed CBR increases from 21.5% to 47.6% using ESP alone on lateritic soil.

Collectively, these studies confirm that ESP and FA are environmentally responsible and technically viable for soil improvement..

3. MATERIALS

Soil Samples:

1. **Black Cotton Soil:** Namburu

Figure-01

2.

3. **Alluvial Soil:** Mangalagiri

Figure-02

4. **Red Soil:** Acharya Nagarjuna University campus

Figure-03

Stabilizers:

5. **ESP:** Collected from local sources, cleaned, dried and powdered.

Figure-04

6. **FA:** Obtained from the nearby thermal power station.

Figure-05

4. MIX RATIO

Table 01: Mix Proportions of ESP and FA for Soil Stabilization

Mix ID	ESP %	FA%
M0	0	0
M1	5	5
M2	10	10
M3	15	15
M4	20	20

◆ **Note**: The percentage values are calculated based on the soil's dry mass. M0 represents the untreated control sample.

5. EXPERMENTAL STUDY

The following experiments are carried out

- Sieve Analysis (IS 383:1970)
- Specific Gravity (IS: 2720 Part 3)
- Natural Moisture Content (IS: 2720 Part 2)
- Atterberg Limits (IS: 2720 Part 5)
- Standard Proctor Compaction (IS: 2720 Part 7)
- California Bearing Ratio – CBR (IS: 2720 Part 16)

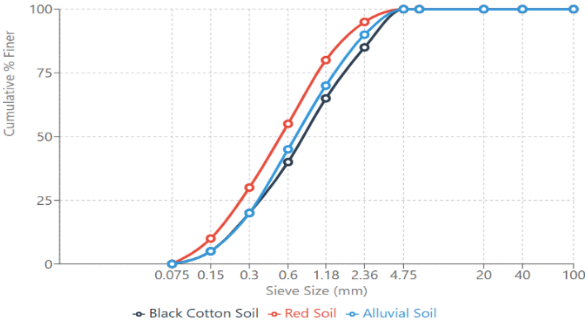
Each test was performed for untreated and treated soil samples to evaluate improvements.

6. RESULTS AND DISCUSSION

This chapter presents the summarized outcomes of various laboratory tests conducted on untreated and treated samples of black cotton soil, red soil, and alluvial soil with varying proportions of Eggshell Powder (ESP) and Fly Ash (FA) ranging from 5% to 20%. The primary aim was to evaluate the improvement in geotechnical properties such as plasticity, strength, moisture sensitivity, and load-bearing capacity.

1. **Sieve Analysis:**

Sieve analysis indicated varying gradation characteristics among the tested soils:



Graph-01: Particle Size Distribution Curves

- Black Cotton Soil was poorly graded, with a coefficient of uniformity (Cu) of 5.32 and, coefficient of curvature (Cc) of 0.923, indicating poor interlocking and high plasticity behavior.
- Red Soil exhibited borderline gradation, with Cu = 6.80 and Cc = 1.02, placing it between poorly and well-graded soils, with moderate suitability for compaction.
- Alluvial Soil was found to be well-graded, with Cu = 9.15 and Cc = 1.14, showing a broad range of particle sizes and good engineering properties for stabilization.

2. **Specific Gravity:**

Table 02: Variation of Specific Gravity with ESP and FA

Mix Type	Black Cotton Soil	Red Soil	Alluvial Soil
M0	2.63	2.32	2.58
M1	2.62	2.38	2.58
M2	2.61	2.38	2.55
M3	2.58	2.35	2.53
M4	2.57	2.34	2.51

The specific gravity values exhibited slight variations with the addition of ESP and FA. While marginal decreases were observed in some cases, all values remained within acceptable geotechnical ranges, indicating no adverse impact from the stabilizers.

- Black Cotton Soil showed a reduction from 2.63 (untreated) to 2.57 at 20% ESP+FA.
- Red Soil exhibited an increase from 2.32 to 2.38, reflecting better densification due to additive integration.
- Alluvial Soil showed a slight decrease from 2.55 to 2.51 at the highest dosage.

These minor changes are attributed to the low specific gravity of ESP and FA themselves, yet they did not compromise the overall structural performance of the treated soils.

3. **Water Content:**

Table 03: Moisture / Water Content at Different ESP and FA Levels

Mix Type	Black Cotton Soil	Red Soil	Alluvial Soil
M0	25.0%	28.2%	29.5%
M1	22.4%	26.1%	27.8%
M2	19.5%	23.9%	25.3%
M3	17.0%	21.5%	22.4%
M4	14.5%	19.0%	20.0%

A noticeable decrease in natural moisture content was observed in all soil types with increasing proportions of ESP and FA, indicating improved moisture regulation and reduced water retention.

- **Black Cotton Soil:** Decreased from 25.0% (untreated) to 14.8% at 20% ESP+FA.
- **Red Soil:** Dropped from 28.2% to 19.0%.
- **Alluvial Soil:** Reduced from 29.5% to 20.0%.

This reduction is attributed to the pozzolanic reaction and filler effect of the additives, which contribute to decreased void space and reduced water absorption. Improved moisture control is especially beneficial in expansive and silty soils, reducing shrink-swell potential and increasing stability.

4. **Atterberg's Limits:**

Table 04: Atterberg Limits (LL, PL, PI) of Treated and Untreated Soils

Soil Type	Mix ID	Liquid Limit(%)	Plastic Limit(%)	Plasticity Index (%)
Black Cotton Soil	M0	62.50	48.80	13.70
	M1	56.30	46.30	10.00
	M2	50.00	43.20	6.80
	M3	43.80	39.20	4.60
	M4	31.25	27.25	4.00
Red Soil	M0	65.63	50.33	15.30
	M1	59.40	46.22	13.18
	M2	52.20	42.88	9.32
	M3	44.60	39.58	5.02
	M4	34.38	28.68	5.70
Alluvial Soil	M0	68.75	51.45	17.30
	M1	60.20	48.28	11.92
	M2	52.50	45.90	6.60
	M3	44.00	42.20	1.80
	M4	37.50	36.20	1.30

The addition of ESP and FA led to a substantial reduction in liquid limit and plasticity index across all soil types, reflecting improved soil workability and reduced plastic behavior.

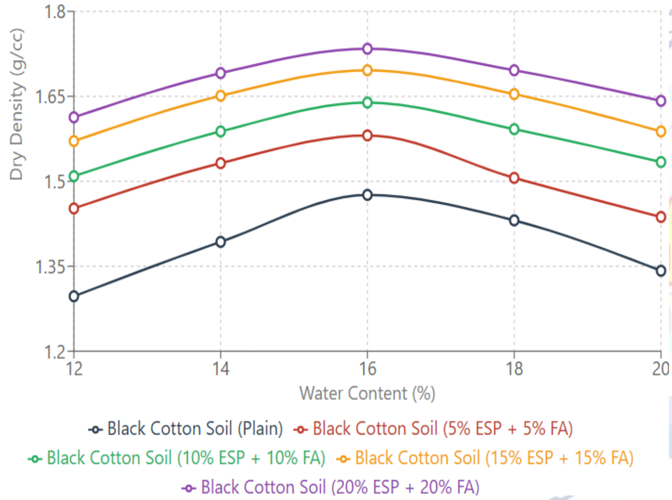
- **Black Cotton Soil**:
  - Liquid Limit decreased from 62.5% to 31.25%.
  - Plasticity Index (PI) reduced from 13.7% to 4.0%
- **Red Soil**:
  - Liquid Limit dropped from 65.63% to 34.38%.
  - PI reduced from 15.3% to 5.7%.

- **Alluvial Soil**:
  - Liquid Limit declined from 68.75% to 37.5%.
  - PI fell significantly from 17.3% to 1.3%.

The increase in plastic limit and the sharp drop in PI are attributed to the flocculation of clay particles and the pozzolanic reaction of the stabilizers, which reduces the soil's affinity for water. These results confirm enhanced dimensional stability and reduced swelling and shrinkage behavior, particularly in Black Cotton and Alluvial Soils.

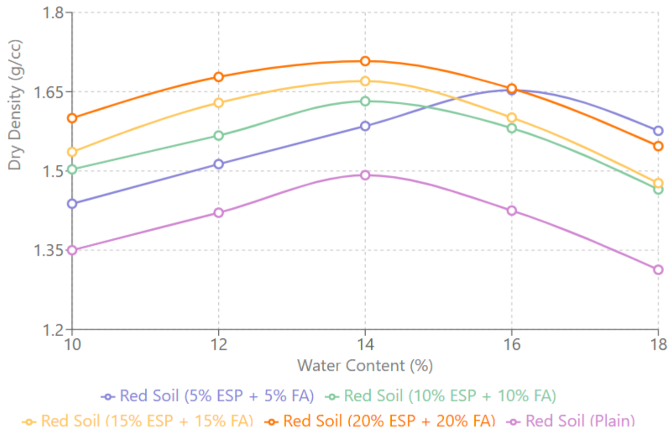
5. Compaction Test:

The compaction test results demonstrated a consistent improvement in Maximum Dry Density (MDD) across all soil types with the addition of ESP and FA, indicating enhanced soil structure and load-bearing potential. A reduction or stabilization in Optimum Moisture Content (OMC) was also observed.



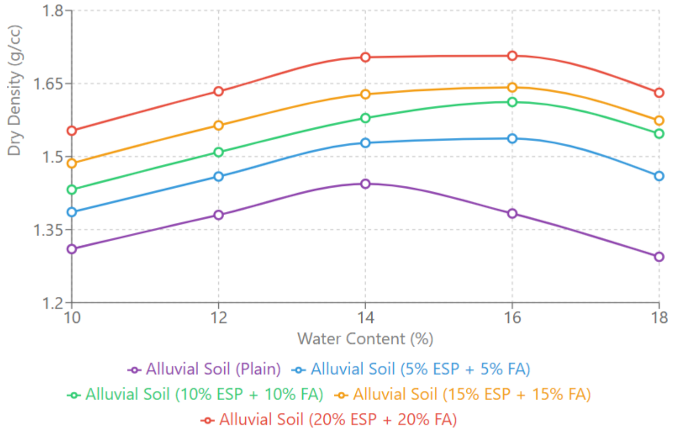
Graph-02: Black Cotton Soil: Dry Density vs Water Content for Different Compositions

- **Black Cotton Soil**: MDD increased from 1.476 g/cc to 1.734 g/cc



Graph-03: Red Soil: Dry Density vs Water Content for Different Compositions

- **Red Soil**: MDD increased from 1.492 g/cc to 1.708 g/cc



Graph-04: Alluvial Soil: Dry Density vs Water Content for Different Compositions

- **Alluvial Soil**: MDD increased from 1.444 g/cc to 1.707 g/cc

These enhancements reflect better particle arrangement, reduced void ratio, and improved compaction efficiency due to the fine, reactive nature of the ESP–FA blend. As a result, the treated soils exhibit superior load distribution capacity, which is critical for pavement and foundation performance.

6. California Bearing Ratio (CBR):

Table 05: CBR Values at Varying ESP and FA Proportions

Mix Type	Black Cotton Soil	Red Soil	Alluvial Soil
M0	2.445	3.891	4.668
M1	3.112	3.891	4.783
M2	3.500	3.500	5.556
M3	4.284	4.668	2.667
M4	5.012	5.391	3.223

The CBR test results demonstrated a significant increase in load-bearing capacity for all soil types following stabilization with ESP and FA. The improvement highlights the formation of a denser, more cohesive soil matrix capable of resisting greater penetration.

- **Black Cotton Soil**: Increased from 24.45% (untreated) to 50.12% at 20% ESP+FA
- **Red Soil**: Rose from 38.91% to 55.59% at 20%
- **Alluvial Soil**: Improved from 46.68% to 55.56%, although a slight dip was observed at the 15%

mix level

These gains are attributed to the pozzolanic and cementitious reactions facilitated by the combined additives, which enhance interparticle bonding and stiffness. The marked improvement, especially in Black Cotton Soil, confirms the effectiveness of this stabilization approach for subgrade and pavement applications.

7. Optimum Mix Proportions:

Based on the experimental outcomes across all geotechnical tests, the optimal dosage of ESP and FA was identified for each soil type:

- Black Cotton Soil exhibited the best overall performance at 20% (ESP+FA), with substantial improvements in CBR, dry density, and reduction in plasticity and moisture content. The expansive nature of this soil type necessitates a higher stabilizer dosage to achieve sufficient modification.
- Red Soil and Alluvial Soil also responded positively to the 20% blend; however, a notable improvement in properties was evident from 10% (ESP+FA) itself. Parameters such as Maximum Dry Density (MDD), Atterberg limits, and CBR began to show stable enhancement from this level onward, indicating that lower dosages may be adequate for these relatively less problematic soils.

These findings suggest that while 20% is the most effective mix for all soils, the minimum effective dosage for Red and Alluvial Soils could be optimized at 10–15%, enabling more economical and sustainable use of stabilizers in field applications.

7. CONCLUSION

This study comprehensively investigated the stabilization of Black Cotton Soil, Red Soil, and Alluvial Soil using Egg Shell Powder (ESP) and Fly Ash (FA) as sustainable additives.

All three soil types exhibited significant enhancement in both physical and strength characteristics following treatment. Notable improvements included reduced natural moisture content, decreased plasticity, increased dry density, and a marked rise in California Bearing Ratio (CBR) values. These enhancements contribute directly to better compaction, increased load-bearing capacity, and improved structural performance.

The optimum dosage for stabilization was identified to lie between 15% and 20% (ESP+FA), offering the best balance between strength, density, moisture resistance, and plasticity control. Specifically, Red Soil achieved the highest dry density, Black Cotton Soil showed the most significant strength gains, and Alluvial Soil recorded the largest reduction in plasticity.

These findings validate the use of ESP and FA as effective, low-cost, and environmentally responsible alternatives to conventional chemical stabilizers. Their successful application to diverse soil types makes this composite treatment a promising solution for subgrades, embankments, and pavement foundations, thereby supporting the principles of sustainable and resource-efficient geotechnical engineering.

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Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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