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Subgrade Stabilization of Roads by Plastic Waste

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Abstract: The dual global challenges of managing escalating plastic waste and constructing resilient, cost-effective infrastructure demand innovative geotechnical solutions. This research investigates the feasibility of stabilizing problematic lateritic silty soil—a common subgrade material—using an eco-friendly composite binder. The study evaluates a proposed method blending 6% Cement, 4% plastic waste (comprising a mix of 2-4mm HDPE bottle strips and shredded waste cement bags), and 2% Rice husk Ash.

The primary objective was to create a sustainable stabilization alternative that mititgates the drawbacks of traditional methods, such as the high cost and carbon footprint of cement-only stabilization, and the poor durability of plastic-only applications. An experimental program was conducted to compare the geotechnical performance of the proposed blend against untreated (control) soil, soil treated with 4% plastic only, and soil treated with 6% cement only. The results demonstrated a significant enhancement in soil properties. The untreated soil exhibited very low bearing capacity (CBR: 2-6%; UCS: 0.05-0.15 MPa). The proposed composite blend achieved a superior California Bearing Ratio (CBR) ranging from 20-45% and an Unconfined Compressive Strength (UCS) of 0.8-3.0 MPa. This performance surpassed the cement-only stabilization (CBR: 15-35%; UCS: 0.6-2.0 MPa) by providing not only higher strength but also improved toughness and reduced brittleness. This study concludes that the proposed 6% Cement + 4% Plastic + 2% Rice husk Ash blend is a highly effective, economical, and sustainable solution. It successfully converts problematic waste materials into valuable engineering resources, reduces the overall carbon footprint by lowering cement consumption, and produces a balanced subgrade material with high strength and durability. This method presents a promising and eco-friendly alternative for road subgrade and foundation works.

Keywords: Subgrade Stabilization, Plastic Waste, Rice husk Ash, Lateritic Soil, California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), Waste Utilization, Sustainable Construction.

I. INTRODUCTION

We live in an era of unprecedented urban growth. Across the globe, demand is surging for new roads, highways, and residential foundations. This foundation of modern society, however, rests on two significant challenges. First, the construction itself is resource-intensive, relying heavily on materials like cement, the production of which is a primary source of global CO_2 emissions. Second, this same development generates mountains of non-biodegradable waste, most notably plastic, creating an environmental crisis that chokes landfills and pollutes ecosystems. The field of geotechnical engineering is uniquely positioned at the intersection of these two problems. The central question is no longer just "How do we build stronger?" but "How do we build smarter, more sustainably, and more cost-effectively?" This research is driven by a simple but powerful idea: What if the waste plaguing our planet could be used to strengthen the ground beneath our feet?

The long-term performance of any pavement structure is critically dependent on the stability of its subgrade layer. Unfortunately, engineers often encounter problematic soils, such as the lateritic silty soil used in this study, which possess poor mechanical properties. These soils often have low bearing capacity and high susceptibility to moisture, leading to pavement failure, rutting, and costly long-term maintenance. For decades, the default solution has been soil stabilization. However, conventional methods are increasingly showing their limitations:

Cement-Only Stabilization: While effective at increasing strength, it is expensive due to high cement usage. It also results in a brittle, rigid layer prone to shrinkage and cracking, and carries a significant environmental footprint.

Lime or Fly Ash Stabilization: These methods can be effective, but often suffer from long curing times and low early-strength gain. Their effectiveness can also be highly dependent on the specific soil chemistry (e.g., lime works best on high-plasticity clays).Mechanical Methods (Geotextiles/Geogrids): These are often costly, require specialized skilled labor for installation, and only provide mechanical reinforcement without improving the chemical or binding properties of the soil itself. These drawbacks create a clear and urgent research gap: the need for a "balanced" stabilization method that is strong, flexible, cost-effective, and environmentally friendly

II. EFFECTS OF OPEN PLASTIC WASTE ON THE ENVIRONMENT, HUMANS, AND ANIMALS

Plastic pollution is now one of the most critical global environmental challenges. When plastic waste is left in open spaces instead of being properly managed, it doesn’t decompose quickly and can remain in the environment for centuries. Over time, large plastic pieces break down into tiny fragments known as micro plastics, which spread through air, soil, and water. These persistent materials negatively affect the natural ecosystem, human health, and wildlife in numerous ways.

A. Impact on the Environment

Openly discarded plastic disrupts almost every natural process on Earth. Plastics clog drainage systems, block water flow, and increase the risk of flooding during heavy rains. In soil, they form an impermeable layer that prevents proper water infiltration, reducing soil fertility and affecting plant growth. When exposed to heat or sunlight, plastic waste releases methane, ethylene, and other greenhouse gases, contributing to rising global temperatures. Burning plastics in open areas is especially harmful, as it releases poisonous gases like dioxins and furans, which pollute the air and harm both humans and animals.

In aquatic environments, plastic waste breaks into smaller particles that float for years. These particles absorb toxic chemicals and are often mistaken for food by fish and other marine organisms. As a result, plastic pollution damages aquatic ecosystems, disrupts food chains, and leads to the death of countless marine species each year. Scientists estimate that millions of tons of plastic enter the oceans annually, forming large “garbage patches” that threaten biodiversity and marine life.

B. Impact on Humans

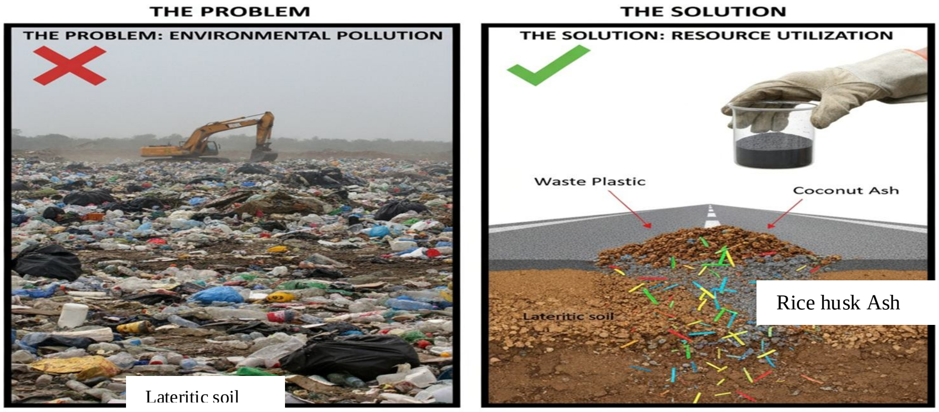
Human exposure to plastic waste can occur through multiple pathways—air, water, and food. People living near open dumping or burning sites breathe in harmful gases and fine particles, leading to respiratory diseases, skin irritation, and eye infections. Long-term exposure can even increase the risk of heart disease and certain types of cancer. Micro plastics have now been detected in drinking water, table salt, fruits, vegetables, and seafood. When consumed, these particles can accumulate inside the human body, disturbing hormonal balance and affecting the immune and reproductive systems. Certain plastic additives, such as bisphenol A (BPA) and phthalates, are known to mimic hormones, leading to health problems over time. In addition, improper plastic disposal also creates unhygienic conditions that attract pests and insects, causing the spread of diseases in nearby communities. These effects are more severe in developing regions, where waste management infrastructure is often lacking.

C. Impact on Animals

Open plastic waste is equally dangerous for animals on land and in water. Stray animals often consume food mixed with plastic bags or wrappers, which can block their digestive system and lead to starvation or death. Birds and small mammals get entangled in plastic threads, bottles, or fishing nets, causing injury or restricted movement. In oceans and rivers, turtles, fish, and seabirds mistake floating plastic for jellyfish or plankton. Once ingested, it causes internal wounds, suffocation, and malnutrition. Research shows that nearly every marine species has traces of plastic in its stomach today, indicating how widespread the issue has become.

The contamination doesn’t stop there—when humans eat seafood, these plastic particles re-enter the human body, creating a continuous cycle of pollution and harm.

FIGURE 1: FROM WASTE TO RESOURCE: A CIRCULAR ECONOMY APPROACH IN IN GEOTECHENTICAL ENGINEERING



1) Lateritic Silty Soil (Subgrade Material)The base material utilized in this research was locally sourced lateritic silty soil. Lateritic soils are residual products of rock weathering common in tropical and subtropical regions. For engineering purposes, these soils often exhibit moderate to high plasticity and are particularly sensitive to moisture content, which can lead to significant volume change and a loss of bearing capacity, classifying them as problematic subgrade material. The control condition (untreated) of this soil established a baseline of Very low bearing capacity with a typical illustrative CBR range of 2-6% and a UCS range of 0.05-0.15 { Mpa}. A critical aspect of this study was improving these poor initial properties to meet the requirements for stable road subgrades and foundations.2. Ordinary Portland Cement (OPC)
2) Ordinary Portland Cement (OPC) was incorporated at a reduced dosage of 6% by weight of the dry soil. Cement serves as the primary chemical binder, responsible for providing high initial strength and forming a rigid matrix. Your data confirms that cement-only stabilization significantly increased the CBR (up to 15-35%) and UCS (up to 0.6-2.0 { Mpa) due to the cementing action. However, its major drawbacks, including high CO_2 emissions, expense, and resulting brittleness prone to shrinkage and cracks, justified the necessity of reducing its quantity and compensating for its limitations with other materials in the proposed blend.
3) Waste Plastic Strips (Mechanical Reinforcement)The study employed 4% plastic waste, which was a specific mixture of two readily available types: HDPE (High-Density Polyethylene) bottle strips and shredded waste cement bags. This plastic was prepared and cut into small strips, with dimensions specified as 2-4 { mm}. This material functions purely as a mechanical reinforcement agent. When used alone, it "improves flexibility but low bonding strength" and results in "poor durability due to weak bonding." However, its crucial role in the composite is to impart ductility and toughness to the stabilized soil, significantly enhancing crack resistance and providing a mechanical interlock that mitigates the inherent brittleness of the cement-stabilized matrix.
4) Rice husk Ash (Pozzolanic Additive) Rice husk Ash was included at a dosage of 10% by weight of the dry soil. Rice husk Ash is an agricultural waste product that possesses pozzolanic properties, meaning it contains siliceous or aluminous material that, when finely divided and in the presence of water, reacts chemically with the calcium hydroxide produced by cement hydration. Its inclusion is strategic: it is an eco-friendly waste material that acts as a partial cement replacement, improving durability and contributing to long-term strength gain. The data shows it improves durability by helping the mix "resist moisture" and reduces the overall environmental impact and cost by lessening the quantity of cement needed in the final blend.
5) The Proposed Composite Blend The ultimate material study focused on the performance of the Cement (6%)+ Plastic (4%) + Rice husk Ash (2%), which was engineered to achieve a Balanced improvement. By combining the binding strength of cement, the toughness and flexibility of plastic, and the long-term durability of Rice husk Ash, the blend aimed for synergy. The results validated this approach, showing High durability and a Reduced cost with a final performance that yielded a CBR of 20-45% and a UCS of 0.8-3.0 { MPa}. This balanced blend represents a successful, sustainable strategy for transforming lateritic silty soil into a high-performance subgrade material.

Parameter	Approximate Value (Typical)	Indian Standard (IS Code)	Role & Notes
Basic Properties			
Specific Gravity (Gs)	2.60	IS: 2720 (Part 3/Sec 1)	Used for calculations involving voids and degree of saturation.
Maximum Dry Density (MDD) (Mg/m^3)	1.75	IS: 2720 (Part 7) (Light Compaction)	Important for preparing stabilized soil samples.
Optimum Moisture Content (OMC) (%)	18.0	IS: 2720 (Part 7) (Light Compaction)	Represents the moisture required to achieve maximum dry density.
Atterberg Limits			
Liquid Limit (LL) (%)	38	IS: 2720 (Part 5)	Defines the water content at which soil changes from plastic to liquid state.
Plastic Limit (PL) (%)	24	IS: 2720 (Part 5)	Defines the water content at which soil changes from semi-solid to plastic state.

Plasticity Index (PI) (%)	14 (LL – PL)	—	Indicates the range of moisture content over which soil remains plastic.
Classification			
Indian Standard Classification (ISC)	CI (Clay of Intermediate Plasticity) or MI (Silt of Intermediate Plasticity)	IS: 1498	Based on grain size distribution and Atterberg limits.
Baseline Performance (From Your Data)			
Untreated CBR (%)	6 (Range: 2–6)	IS: 2720 (Part 16)	Indicates low strength; unsuitable for high-traffic subgrade.
Untreated UCS (kPa)	53 (Range:50-150)	IS: 2720 (Part 10)	Shows low unconfined compressive strength of soil.

III. MATERIAL RESEARCH

Table 1 Advantages and limitations of Plastic waste mainly consists of materials such as polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (PET). These materials are commonly found in carry bags, packaging films, bottles, wrappers, and disposable products. When shredded into small pieces and mixed with soil, plastic acts as a reinforcing agent and reduces moisture sensitivity of the subgrade soil.

Sr. No	Material	Advantages	Limitations	Cooling ability
1	Polyethylene (PE) (carry bags, films)	Lightweight, easily available, improves soil density	Requires shredding, does not bond chemically	Moderate
2	Polypropylene (PP) (plastic cups, ropes)	Enhances load bearing capacity, increases CBR	Requires uniform mixing for best results	High
3	PET (bottle plastic)	High strength, good durability	Hard to shred and needs special cutting tools	High
4	Mixed Plastic Waste	Very low cost, uses non-recyclable waste	Need segregation to remove harmful/metal pieces	Moderate

IV. RESEARCH AND METHODOLOGY

The experimental investigation was conducted to evaluate the efficacy of the proposed composite blend for stabilizing lateritic silty soil. The methodology centered on a comparative study, analyzing the performance of the untreated control soil against four distinct treatment groups. The primary soil, lateritic silty soil, was first characterized for its basic geotechnical properties. Four different stabilization scenarios were then prepared: (1) Untreated Control, (2) Only Plastic (4%), (3) Only Cement (6%), and the (4) Proposed Composite Blend (Cement 6% + Plastic 4% + Rice husk Ash 2%). All additive percentages were calculated by weight of the dry soil. The waste plastic (HDPE strips and cement bags) was processed into 2-4 { mm} strips to ensure uniform mixing and mechanical interlock.

Test specimens were prepared at their optimum moisture content and maximum dry density, determined through standard Proctor compaction tests. Key engineering parameters—specifically the California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS)—were measured for all groups after appropriate curing periods (e.g. 7 or 28 days) to assess immediate and long-term strength. The comparative analysis of these results allowed for a rigorous evaluation of the individual contributions of plastic and cement, ultimately validating the superior, balanced performance of the final sustainable composite mixture.

A. *Research Objective*

- To determine the improvement in strength and stability of subgrade soil when mixed with different percentages of shredded plastic waste.
- To provide a sustainable road construction technique that utilizes non-recyclable plastic as a valuable resource.

B. *Research Design*

A laboratory-based comparative experimental design is used.
Soil samples are tested before and after adding plastic in different proportions (0%, 2%, 4%, 6%, and 8%).

C. *Data Collection Methods*

1) *Experimental Testing*

Step	Description
Sample Collection	Soil is collected from the proposed subgrade site and dried. Plastic waste is collected and shredded (2–4 mm size).
Mixing Proportions	Soil is mixed with plastic in fixed percentages.
Preparation of Samples	Samples are prepared for lab tests under standard conditions.

2) *Parameters Monitored*

Parameter	Purpose
Moisture Content and Dry Density (Proctor Test)	To determine optimum compaction characteristics.
California Bearing Ratio (CBR)	To evaluate load-bearing strength of the stabilized soil.
Atterberg Limits	To assess change in plasticity and workability of soil.
Shear Strength Test	To measure resistance against deformation and failure.

- Data Analysis
  - The results of soil mixed with plastic are **compared** with natural soil.
  - CBR values generally **increase** with plastic addition up to an optimum percentage (**6%**).
  - Plastic reduces soil swelling and moisture absorption, improving long-term stability.
- Cost Analysis
  - Proposed technique works much more efficiently at a lower cost compared to other techniques.
  - Usage of plastic and ash helps in lowering cost of cement and overall project costs.
  - Better durability implies less maintenance and savings over a period of time.

Method	Cost (Lakhs/km)	Remarks
Proposed Method (Cement + Plastic + Ash)	40–45 Lakhs	Material cost ≈ 24 Lakhs, economical & sustainable
Lime Stabilization	25 Lakhs	Not durable for long-term
OPC Cement Stabilization	25 Lakhs	Brittle, environmental concerns
Soil-Bitumen Stabilization	57–60 Lakhs	Expensive
Granular Replacement	123 Lakhs	Very high cost
Geotextile Method	125 Lakhs	Requires skilled labour

3) *Experimental Results*

Table 2: CBR Values of Different Soil Mixes

Sr. No	Soil Condition	CBR Value (%)
1	Untreated Soil	6%
2	Only Plastic	10%
3	Only Cement	20%
4	Cement + Plastic + Rice Husk Ash	43%

Table 3: Unconfined Compressive Strength (UCS)

Sr. No	Soil Condition	UCS (MPa)
1	Untreated Soil	0.052 MPa
2	Only Plastic	0.20 MPa
3	Only Cement	1.36 MPa
4	Cement + Plastic + Rice Husk Ash	3.10 MPa

Table 4: Deflection Test Results

Sr. No	Layer Type	Deflection (mm)
1	Natural Soil	2.1 mm
2	Soil + Cement	1.5 mm
3	Soil + Cement + Plastic	1.0 mm
4	Soil + Cement + Plastic + Rice Husk Ash	0.8 mm

Table 5: Swell Test Results

Sr. No	Soil Condition	Swell (%)
1	Natural Soil	3.6%
2	Soil + Cement	2.1%
3	Soil + Cement + Plastic	1.6%
4	Soil + Cement + Plastic + Ash	1.2%

4) *Limitations*

- Plastic waste requires proper shredding for uniform mixing.
- Excessive plastic can make soil too loose, reducing bonding.
- Field implementation requires proper supervision and compaction control.

V. CONCLUSION

In this case, the research shows that there are improvements in terms of increasing soil strength and sustainability through the integration of these materials. It is clear that the improvement can be noticed from the increase of CBR values from 6% to 43%, while UCS was enhanced to 3.10 MPa from 0.052 MPa. Moreover, deflection and swelling were also decreased significantly.

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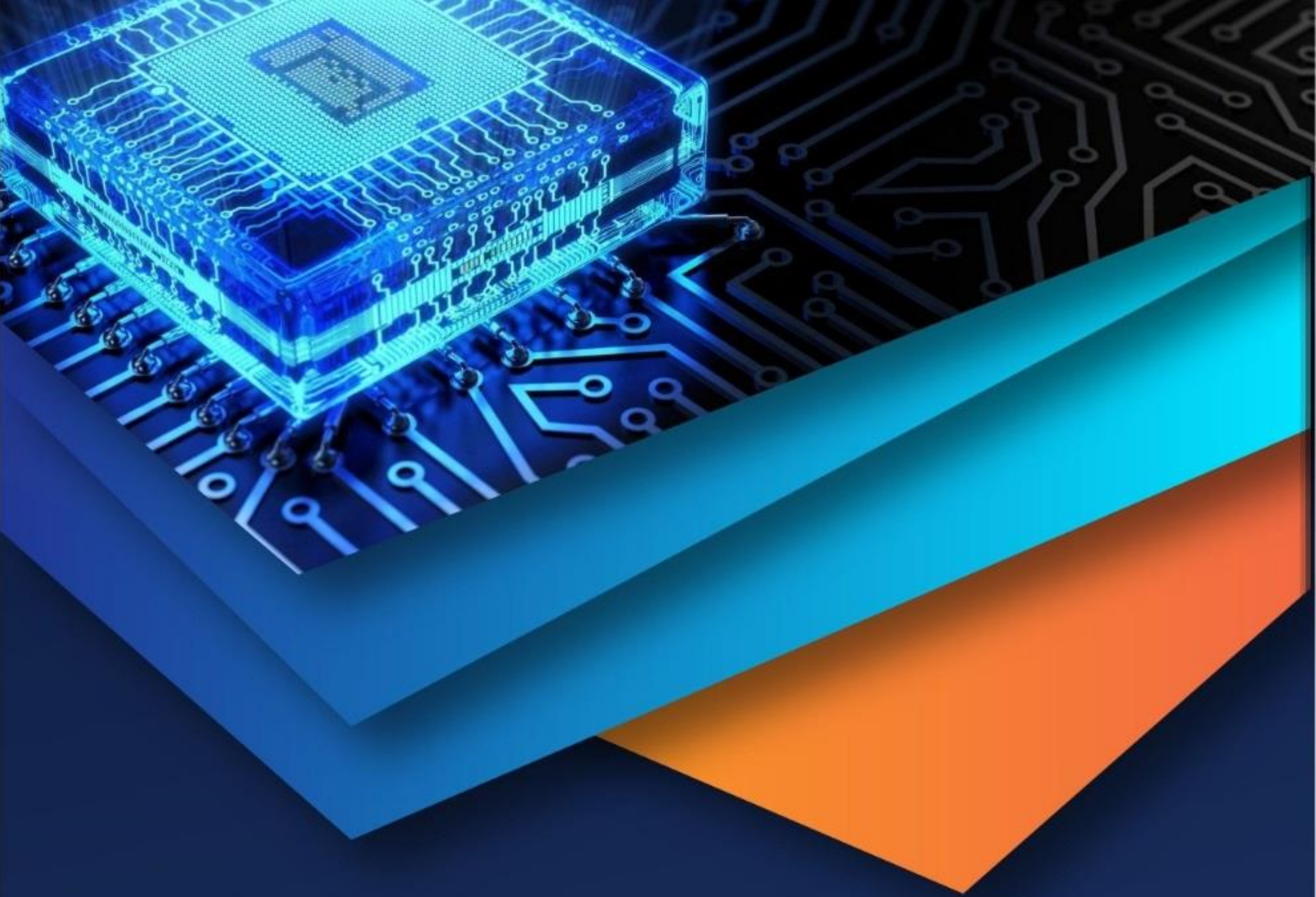

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