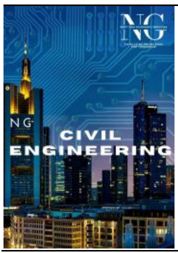

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Reinforcing Soil Stability Through Human Hair Application

Chinmaya Chidananda Sahu[1] and Shradhanjalee Pradhan[2]*

[1] Government College of Engineering Keonjhar, Odisha, 758002, India
[2] Veer Surendra Sai University of Technology, Burla, 768018, India

*Corresponding author email ID: shradhanjaleephdce21@vssut.ac.in

HIGHLIGHTS

- Human hair fibers (HHF) offer an eco-friendly approach to soil stabilization by improving shear strength and bearing capacity.
- Studies show that incorporating HHF into soil can significantly enhance its load-bearing capabilities, potentially replacing costly commercial fibers.
- This method also provides a sustainable solution for non-biodegradable hair waste.

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ABSTRACT

Soil stabilization is an extremely important process in civil engineering that helps improve the properties of soil so that it can be used in Construction or other works. The application of human hair fibers (HHF) as a soil stabilization reinforcement material offers a novel and environmental-friendly method. Not only this method enhances the engineering characteristics of soil like shear strength and bearing capacity but also offers a permanent solution for the dumping of non-biodegradable human hair waste. Some studies conducted recently have revealed that the soil's load-bearing capacities can be enhanced considerably by integrating HHF into the samples of the soil. The process entails mixing human hair fibres in the soil of differing percentages and conducting the standard laboratory tests to obtain the best mix ratio that produces the best mechanical properties. The findings establish that HHF could be an alternative for commercial fiber materials and this is a cost-effective approach and environmentally important for stabilizing the soil.

1. INTRODUCTION

In civil engineering, soil stabilization is a crucial process where soil properties are modified and enhanced to improve its strength, durability, or load-bearing capacity (Firoozi et al., 2017). Chemical stabilizers like lime and cement are commonly used to strengthen the soils through more traditional methods (Amhadi & Assaf, 2018). Assess the functionality of human hair fibers to enhance the physical properties such as strength, stability, and load-bearing capacity of soil (Abdel-Rahman, 2020; Butt et al., 2016). Knowing how human hair fibers influence soil

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properties such as reinforcement, interlocking, and moisture retention. Know how human hair fibers will be efficient compared to a well-established and more expensive civil engineering practice for soil stabilization (lime, cement), costs of application, including environmental consequences, and long-lasting efficiency. The ecological and economic benefits of using human hair fibers: a) exploitation of recycled waste material b) cost savings c) less dependency on chemical stabilizers (Ghani et al., 2022).

Swelling clay, heave soil, and expansive soil can be called by many names. It is the soil that undergoes much volume change when it changes in moisture content. Where the breakdown of the igneous rocks occurs in extreme weather conditions seasonally, under expansive soils. In India, these soils usually develop due to weathering action on basalt rocks. Other than basaltic rocks, deposits have been obtained from many other types, such as extremely old sedimentary deposits. These minerals found in the clay fraction are montmorillonite and a mixture of montmorillonite and illite.

Figure 1: Improvement of a soil property of the existing soil.

1.1. Human Hair as a Stabilizing Material

Properties of Human Hair o Composition and structural characteristics. Human hair possesses high tensile strength. It is highly flexible and interlocked with soil particles, easily developing soil cohesion and reducing erosion. The biodegradability of human hair is slow, so it can provide long-term stability to soil. Human hair fibers have water-retention capacity, which helps lessen the swell-shrink behavior of the soil. Human hair is a cost-effective product and it is available easily. provides thermal insulation also. Human hair's chemical structure is unique. Composed primarily of keratin. Nitrogen-Rich Material: Nitrogen is important in the process of decomposing organic substances present in human hair since hair is nutritional for human beings and therefore must be a nutrient also for the soil. When hair is incorporated into the soil, it acts as an important nitrogen provider component for microbial use. Microbial Breakdown: Organisms in the soil cutters break the hair into several small portions through the activities of bacteria and fungi. They have enzymes that secrete onto the hair fibers and feed on the keratin protein, which is in the form of amino acids. Timeframe: The decomposition rate is not constant because the conditions it goes through, such as the soil type, temperature, and moisture, vary. All in all, hair does not decompose as fast to decompose as the rest of the organic matter (Zafar et al., 2023). Environmental Impact: Reducing Waste: Applying human hair in the management of soil stabilization is one of the unique and creative ways of dealing with waste. Hair does not decompose like food waste, paper, or plastic, and therefore we must find ways of turning hair into other valuable products.

Minimizing Land Use: The disposal of solid waste (including hair) occupies a large area of land to collect it in layers. Incorporation of hair into the stabilization of soil saves on the use of landfills, further helping limit environmental degradation (Bheel et al., 2024).

Eco-Friendly Alternative: The Clayey soil can be reinforced cheaply and effectively by applying human hair fibers. This approach also reduces the cost implication for hair disposal and the negative effect this poses on the environment.

Practical Considerations: Shear Strength and Bearing Capacity: Human hair fibers positively affect the mechanical properties of soil, improving their shear strength and bearing (Gowthaman et al., 2018).

2. LITERATURE REVIEW

The current trend in treating soil for improvement of its engineering properties is that of stabilization by use of different additives, particularly through using industrial wastes in projects, creating a high scope for the best use of abundantly available industrial waste at a very low cost. "Stabilization" will, therefore, not only increase strength and durability but also help in the effective prevention of soil erosion in the controlled media. However, it has been found that in actual practice, there is so much diversity within the structural components of the soil that site-specific treatment options need to be validated through soil stabilizer mixing tests.

Soil stabilization is a critical aspect of geotechnical engineering, particularly in regions prone to erosion, landslides, and poor load-bearing capacity. Traditional stabilizers such as cement, lime, and geosynthetics have been widely used; however, the increasing emphasis on sustainability and environmental compatibility has led researchers to explore alternative, biodegradable, and cost-effective materials. Among these, human hair, a natural waste material rich in keratin protein, has shown potential as a reinforcing agent in soil.

Human hair fibers possess tensile strength, elasticity, and a non-biodegradable nature in soil environments, making them suitable for soil reinforcement applications. Several studies have demonstrated the improvement of soil properties such as shear strength, cohesion, and compaction behaviour with the inclusion of human hair. For example, Jain (2024) reported that adding human hair to black cotton soil significantly enhanced its unconfined compressive strength and CBR values. Similarly, Narayanan and Sharmila (2017) observed increased shear strength in clayey soils mixed with varying percentages of human hair, attributing this to the fiber-soil interlocking mechanism.

The mode of reinforcement by hair fibers can be likened to the principles of fiber-reinforced soil, where randomly distributed discrete fibers act as tension-resistant inclusions within the soil matrix. Studies by Bheel et al. (2024) showed that fiber length and dosage are critical parameters influencing the extent of improvement, with optimal results observed at 1.5–2% hair content by dry weight of soil.

Furthermore, the use of human hair aligns with sustainable construction practices. As hair is abundantly available as salon waste, its utilization in geotechnical applications also addresses solid waste management challenges. However, the variability in fiber dimensions, biodegradability over extended periods, and potential health concerns during handling necessitate standardized treatment and testing protocols before large-scale adoption.

3. MATERIALS AND METHODS

3.1 Sample Collection: SOIL:

The soil that is being discussed in the present study was collected from an area called Humma, located in the Sambalpur district of the state of Odisha, India. The stored soil sample is identified from the reservoir bed and is attributed to high plasticity clay soil (CH) having considerable amounts of silt. The detailed properties of soil can be found in Chapter 4, Table 4.1. Thereafter, the soil is prepared for laboratory tests. The ground soil was then air-dried or oven-dried. The clods were broken by a wooden mallet and pulverised. The sieving was done through a 4.75 mm sieve, after which tests were carried out. The site of the collected soil sample and the oven-dried soil sample are shown in Figure 2.

Figures 2: Soil sample

3.2 Tests Performed on Soil

To evaluate the engineering properties of expansive soil, a series of standardized laboratory tests were conducted. These tests help determine various physical characteristics of the soil that are essential for geotechnical analysis and the design of civil engineering structures.

3.2 Specific Gravity Test (Density Bottle Method)

The specific gravity of soil was determined using the density bottle method, a widely adopted procedure for fine-grained soils. The test begins by oven-drying the soil to a constant weight. A clean, dry density bottle is first weighed empty. Then, a known quantity of the dried soil is added, and the bottle is weighed again. Distilled water is added to the bottle containing the soil, and care is taken to eliminate all air bubbles. The bottle is then filled to the calibration mark, and the final weight is recorded. As a reference, the bottle is also filled with only distilled water and weighed. Using these recorded weights, the specific gravity is calculated, which provides critical insight into the soil's mineral composition and is essential for further soil classification and strength analysis.

Figure 3: Determination of specific gravity using a density bottle.

3.3 Sieve Analysis of Expansive Soil

Sieve analysis, as per IS:2720 (Part 4) – 1980, was conducted to determine the particle size distribution of the soil. The oven-dried sample was first passed through a 4.75 mm IS sieve to separate coarse particles. The finer portion was washed through a 75 µm sieve to remove silt and clay particles, continuing until the passing water ran clear. The retained material was then oven-dried. The dried soil was subjected to a stack of sieves arranged in descending mesh sizes (2.36 mm to 75 µm), mounted on a sieve shaker. After shaking, the amount of soil retained on each sieve was weighed. From this, the percentage retained and percentage passing for each sieve were calculated, enabling the development of a grain size distribution curve, essential for soil classification and construction suitability.

3.4 Consistency of Soil

Liquid Limit Test

Liquid limit test determines soil moisture at which soil changes its state from plastic to liquid. Using Casagrande apparatus, a soil paste is put in the brass cup and a groove is cut through it using the conventional grooving tool. The cup is then dropped several times from 10 mm at a rate of two drops per second. The number of strokes needed to close 12 mm of length of the groove is noted. This process is repeated for multiple moisture contents to develop a flow curve. The moisture content corresponding to 25 blows is interpolated and recorded as the liquid limit, which is vital for classifying soil and predicting its behavior under varying moisture conditions.

Plastic Limit Test

The plastic limit defines the moisture content at which soil changes from a plastic to a semi-solid state. In this test, air-dried soil is mixed with water to a workable consistency. A small portion is rolled into threads on a glass plate until it begins to crumble at a diameter of approximately 3 mm. The crumbled threads are collected, and their moisture content is determined. This value is recorded as the plastic limit. Together with the liquid limit, it helps compute the plasticity index and gives insight into the soil's consistency range.

3.5 Free Swell Index (FSI) Test

The Free swell index test is used for determining the swelling ability of expansive soils. There is the use of two identical 10-gram samples of soil that go into separate 100 ml graduated cylinders, one filled with distilled water and the other with kerosene that lack air bubbles/ The samples are left for 24 hours so as to enable swelling. The last volumes are written for each sample. The FSI is obtained by utilizing the formula:

$$FSI=Vw-Vk/\ Vk *100 \qquad (1)$$

where Vw is the final volume of soil in water and Vk is the final volume of soil in kerosene. This test helps assess the swelling characteristics of soils, which is crucial for understanding their behavior and suitability for construction projects.

3.6 Modified Proctor Compaction Test

The Modified Proctor Compaction Test, Modified Compaction Test is carried out so as to obtain the best moisture content (OMC) and maximum dry density (MDD). A representative soil sample is compacted in a standard mould in five layers, each layer receiving 25 blows from a 4.54 kg rammer dropped from a height of 457.2 mm. The bulk density is calculated from the weight of the mould and its compacted contents. This procedure is repeated at various moisture contents to develop a compaction curve. The peak of the curve represents the OMC, at which the MDD is achieved. This test provides vital data for designing embankments, pavements, and foundations by ensuring adequate compaction and load-bearing capacity.

4. RESULT AND DISCUSSION

The outcomes of a set of cohesiveness test, free swell index test, compaction tests, and specific gravity tests carried out on soil devoid of additives have been presented in this chapter in the form of tables and figures.The properties of soils are studied thoroughly and discussed elaborately, citing the results published in the literature.

4.1 Properties and Characteristics of Expansive Soil:

Specific gravity: By conducting the specific gravity test was conducted on the soil sample was found to be 2.67. The specific gravity of a high plasticity soil typically ranges from 2.65 to 2.80.

Table 1: Determination of Specific Gravity

Sl.No.	Wt. of Container(gm) M1	Wt. of Container+Soil(gm) M2	Wt. of Container +Soil+Water (gm)M3	Wt. of Water+ Container (gm) M4	The specific gravity of soil
1	37.63	47.67	96.79	90.51	2.66
2	32.65	42.66	92.67	86.39	

Consistency Characteristics:

Expansive soils significantly impact the consistency characteristics of soils, as indicated by a liquid limit of 54.108 %. A liquid limit of over 50% suggests the soil is highly plastic and contains a substantial amount of clay, allowing it to retain a large quantity of water. These high-liquid-limit soils tend to experience significant swelling and shrinkage, necessitating specialized construction methods to ensure foundation stability and structural integrity.

According to the Unified Soil Classification System (USCS), soils exhibiting a liquid limit above 50% and a high plasticity index are categorized as CH, or high plasticity clays, reflecting their significant clay content and associated engineering challenges.

Table 2: Liquid Limit Test

No of blows	Moisture content
21	90.84
27	87.83
32	86.03
35	84.44

The liquid limit (LL) is the moisture content at 25 drops. Therefore, Liquid Limit (LL) = 88.83

Table 3: Plasticity Index

Tin No	Wt of Tin (gm)	Wt. of Tin +Wet Soil(gm)	Wt. of Tin+ Oven dry soil (gm)	Wt. of Water (gm)	Wt of wet soil	Wt. of oven-dry soil(gm)	Water Content
21.9	25.95	41.98	37.52	4.46	16.03	11.57	38.54

A plasticity index (PI) of 38.54% indicates that the soil exhibits a high level of plasticity, meaning it can deform significantly before showing signs of cracking or failure. Here's what this implies:

PI=Liquid Limit (LL)−Plastic Limit (PL)

PI=88.83−38.54=50.29

Flow index (IF) = w1−w2/log(N2)−log(N1)

$$IF = \frac{\mathbf{90.84-84.44}}{\mathbf{\log(35)-\log(21)}} = \mathbf{28.83}$$

Toughness Index (TI) = PI/IF

TI = 50.29/28.83=1.74

Table 4: Plasticity Index

Modified Proctor Test:

Sl. No	Moisture Tin no.	Empty Wt. of Tin (gm)	Wt. of tin+ wet soil (gm)	Wt. of Tin with dry soil (gm)	Wt. of wet soil (gm)	Wt. of dry soil (gm)	Moisture Content	Average Moisture Content
1	1	34.18	80.9	73.89	45.84	39.71	13.43	24.71
2	14	40	106.84	95.7	66.8	55.7	19.87	
3	11	39.9	99.12	87.2	59.1	47.3	25.03	
4	3	26	123.18	102	99.1	76.6	29.37	
5	5	26.3	146.2	115	119	89.5	33.87	

Table 5: Dry density of soil sample

Sl. No.	Vol of mould	Empty weight of mould	Weight of mould with soil	Work unit wt.	Moisture content	Dry density
1	965.55	1987	3582	1.65	13.43	1.43
2	965.55	1987	3721	1.79	19.87	1.49
3	965.55	1987	3911	1.99	25.03	1.59
4	965.55	1987	3872	1.95	29.37	1.51
5	965.55	1987	3773	1.85	33.87	1.38

The Modified Proctor Test graph shows that the soil achieves its highest compaction level at an optimal moisture content of 24.714%, with a maximum dry density of 1.59 g/cm³. This indicates that, for construction purposes, the soil should be compacted at this specific moisture content to achieve the best possible dry density. Ensuring proper compaction at this moisture level is essential for maintaining the soil's stability and strength, which are vital for the foundation and overall structural integrity of engineering projects. FSI value is 75%, the soil exhibits a moderate swelling potential.

Table 6: Sieve analysis

Sl. No.	Sieve size (in mm)	Weight of empty sieve (in g)	Cumulative retained	% passing
1	4.75	335	0	100
2	2.36	335	11.11	88.89
3	1.18	310	24.99	75.01
4	0.6	304	36.1	63.9
5	0.3	297	41.66	58.34
6	0.15	264	44.44	55.56
7	0.075	267	47.22	52.78
8	Pan	247	100	-

5. CONCLUSION

the incorporation of human hair fibers (HHF) in soil stabilization offers a promising and sustainable alternative to conventional methods. This eco-friendly technique not only enhances key geotechnical properties—such as shear strength, cohesion, and bearing capacity—but also addresses the environmental concern of human hair waste disposal. Experimental findings support the effectiveness of HHF in reinforcing soil, with optimal fiber content leading to significant improvements in load-bearing capacity. As a low-cost, readily available, and non-toxic material, human hair fibers have the potential to revolutionize sustainable construction practices, especially in regions with limited access to expensive stabilization materials. Further research and field-scale applications could help standardize the use of HHF in geotechnical engineering and expand its practical implementation in infrastructure development.

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REFERENCES

Abdel-Rahman, M. M. (2020). Review of soil improvement techniques. In *Advancements in Geotechnical Engineering: The official 2020 publications of the Soil-Structure Interaction Group in Egypt (SSIGE)* (pp. 175-199). Springer.

Amhadi, T. S., & Assaf, G. J. (2018). Overview of soil stabilization methods in road construction. International Congress and Exhibition" Sustainable Civil Infrastructures: Innovative Infrastructure Geotechnology",

Bheel, N., Shams, M. A., Sohu, S., Buller, A. S., Najeh, T., Ismail, F. I., & Benjeddou, O. (2024). A comprehensive study on the impact of human hair fiber and millet husk ash on concrete properties: response surface modeling and optimization. *Scientific reports*, *14*(1), 13569.

Butt, W. A., Mir, B., & Jha, J. (2016). Strength behavior of clayey soil reinforced with human hair as a natural fiber. *Geotechnical and Geological Engineering*, *34*, 411-417.

Firoozi, A. A., Guney Olgun, C., Firoozi, A. A., & Baghini, M. S. (2017). Fundamentals of soil stabilization. *International Journal of Geo-Engineering*, *8*, 1-16.

Ghani, S., Kumari, S., Choudhary, A., & Chatterjee, A. (2022). Geotechnical characterization of human hair fiber in strength enhancement for clayey soil of South Bihar. *Sādhanā*, *47*(3), 176.

Gowthaman, S., Nakashima, K., & Kawasaki, S. (2018). A state-of-the-art review on soil reinforcement technology using natural plant fiber materials: Past findings, present trends and future directions. *Materials*, *11*(4), 553.

Jain, P. K. (2024). Enhancing the properties of swelling soils with lime, fly ash, and expanded polystyrene-A review. *Heliyon*, *10*(12).

Narayanan, K. S., & Sharmila, S. M. R. (2017). Stabilization of clay with human hair fiber. *International Journal of Civil Engineering and Technology (IJCIET)*, *8*(4), 664-668.

Zafar, T., Ansari, M. A., & Husain, A. (2023). Soil stabilization by reinforcing natural and synthetic fibers–A state of the art review. *Materials Today: Proceedings*.