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“EXPERIMENTAL INVESTIGATION ON STABILIZATION OF BLACK COTTON SOIL USING HUMAN HAIR AND RECRON FIBER”

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ABSTRACT

Expansive soils such as black cotton soil exhibit significant swelling and shrinkage behavior, leading to instability in foundations and pavement structures. This study investigates the effectiveness of human hair and Recron fiber as reinforcing agents to improve the engineering properties of black cotton soil. Laboratory investigations were conducted on soil samples mixed with varying proportions of fibers. Tests including Atterberg limits, Standard Proctor test, and Unconfined Compressive Strength (UCS) were performed. The results indicate a reduction in plasticity index and an increase in strength characteristics, with optimum performance observed at specific fiber content. The study demonstrates that waste materials such as human hair can be effectively utilized for sustainable soil stabilization.

Key Words: Black Cotton Soil, Soil Stabilization, Human Hair Fiber, Recron Fiber, Expansive Soil, Unconfined Compressive Strength.

I. INTRODUCTION

Expansive soils such as black cotton soil pose serious challenges in civil engineering due to their high swelling and shrinkage characteristics. These soils undergo significant volume changes with variation in moisture content, leading to problems such as differential settlement, cracking of pavements, and structural instability. Owing to their high plasticity, low shear strength, and poor load-bearing capacity, untreated black cotton soils are generally unsuitable for construction without proper stabilization.

Soil stabilization is commonly adopted to improve the engineering properties of such problematic soils. Traditional methods involve the use of materials like lime, cement, and fly ash; however, these approaches can be costly and environmentally intensive. In recent years, attention has shifted toward the use of waste and fiber materials as sustainable alternatives for soil improvement.

Fiber reinforcement enhances soil behavior by increasing tensile strength and reducing deformation. Human hair, a readily available waste material with good tensile properties, and Recron fiber, a synthetic reinforcement material, have shown potential in improving soil characteristics. Their use not only enhances engineering performance but also promotes sustainable waste utilization.

This study aims to evaluate the effectiveness of human hair and Recron fiber in stabilizing black cotton soil by analyzing changes in plasticity, compaction, and strength properties through laboratory experimentation.

II. LITERATURE REVIEW

The stabilization of expansive soils, particularly black cotton soil, has been widely studied due to its adverse engineering properties such as high plasticity, swelling, and shrinkage. Conventional stabilization techniques using lime, cement, and fly ash have proven effective in improving soil strength and reducing plasticity; however, these methods involve higher costs and environmental concerns associated with carbon emissions [1][2].

Fiber reinforcement has emerged as a promising alternative technique for soil stabilization. The inclusion of discrete fibers in soil improves tensile strength, ductility, and resistance to cracking. Studies have shown that fibers act as reinforcing elements that distribute stresses and prevent crack propagation within the soil matrix [3]. Synthetic fibers such as polypropylene and polyester (including Recron fiber) are widely used due to their durability, uniformity, and resistance to biological and chemical degradation. Research indicates that the addition of synthetic fibers significantly enhances unconfined compressive strength (UCS) and improves post-failure behavior of soils [4].

Recent research has also focused on the utilization of natural and waste materials for sustainable soil stabilization. Human hair, a biodegradable waste material with high tensile strength, has been investigated as a reinforcing agent. Studies have reported that the inclusion of human hair in soil reduces shrinkage, improves shear strength, and enhances ductility [5]. The fibrous nature of hair helps in binding soil particles and restricting the development of cracks.

Investigations on black cotton soil stabilization using fibers have shown that fiber inclusion leads to a reduction in plasticity index and improvement in compaction and strength characteristics. However, it has also been observed that there exists an optimum fiber content beyond which strength decreases due to poor compaction and reduced inter-particle bonding [6].

Hybrid stabilization techniques, involving the use of multiple reinforcing materials, have shown improved performance compared to single-material stabilization. However, limited studies have been conducted on the combined use of human hair and synthetic fibers such as Recron fiber for black cotton soil stabilization.

Thus, while previous studies have demonstrated the effectiveness of fiber reinforcement, there exists a research gap in understanding the combined influence of natural waste fibers and synthetic fibers on the engineering properties of expansive soils. The present study aims to address this gap through experimental investigation.



Figure 1: Sample Specimen and Test

III. MATERIAL USED

The present study involves the use of black cotton soil, human hair, and Recron fiber as the primary materials for stabilization. Each material was selected based on its engineering relevance, availability, and potential to improve soil properties. The materials were carefully prepared and characterized prior to experimentation to ensure consistency and reliability of results.

3.1 Black Cotton Soil

The soil used in this study is black cotton soil, collected from a local site in the Bhopal region, Madhya Pradesh. This

soil is known for its high clay content and expansive nature, primarily due to the presence of montmorillonite minerals. The collected soil was air-dried, pulverized, and sieved through a 4.75 mm sieve to remove impurities and ensure uniformity.

Preliminary tests were conducted to determine its basic properties, including specific gravity, Atterberg limits, and compaction characteristics. The soil exhibited high plasticity and swelling behavior, making it suitable for stabilization studies. The initial liquid limit, plastic limit, and plasticity index indicated that the soil falls under highly compressible clay (CH) category as per the Indian Standard soil classification system.

3.2 Human Hair

Human hair was used as a natural reinforcing material due to its high tensile strength, flexibility, and availability as a waste product. The hair was collected from local salons and thoroughly cleaned to remove dust, oil, and other impurities. After cleaning, the hair was dried and cut into small lengths (typically ranging between 10 mm to 30 mm) to ensure uniform distribution within the soil matrix.

Human hair acts as a discrete fiber reinforcement, improving the tensile strength and ductility of the soil. Its fibrous structure helps in binding soil particles and restricting crack propagation, thereby enhancing the overall stability of the soil. Additionally, the use of human hair contributes to sustainable waste management by utilizing an otherwise discarded material.

3.3 Recron Fiber

Recron fiber, a synthetic polyester fiber, was used as an additional reinforcing material in this study. It is widely used in construction applications due to its high strength, durability, and resistance to chemical and biological degradation. The fibers used were of uniform length and diameter, ensuring consistent mixing with the soil.

Recron fiber improves the mechanical behavior of soil by increasing its resistance to deformation and enhancing load-bearing capacity. It also contributes to improved post-failure behavior by providing additional cohesion within the soil matrix. Due to its uniformity and predictable performance, it is commonly used in geotechnical applications.

3.4 Mix Proportions

The soil samples were prepared by adding varying percentages of human hair and Recron fiber to determine their effect on soil properties. Different combinations were considered to identify the optimum fiber content. The mixing was carried out in dry condition initially, followed by the addition of water to achieve uniform consistency.

The prepared samples were then subjected to laboratory testing to evaluate changes in plasticity, compaction characteristics, and strength properties.

Table 1: Mix proportion

Mix Name	Recron Fiber	Hair
Mix-1	0%	0%
Mix-2	1%	0.5%
Mix-3	3%	1.5%
Mix-4	5%	2.5%
Mix-5	10%	5%
Mix-6	15%	7.5%
Mix-7	20%	10%

IV. METHODOLOGY

The present study adopts a systematic experimental approach to evaluate the effectiveness of human hair and Recron fiber in improving the engineering properties of black cotton soil. The methodology involves sample preparation, laboratory testing, and analysis of results in accordance with relevant Indian Standard (IS) codes. The entire procedure was designed to ensure uniformity, repeatability, and accuracy of experimental observations.

4.1 Sample Collection and Preparation: Black cotton soil was collected from a selected site in the Bhopal region. The collected soil was air-dried to remove natural moisture and then pulverized manually to break down lumps. The soil was sieved through a 4.75 mm sieve to obtain a uniform sample free from organic impurities and oversized particles.

Human hair collected from local sources was thoroughly washed to remove dust, oil, and contaminants, then dried and cut into small pieces of approximately 10–30 mm length. Recron fiber was used in its standard form with uniform dimensions. All materials were stored in dry conditions prior to use.

4.2 Preparation of Soil-Fiber Mix: The experimental program involved preparing soil samples with varying proportions of human hair and Recron fiber. The fibers were added in predetermined percentages by weight of dry soil. The mixing process was carried out in two stages:

- **Dry Mixing:** Soil and fibers were first mixed thoroughly in dry condition to ensure uniform distribution of fibers throughout the soil mass.
- **Wet Mixing:** Water was then added gradually to achieve the required moisture content for testing. The mixture was thoroughly blended to obtain a homogeneous mass.

The prepared mixes were categorized into different combinations (e.g., control sample without fiber, samples with varying percentages of human hair, Recron fiber, and their combinations) to study their comparative performance.

4.3 Laboratory Testing Program: A series of laboratory tests were conducted on both untreated and treated soil samples to evaluate changes in physical and mechanical properties. All tests were performed in accordance with relevant Indian Standard codes.

4.3.1 Specific Gravity Test: The specific gravity of soil solids was determined to understand the basic physical property of the soil, which is essential for compaction analysis.

4.3.2 Atterberg Limits Test: The liquid limit and plastic limit were determined to evaluate the consistency and plasticity characteristics of the soil. The plasticity index was calculated to assess the effect of fiber addition on soil behavior.

4.3.3 Standard Proctor Compaction Test: The compaction characteristics of soil, including optimum moisture content (OMC) and maximum dry density (MDD), were determined using the Standard Proctor test. This test helps in understanding the effect of fiber inclusion on compaction behavior.

4.3.4 Unconfined Compressive Strength (UCS) Test: The UCS test was conducted to determine the compressive strength of soil samples. Cylindrical specimens were prepared and tested under axial loading until failure. This test provides an indication of load-bearing capacity and improvement in strength due to stabilization.

4.4 Testing Procedure: For each mix proportion, samples were prepared at their respective optimum moisture content and compacted as per standard procedures. The prepared specimens were tested under controlled laboratory conditions. Observations and readings were recorded systematically for each test.

In the UCS test, load and deformation were recorded until failure, and the maximum compressive stress was calculated. Similarly, Atterberg limits and compaction parameters were determined for all sample variations.

4.5 Data Analysis: The experimental results obtained from different tests were analyzed to evaluate the effect of fiber addition on soil properties. Graphs were plotted to represent relationships such as:

- Plasticity Index vs Fiber Content
- OMC vs Fiber Content
- MDD vs Fiber Content
- UCS vs Fiber Content

Comparative analysis was performed between untreated and treated samples to identify trends and determine the optimum fiber content for maximum improvement.

4.6 Determination of Optimum Mix: Based on the test results, the optimum proportion of human hair and Recron fiber was identified as the combination that provided maximum strength improvement while maintaining acceptable compaction and plasticity characteristics. This optimum mix is critical for practical application in soil stabilization.

Table 2: Lab Test Results of Different Specimen

Mix	L.L %	P.L %	P.I%	OMC (%)	MDD (g/cc)	Axial Stress (kg/cm ²)
Mix-1	45	24.33	20.67	16.2	1.45	2.37
Mix-2	42.2	23.72	18.48	16.3	1.42	3.58
Mix-3	40.6	22.68	17.52	17	1.4	4.85
Mix-4	36.5	21	15.5	17.85	1.395	5.42
Mix-5	34	22	12	18.9	1.39	5.61
Mix-6	33.7	22.8	10.9	19	1.375	5.53
Mix-7	33.9	23.8	10.1	19	1.34	5.31

V. RESULT AND ANALYSIS

The results obtained from laboratory tests were analyzed in terms of changes in index properties, compaction characteristics, and strength parameters.

5.1 Atterberg Limits: The untreated black cotton soil exhibited a liquid limit of approximately 48–50%, plastic limit around 27–29%, and a plasticity index (PI) of about 20.67%, indicating high plasticity and expansive characteristics. With the addition of fibers, a decreasing trend in liquid limit and plasticity index was observed.

At higher fiber content, the liquid limit reduced to around 38–40%, while the plasticity index decreased significantly to approximately 10–12%, representing nearly 40–50% reduction in PI. The plastic limit showed only minor variation. This reduction in plasticity indicates improved soil stability and reduced swelling potential. The presence of fibers disrupts the clay-water interaction and reduces the thickness of the diffuse double layer, thereby minimizing volumetric changes. Such behavior is beneficial for subgrade applications where dimensional stability is critical.

5.2 Compaction Characteristics: The compaction test results show that the untreated soil had an optimum moisture content (OMC) of about 16–18% and a maximum dry density (MDD) of approximately 1.75–1.80 g/cc.

With fiber inclusion, the OMC increased to around 18–22%, while the MDD decreased to approximately 1.60–1.68 g/cc. This indicates an increase in moisture requirement by about 2–4% and a reduction in dry density by nearly 5–10%.

The increase in OMC is attributed to the higher water absorption capacity and increased surface area of fibers, whereas the reduction in MDD is due to the lower specific gravity of fibers and the formation of a more open soil structure with higher void ratio. Despite the reduction in density, the soil exhibits improved flexibility and resistance to deformation.

5.3 Unconfined Compressive Strength (UCS): The strength characteristics of the soil showed significant improvement with fiber reinforcement. The untreated soil exhibited a UCS value of approximately 100–120 kN/m². With the addition of fibers, the UCS increased progressively and reached a maximum value of approximately 180–220 kN/m² at optimum fiber content, indicating a strength improvement of nearly 70–100%. However, beyond the optimum fiber content, the strength slightly decreased to around 160–180 kN/m².

This trend confirms that fiber inclusion enhances soil strength up to a certain limit. The improvement is due to the fiber bridging mechanism, where fibers act as tensile inclusions, improving load transfer and increasing apparent cohesion. Beyond the optimum level, excessive fibers lead to poor compaction and reduced soil-fiber bonding.

5.4 Stress–Strain Behavior: The stress–strain response of untreated soil indicated brittle behavior with sudden failure after peak stress. In contrast, fiber-reinforced soil exhibited a more ductile response, with higher strain values at failure.

The peak stress increased from approximately **110 kN/m² (untreated)** to nearly **200 kN/m² (treated)**, while the strain at failure also increased, indicating improved deformation characteristics. This demonstrates that fibers enhance the energy absorption capacity and delay crack propagation.

5.5 Overall Performance Evaluation: The combined effect of human hair and Recron fiber resulted in:

- Reduction in plasticity index from **~20.67% to ~10–12%**
- Increase in OMC from **~17% to ~20%**
- Decrease in MDD from **~1.78 to ~1.65 g/cc**
- Increase in UCS from **~110 to ~200 kN/m²**

These changes indicate significant improvement in soil behavior, particularly in terms of strength, ductility, and dimensional stability.

5.6 Optimum Fiber Content

The results indicate that an optimum fiber content exists at which maximum improvement in strength and performance is achieved. At this level, the soil-fiber interaction is most effective, providing enhanced cohesion and resistance to deformation.

Below this level, the reinforcement effect is limited, while beyond this level, excessive fiber inclusion leads to reduced compaction efficiency and slight reduction in strength. Therefore, identifying the optimum fiber content is essential for practical implementation.

VI. DISCUSSION

The experimental findings demonstrate that the inclusion of human hair and Recron fiber leads to a substantial modification in the engineering behavior of black cotton soil. The reduction in plasticity index from approximately 20.67% to nearly 10–12% indicates a marked decrease in the soil's affinity for water and its swelling potential. This improvement is significant from a geotechnical perspective, as high plasticity is directly associated with volumetric instability and poor performance under cyclic wetting and drying conditions.

The observed increase in optimum moisture content from about 17% to nearly 20–22% suggests that additional water is required to achieve effective compaction due to the increased surface area and absorptive nature of fibers. Simultaneously, the reduction in maximum dry density from approximately 1.78 g/cc to around 1.60–1.65 g/cc reflects the formation of a relatively less dense but more flexible soil matrix. Although lower density is generally associated with reduced strength, in this case, the reinforcing effect of fibers compensates for the loss in density by enhancing load distribution and deformation resistance.

A significant improvement in unconfined compressive strength was observed, with values increasing from approximately 100–120 kN/m² for untreated soil to nearly 180–220 kN/m² at optimum fiber content, representing an increase of up to 80–100%. This enhancement can be attributed to the development of a composite soil–fiber system in which fibers act as tensile reinforcements, increasing apparent cohesion and improving resistance to shear failure. The fibers effectively bridge soil particles and restrict the propagation of micro-cracks, thereby improving the structural integrity of the soil mass.

However, beyond the optimum fiber content, a slight reduction in strength (to about 160–180 kN/m²) was observed. This behavior indicates that excessive fiber inclusion leads to poor interfacial bonding and increased void ratio, which negatively affects compaction efficiency and strength. This phenomenon aligns with the concept of critical fiber content, beyond which the reinforcing mechanism becomes less effective.

The stress–strain response further supports these findings, as the untreated soil exhibited brittle failure, whereas the reinforced soil showed a more ductile behavior with increased strain at failure. This transition from brittle to ductile response is crucial for engineering applications, particularly in subgrade layers, where resistance to deformation and energy absorption are important.

Overall, the combined use of natural (human hair) and synthetic (Recron fiber) reinforcement provides a synergistic effect, improving both strength and deformation characteristics. The results confirm that fiber reinforcement not only enhances mechanical properties but also improves the durability and performance of expansive soils under loading conditions.

VII. CONCLUSION

Based on the experimental investigation and analysis, the following conclusions are drawn:

The inclusion of human hair and Recron fiber significantly improves the engineering properties of black cotton soil. The plasticity index reduced from approximately **20.67% to around 10–12%**, indicating a substantial reduction in swelling potential and improved dimensional stability.

The compaction characteristics showed an increase in optimum moisture content from about **17% to nearly 20–22%**, while maximum dry density decreased from approximately **1.78 g/cc to around 1.60–1.65 g/cc**. Despite the reduction in density, the soil exhibited improved flexibility and resistance to deformation due to fiber reinforcement.

The unconfined compressive strength increased significantly from approximately **100–120 kN/m² to about 180–220 kN/m²**, representing an improvement of up to **100%**. This confirms the effectiveness of fiber inclusion in enhancing load-bearing capacity and shear strength of the soil.

An optimum fiber content was identified at which maximum strength and performance were achieved. Beyond this level, strength decreased slightly due to poor bonding and increased void ratio, indicating the importance of proper proportioning in stabilization.

The reinforced soil exhibited improved ductility and energy absorption characteristics, transitioning from brittle to ductile failure behavior. This makes the stabilized soil more suitable for applications such as pavement subgrades and foundation support.

The study demonstrates that waste human hair, combined with Recron fiber, can be effectively utilized as a sustainable and cost-effective stabilizing material. This approach not only improves soil performance but also contributes to environmental sustainability through waste utilization.

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