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Sustainable Stabilization Of Expansive Black Cotton Soil Using Recycled PET Plastic Waste For Flexible Pavement Subgrade: An Experimental Approach

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Abstract
The stabilization of problematic soils to enhance their engineering performance, particularly shear strength and bearing capacity, is a critical requirement in geotechnical engineering. In India, expansive soils such as black cotton soil present significant challenges for infrastructure development due to their pronounced swelling, shrinkage, and settlement characteristics, which often lead to structural instability and failure. Traditional soil stabilization techniques, including the use of cement, lime, and industrial by-products like fly ash, although effective, are frequently associated with high costs and environmental concerns. In the present study, an innovative and sustainable approach to soil stabilization is investigated through the incorporation of waste plastic as a soil modifier. This methodology not only addresses the persistent issue of plastic waste management but also offers an eco-friendly and cost-effective solution to improve soil behaviour. A series of laboratory experiments, including particle size distribution (sieve analysis), Modified Proctor compaction tests, and California Bearing Ratio (CBR) tests, were conducted to evaluate the influence of shredded plastic waste on the geotechnical properties of black cotton soil.
The sieve analysis provided essential insights into the gradation and physical characteristics of the soil. The Modified Proctor test, which is more suitable for applications requiring high compaction such as subgrade layers in road construction, was employed to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). The CBR test was utilized to assess the load-bearing capacity of the stabilized soil and to establish the Optimum Plastic Content (OPC)—the percentage of plastic addition beyond which the CBR value starts to decline.
The results indicate that the inclusion of plastic waste significantly enhances the load-bearing capacity of the soil up to an optimal dosage, beyond which performance deteriorates. The study confirms that waste plastic can serve as a viable and economical soil stabilizer, contributing to both geotechnical performance enhancement and environmental sustainability. This approach demonstrates considerable potential for application in low-volume roads and embankment construction, providing an effective pathway for the circular utilization of plastic waste in civil engineering practices.
Key words: *Optimum Plastic Content, Plastic Waste, Dry Density, Plastic strips, Shear strength,*

1. INTRODUCTION

1.1 Background and Motivation

The construction of civil engineering infrastructure is often constrained by the inadequate geotechnical properties of the natural soils available at project sites. In particular, expansive soils such as black cotton soil, prevalent across large regions of India, pose significant challenges due to their high swelling and shrinkage potential. These volumetric instabilities can cause severe distress to foundations, pavements, and other structures, necessitating the adoption of effective soil stabilization techniques to improve bearing capacity, shear strength, and long-term durability.

Soil stabilization refers to the process of altering the physical, mechanical, or chemical characteristics of soil to enhance its performance under structural loads. Traditionally, stabilization has relied on the addition of conventional binders such as lime, cement, and fly ash, or through mechanical means such as compaction and pre-consolidation. These methods improve the soil's load-bearing capacity, reduce permeability and compressibility, and mitigate shrink-swell behavior, thereby increasing the reliability and service life of structures constructed on weak subgrades.

However, the use of conventional stabilizers is often associated with high material and environmental costs. In recent years, the construction industry has witnessed a paradigm shift towards sustainable engineering solutions, driven by the increasing need to minimize environmental impact and promote circular economy practices. The utilization of waste materials, particularly plastic waste, for soil stabilization has emerged as a promising alternative. Plastics, being non-biodegradable and abundantly available in municipal solid waste, present a dual opportunity: enhancing soil properties while simultaneously addressing the escalating problem of plastic waste disposal.

Fig 1: Catalytic Upcycling of PET Plastic Waste into Aromatic Compounds Using In-Situ Formed Ni_2P Catalyst

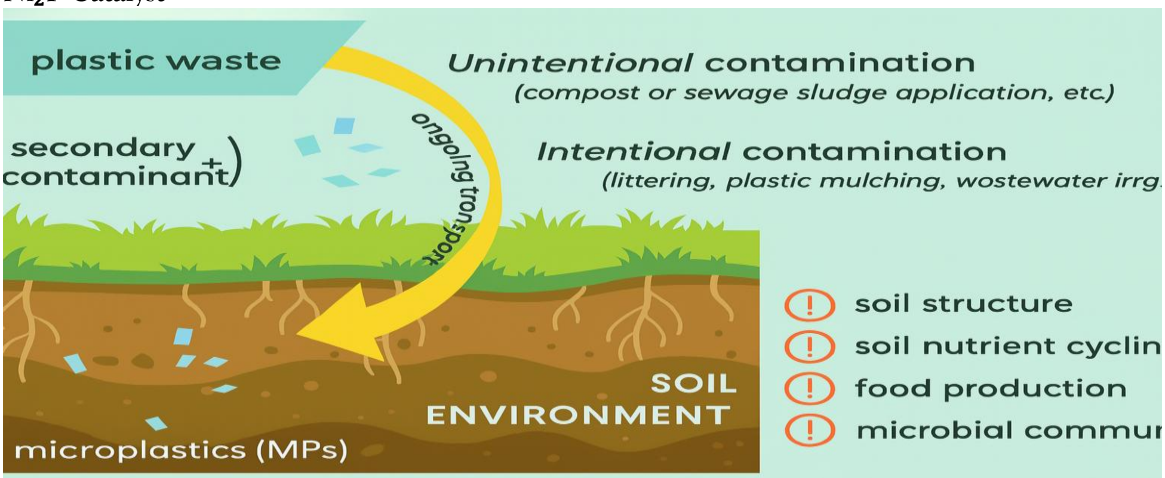

Fig 2: Pathways and Impacts of Microplastic Contamination in Soil Environments

1.2 Significance and Need for the Study

The growing environmental crisis posed by plastic waste, coupled with the demand for cost-effective soil stabilization solutions, underscores the importance of this research. Conventional methods such as soil replacement or deep foundations are not only economically burdensome but also resource intensive. Soil stabilization, when performed using recycled materials, offers a sustainable and economical alternative, particularly for low-volume roads, rural infrastructure, and temporary construction works.

The key advantages of adopting soil stabilization techniques include:

- Significant improvement in soil strength and bearing capacity.
- Reduction in settlement, shrink-swell behavior, and volume changes due to moisture fluctuations.
- Enhanced slope stability and overall durability of soil-based structures.
- Reduction in material and energy consumption compared to more invasive ground improvement methods.

- Contribution to environmental protection by diverting plastic waste from landfills and waterways.

In this context, the application of plastic waste in soil stabilization presents a unique solution that aligns with global sustainability goals, offering both engineering and environmental benefits. The present study focuses on evaluating the efficacy of shredded plastic waste as a soil stabilizer, specifically targeting black cotton soil, which is widely regarded as problematic in geotechnical applications.

1.3 Overview of Soil Stabilization Techniques

Soil stabilization encompasses a wide array of techniques broadly categorized into mechanical and chemical methods. Mechanical stabilization involves the modification of soil gradation through compaction or the addition of granular materials to improve density and load distribution. Chemical stabilization, on the other hand, alters the mineralogical properties of the soil through additives such as lime, cement, or industrial by-products, leading to pozzolanic reactions that enhance strength and durability.

Recent advancements have introduced alternative stabilization strategies that leverage waste materials, including plastic, rubber, glass, and industrial by-products. Among these, the recycling of plastic waste—particularly in the form of shredded polyethylene terephthalate (PET) bottles and plastic films—has demonstrated notable potential in improving the mechanical behavior of expansive soils. The inclusion of plastic strips or fibers enhances tensile strength, reduces brittleness, and limits crack propagation within the soil matrix.

The present research explores the potential of incorporating plastic waste as a reinforcing agent in black cotton soil through laboratory-based experimental investigations. Key geotechnical tests, including sieve analysis for soil classification, Modified Proctor test for determining optimum moisture content and maximum dry density, and California Bearing Ratio (CBR) tests for strength evaluation, were employed to assess the effectiveness of plastic waste in soil stabilization.

The study also highlights the broader implications of this approach in reducing the environmental footprint of construction projects while offering an economically viable solution for infrastructure development on problematic soils.

MATERIALS AND METHODS

2.1 Soil Characteristics

The study focuses on black cotton soil, a highly expansive clayey soil prevalent across India, characterized by the presence of montmorillonite minerals responsible for significant swelling, shrinkage, and cracking upon moisture variation. This inherent instability makes such soils unsuitable for direct construction without stabilization.

2.2 Plastic Waste Reinforcement

In this research, shredded plastic waste, primarily from polyethylene terephthalate (PET) bottles, was incorporated into the soil to improve its geotechnical behavior. When mixed with soil, plastic waste acts as randomly distributed discrete fibers, enhancing strength isotropy, shear strength, ductility, and reducing compressibility. This method, known as Randomly Distributed Fibre-Reinforced Soil (RDFS), offers a cost-effective and sustainable alternative to conventional stabilization techniques using cement or lime. Fibre-reinforced soil finds application in subgrades, embankments, and other geotechnical structures requiring enhanced performance.

2.3 Problem Statement

Expansive soils, like those found in Cyprus and parts of India, are associated with construction failures such as road distress and foundation cracking due to their low shear strength and high swell potential. Simultaneously, improper plastic waste disposal exacerbates environmental degradation, with vast amounts of waste ending up in landfills, contributing to pollution and resource inefficiency. This study addresses both issues by utilizing plastic waste for soil stabilization, transforming an environmental hazard into a valuable construction material.

2.4 Objectives

- To enhance soil strength and bearing capacity using plastic waste reinforcement.
- To provide an eco-friendly alternative for plastic waste management.
- To reduce soil stabilization costs by replacing conventional materials.
- To promote sustainable construction through circular waste utilization.

LITERATURE REVIEW

- Expansive soils, particularly black cotton soil rich in montmorillonite, pose significant geotechnical challenges due to their high swelling, shrinkage, and moisture sensitivity. Soil stabilization, aimed at improving strength and reducing volume change, has been extensively explored using various additives. In recent years, the reuse of industrial and agricultural wastes as soil stabilizers has gained traction, offering environmental and economic benefits.
- Pankaj Kumar and Abhishek Tiwari (2018) investigated the incorporation of plastic waste into black cotton soil. Their study demonstrated that adding 4% waste plastic strips enhanced the California Bearing Ratio (CBR) and strength, providing a sustainable solution to both soil instability and plastic waste management.
- Kirubakaran et al. (2018) reported that adding 5% PET plastic waste to expansive soils improved load-bearing capacity and CBR values. This approach effectively addressed environmental concerns related to plastic disposal while enhancing soil performance.
- SK Mehruddin et al. (2017) evaluated polypropylene plastic strips for soil stabilization, finding that a 2% plastic content significantly increased CBR values. They concluded that waste plastics could serve as effective soil reinforcement materials.
- Aparna Chavan et al. (2019) experimented with different aspect ratios and percentages of plastic strips, determining that a 0.5% inclusion with an aspect ratio of 2 provided optimal improvement in soil strength.
- P. Harsha Vardhan and Mutluri Yamunna (2017) highlighted the dual benefits of plastic waste utilization—enhanced soil stabilization and reduced environmental pollution—by demonstrating CBR improvement through plastic reinforcement.
- Himani Saini et al. (2019) explored the use of sugarcane bagasse ash as a soil stabilizer. Their findings revealed that a 5% addition reduced plasticity and increased both CBR and maximum dry density, enhancing soil suitability for construction.
- Hitesh Sant et al. (2016) confirmed that sugarcane bagasse ash improved the stability of black cotton soil, with optimum performance observed at an 8% mix, enhancing the soil's strength for highway applications.
- Chandra Pachori and Ajeet Saxena (2019) further validated the use of bagasse ash in reducing plasticity and swelling potential while increasing CBR values, suggesting its viability for subgrade stabilization.
- Vishal Ghutke et al. (2018) examined rice husk ash (RHA) as an additive and observed that a 12% RHA content significantly improved CBR and geotechnical properties due to its high silica content, making it a promising eco-friendly stabilizer.
- Collectively, these studies confirm that the incorporation of plastic waste, bagasse ash, and rice husk ash into expansive soils offers a sustainable, cost-effective approach to improving soil strength and durability while addressing pressing waste disposal challenges.
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MATERIALS AND METHODOLOGY

Materials

This study utilized locally sourced expansive soil (black cotton soil) and waste polyethylene terephthalate (PET) plastic strips as stabilizing materials. The PET plastic strips, cut from discarded bottles, measured approximately 5 mm in length and 0.5 mm in width. The plastic was added to the soil in varying proportions of 3%, 5%, and 7% by dry weight of soil.

Black cotton soil, known for its high clay content and significant swelling-shrinkage behavior, poses challenges for construction. Stabilization using additives such as PET waste aims to enhance strength, reduce plasticity, and control volume changes, making the soil more suitable for engineering applications.

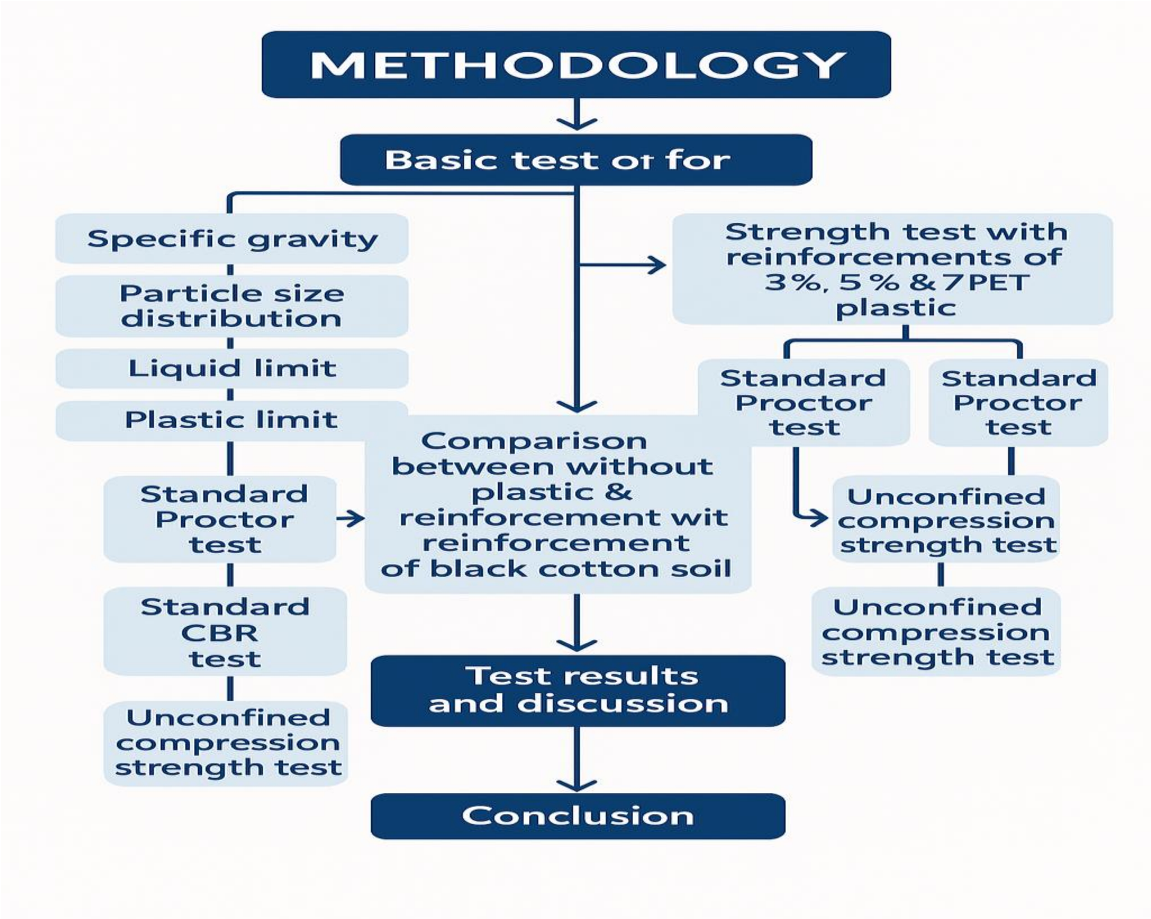

Fig 3. Flowchart of Methodology

5. Experimental Study

The experimental program consisted of the following key steps:

1. Determination of soil specific gravity.
2. Measurement of Atterberg Limits (Liquid Limit and Plastic Limit).
3. Sieve analysis to determine particle size distribution.
4. Preparation of reinforced soil samples with PET waste.
5. Standard Proctor Compaction Test to determine Maximum Dry Density (MDD) and Optimum Moisture Content (OMC).
6. California Bearing Ratio (CBR) Tests:
    - Unsoaked CBR
    - Soaked CBR (after 96 hours of soaking)
7. Unconfined Compression Strength (UCS) Tests:
    - Unsoaked UCS
    - Soaked UCS after curing for 7, 14, and 28 days.

METHODOLOGY

The study followed these methodological steps:

- Soil was oven-dried and sieved through a 4.75 mm sieve.
- Shredded PET plastic waste was blended into the soil at 3%, 5%, and 7% by weight.
- All laboratory tests were conducted in accordance with IRC: SP:72-2015 and relevant Indian Standards (IS 2720 series).

Tests Conducted:

- **Index Properties:** Liquid Limit, Plastic Limit, and Specific Gravity following IS 2720 (Parts 3 and 5).
- **Grain Size Distribution:** Conducted using sieve analysis as per IS 2720 (Part 4).

- **Compaction Characteristics:** Determined through the Standard Proctor Test (IS 2720 Part 7) to find MDD and OMC.
- **California Bearing Ratio (CBR) Test:** Performed under both soaked and unsoaked conditions following IS 2720 (Part 16).
- **Unconfined Compression Strength (UCS) Test:** Conducted according to IS 2720 (Part 10) on both soaked and unsoaked samples, with curing periods of 7, 14, and 28 days.

Comparative analysis was carried out between untreated soil and PET-reinforced soil to assess improvements in Plasticity Index, MDD, OMC, CBR, and UCS, demonstrating the influence of PET waste inclusion on soil performance.

Fig 4: Unconfined Unsoaked Sample

Fig 5: CBR Test for Soaked Condition

Fig 6: Unconfined Compression Strength

RESULTS AND DISCUSSION

Table 1: Properties of Black Cotton Soil Sample

Properties	Result	Limit	Relevant Code
Liquid Limit	27.1324%	40-100%	IS 2720 Part 5
Plastic Limit	30.6324%	-	IS 2720 Part 5
Specific Gravity	2.7024	2.65-2.8	IS 2720 Part 5
Unconfined Compression Test	0.1639 N/mm²	-	IS 2720 Part 10
Maximum Dry Density	1.6424 g/cc	>1.59	IS 2720 Part 8
Optimum Moisture Content	20.1324%	-	IS 2720 Part 8
California Bearing Ratio (CBR)	16.1324% & 4.9324%	-	IS 2720 Part 8
Sieve Analysis Cu/Cc	Cu = 9.1324, Cc = 1.6924	-	IS 2720 Part 5

Standard Proctor Compaction

- Without reinforcement: MDD = 1.6424 g/cc, OMC = 20.1324%
- With 3% PET: MDD = 1.6624 g/cc, OMC = 19.1324%
- With 5% PET: MDD = 1.6824 g/cc, OMC = 19.1324%
- With 7% PET: MDD = 1.7024 g/cc, OMC = 18.1324%

California Bearing Ratio (CBR) Test

Table 2: Unsoaked CBR Results

% PET Content	CBR Value (%)
0	16.1324
3	21.1324
5	23.1324
7	17.1324

Table 3: Soaked CBR Results

% PET Content	CBR Value (%)
0	2.5224
3	2.8824
5	3.4724
7	3.1124

Unconfined Compression Strength (UCS) Test: The Unconfined Compression Strength (UCS) test is a laboratory method used to determine the compressive strength of cohesive soils, particularly clays, without any lateral confinement. It provides a quick and simple measure of the undrained shear strength of the soil, essential for foundation and stability analysis.

Table 4: Unsoaked UCS Values

% PET Content	UCS Value (N/mm²)
0	0.1599
3	0.1630
5	0.1637
7	0.1626

Table 5: Soaked UCS Values (7 Days):

% PET Content	UCS Value (N/mm²)
0	0.1571
3	0.1582
5	0.1599
7	0.1658

Table 6: Soaked UCS Values (14 Days):

% PET Content	UCS Value (N/mm²)
0	0.1593
3	0.1599
5	0.1626
7	0.1599

Table 7: Soaked UCS Values (28 Days)

% PET Content	UCS Value (N/mm²)
0	0.1582
3	0.1593
5	0.1630
7	0.1593

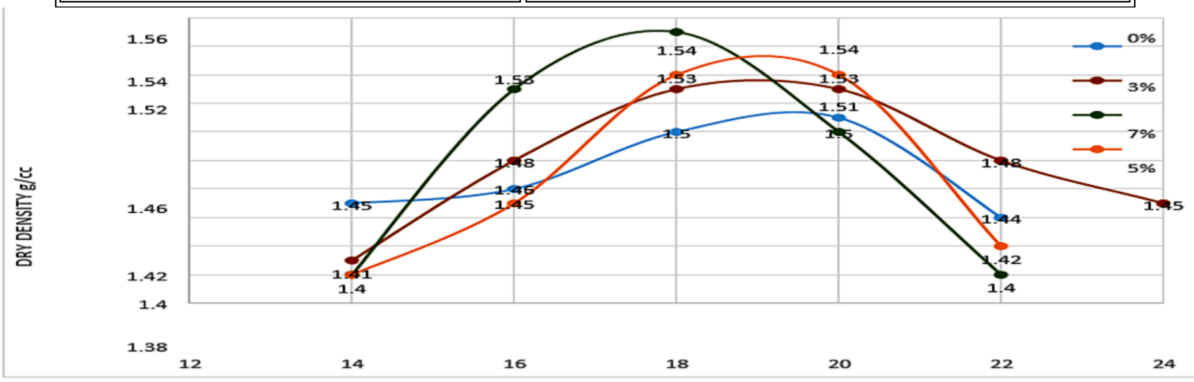

Figure 7 : Comparative Analysis of SPT Test

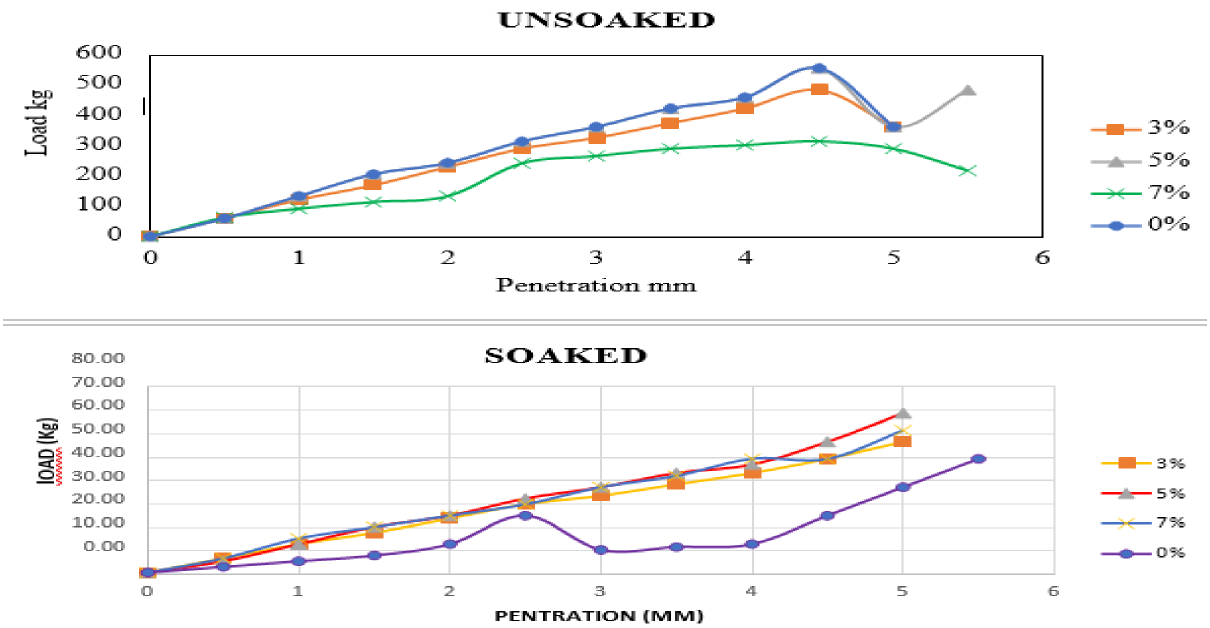

Figure 8 : CBR test results for Soaked and Unsoaked Condition

CONCLUSIONS

Based on the findings of this study, the following conclusions can be drawn:

1. The inclusion of waste PET plastic strips enhances the bearing capacity of black cotton soil, as demonstrated by the improved Unconfined Compressive Strength (UCS) values.
2. Test results confirm that incorporating PET waste significantly increases the load-bearing capacity of the soil, making it a viable alternative for soil stabilization.
3. Adding PET waste to soil not only improves its strength but also offers a sustainable method for managing plastic waste.
4. The increased soil stability achieved through PET waste inclusion could potentially improve earthquake resistance of foundations built on expansive soils.
5. Waste PET plastic, though generally considered end-of-life material, can be effectively recycled as a stabilizer in foundation soils, offering both environmental and engineering benefits.

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