Soil Stabilization Using Natural Fibre (Luffa)

Prof. V. T. Patil Vikas S. Gaykwad, Premkant P. Giradkar, Akash S. Parghane, Vedant D. Mule, Mahesh D. Padkonde.

HOD, Department of Civil Engineering, Government College of Engineering Jalgaon Maharashtra, India.

Students, Department of Civil Engineering, Government College of Engineering, Jalgaon, Maharashtra, India.

Abstract—**Soil stabilization is an important technique in geotechnical engineering used to improve the engineering properties of weak soils for construction purposes. In many construction sites, the natural soil available does not possess sufficient strength or stability to support foundations, pavements, or embankments. Traditional stabilization methods involve the use of cement, lime, and chemical additives, which increase construction cost and may cause environmental impacts. Therefore, the use of natural fibres has emerged as a sustainable and eco-friendly alternative for soil reinforcement. This research investigates the use of natural luffa fibre as a reinforcement material to improve the engineering properties of soil. Luffa fibre, obtained from the dried fruit of Luffa cylindrica, is lightweight, biodegradable, and possesses a fibrous structure that can interlock with soil particles. Laboratory tests such as moisture content determination, specific gravity test, particle size distribution, and compaction tests were carried out on untreated and fibre- reinforced soil samples. The results show that the addition of luffa fibres improves soil stability, increases load-bearing capacity, and reduces soil deformation. The study demonstrates that luffa fibre can be used as an environmentally friendly and cost-effective soil stabilization material for applications such as road subgrades and foundation soils.**

I. INTRODUCTION

1.1 Background and History

Soil is one of the most important natural materials used in construction. It acts as the foundation for roads, buildings, dams, and other infrastructure. However, not all soils possess the required engineering properties for construction. Weak soils often exhibit low bearing capacity, high compressibility, and sensitivity to moisture changes, which can lead to structural instability and settlement problems. To overcome these problems, engineers have used various soil stabilization techniques for many decades. Traditionally, materials such as cement, lime, and bitumen were used to improve soil strength and durability. While these methods are effective, they are often expensive and may have negative environmental effects due to high carbon emissions. In recent years, sustainable construction practices have encouraged the use of natural materials for soil stabilization. Natural fibres obtained from plants such as jute, coir, bamboo, and sisal have been widely studied for their ability to reinforce soil and improve its mechanical properties. Among these natural materials, luffa fibre has gained attention due to its fibrous structure and natural roughness, which allows strong interlocking with soil particles.The fibre acts as a reinforcement within the soil matrix, improving strength and resistance to deformation.

1.2 Definitions and Key Terms Soil Stabilization

Soil stabilization refers to the process of improving the physical and engineering properties of soil to increase its strength, durability, and load-bearing capacity.

Natural Fibre Reinforcement

Natural fibre reinforcement involves mixing biodegradable fibres into soil to enhance soil strength and reduce cracking or deformation.

Luffa Fibre

Luffa fibre is a natural fibrous material obtained from the dried fruit of Luffa cylindrica. It consists of a network of cellulose fibres that provide tensile strength and flexibility.

Compaction

Compaction is the process of increasing soil density by reducing air voids through mechanical means.

CBR (California Bearing Ratio)

CBR is a test used to evaluate the load-bearing capacity of soil, especially for pavement design.

Existing Evidence

Several researchers have investigated the use of natural fibres for soil stabilization. Studies have shown that natural fibres improve the shear strength, compressive strength, and bearing capacity of soil. For example, research on jute and coir fibres has demonstrated significant improvement in soil strength when fibres are mixed with clay soils. Similarly, studies using bamboo and vetiver fibres have shown increased cohesion and reduced soil permeability. Experimental investigations have also shown that natural fibres act as reinforcement within the soil mass by creating a three- dimensional interlocking network that distributes stresses and prevents soil cracking. Although many natural fibres have been studied, limited research is available on the use of luffa fibre for soil stabilization, which highlights the importance of conducting further experimental studies.

1.3 Objectives of the Study

To study the basic engineering properties of soil used in the experiment.

To investigate the effect of adding natural luffa fibres on soil properties.

To determine the optimum percentage of luffa fibre required for maximum improvement in soil strength.

To evaluate the compaction characteristics of fibre-reinforced soil. To compare the performance of untreated soil and luffa fibre-stabilized soil.

To examine the suitability of luffa fibre for use in geotechnical engineering applications.

1.4 Research Gap

Although many studies have been conducted on natural fibre reinforced soil, thereare still several areas that require further investigation. Most existing research focuses on fibres such as jute, coir, sisal, and bamboo, while limited work has been done on luffa fibre stabilization. Additionally, the long-term durability of natural fibres in soil environments is not fully understood. Another important gap in research is the degradation behavior of natural fibres under environmental conditions, including moisture variation and chemical exposure. Understanding how luffa fibres degrade over time is essential for evaluating their long-term effectiveness in soil stabilization. Therefore, this study aims to address these gaps by investigating the performance and durability of soil reinforced with natural luffa fibres.

1.5 Scope

Studying the basic properties of soil through laboratory tests. Investigating the effect of adding different percentage of luffa fibre in soil for evaluating strength and compaction characteristics. Comparing untreated soil with fibre-reinforced soil. Evaluating the potential use of luffa fibre in geotechnical engineering applications such as road construction and foundation improvement.

1.6 Constraints

The research is limited to laboratory-scale experiments. Only a specific type of soil is used in the study. Environmental conditions such as rainfall, temperature variation, and long-term field performance are not considered. Fibre durability over very long periods requires further investigation.

II. MATERIALS AND METHODS

2.1 Materials Used in the Experiment

2.1.1 Soil Sample

The soil used in this study was collected from a selected location and brought to the laboratory for testing. The soil was air-dried, pulverized, and sieved to remove large particles and organic matter. Basic soil properties were determined through standard laboratory tests.

2.1.2 Luffa Fibre

Luffa fibre was obtained from matured luffa fruits. The fibres were cleaned, dried, and cut into uniform lengths before mixing with soil. The fibre acts as a reinforcement element within the soil matrix and improves tensile resistance.

2.1.3 Water

Clean water was used during the preparation of soil samples and for conducting compaction tests.

2.2 Mix Proportions

To analyze the effect of fibre reinforcement, soil samples were prepared with different percentages of luffa fibre by weight of dry soil

Sample.	Fibre Content
S1.	0%
S2.	0.5%
S3.	1%
S4.	1.5%

Each mixture was thoroughly blended to ensure uniform distribution of fibre in the soil.

2.3 Experimental Procedure (Step-by-Step)

Step 1: Soil Collection

Soil samples were collected from the selected site and transported to the laboratory in sealed bags to prevent moisture loss.

Step 2: Soil Preparation

The collected soil was air-dried and passed through a sieve to remove gravel and impurities.

Step 3: Fibre Preparation

Luffa fibres were washed to remove dust and organic matter, dried in sunlight, and cut into small uniform pieces.

Step 4: Mixing of Soil and Fibre

The prepared fibres were mixed with soil in predetermined proportions (0.5%, 1% and 1.5%).

Step 5: Sample Preparation

Water was added gradually to achieve the required moisture content, and the mixture was thoroughly blended.

Step 6: Laboratory Testing

The following tests were conducted on the soil samples: Moisture Content Test

Specific Gravity Test Atterberg Limits Test

Standard Proctor Compaction Test Strength behaviour observation Step 7: Data Recording

The results obtained from each test were recorded carefully for analysis and comparison.

III. RESULT AND DISCUSSION

This result and discussion section represents collected data analysis and work to be conducted. This research purpose is to compare soil physical and mechanical properties with different luffa fibre percentage and increase the strength and stability of soil. All observation data can see in table and graph.

Water Content Test

The water content (w) of bare soil sample is defined as mass of water present in the voids divided by mass of soil solids. The natural water content of the soil gives the details about the how much water present in the soils.

Moisture content of bare soil sample by using oven drying method is 14.40 %.

Specific Gravity Test

Specific gravity of the soil is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of water at stated temperature. Equipment required for the evaluate Specific gravity are Pycnometer of about 1liter capacity, balance accurate to 1g, glass rod, de-aired distilled water.

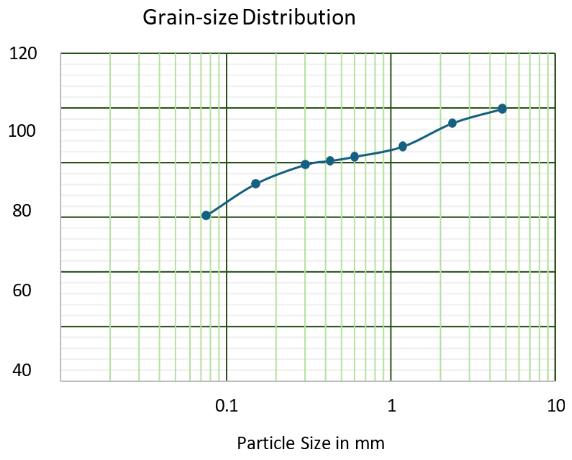
By using Pycnometer Bottle the specific gravity of soil sample is 2.26.

Particle Size Distribution

This test helps to found out the percentage of different grain sizes contained within soil. The mechanical or sieve analysis determines the distribution of coarse-grained soil and helps classify soil as gravel, sand, silt or clay. Sieves used: 4.75 mm, 2.0 mm, 1.0 mm, 600 µm, 300 µm, 150 µm, and 75 µm (IS 460-1962).

Sieve Size (mm)	Wt. Retained (gm)	% Wt. Retained	Cumulative % Retained	% Finer
4.75	0.39	0.13	0.13	99.87
2.36	15.79	5.26	5.39	94.61
1.18	25.66	8.55	13.95	86.05
0.60	11.29	3.76	17.71	82.29
0.425	4.63	1.54	19.25	80.75
0.30	4.25	1.42	20.67	79.33
0.15	20.88	6.96	27.63	72.37
0.075	34.89	11.63	39.26	60.74
Pan	0	—	—	—
Total	117.78	—	—	—

Table no.1 :- Dry Sieve Analysis



The particle size distribution analysis test Evaluate data of the soil, which is contained the 0.13% gravel, showing a negligible coarse fraction. The sand content is about 39.13%, representing a moderate proportion of coarse particles. A significant portion of the soil, 60.74%, consists of fine particles passing the 0.075 mm sieve. This high percentage of fines indicates that the soil is predominantly fine-grained.

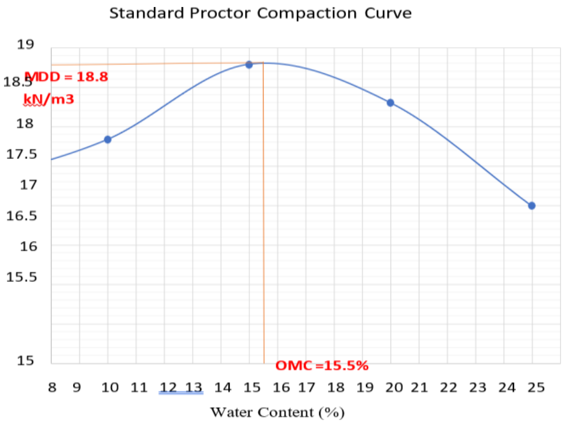
Compaction Test (Standard Proctor Test)

The compaction test determines the relationship between moisture content and dry density of soil under compression effort. With this test we calculate the optimum moisture content (OMC) corresponds to the maximum dry density (MDD). Test procedure: - soil filled in mould in 3 equal layers; 25 blows per layer from 2.6 kg rammer dropping from 310mm height (light compaction).

1. Bare soil sample test result

Sr no.	Mass of empty Mould (g)	Mass of Mould +soil (g)	Mass of soil (g)	Bulk Density (g/cc)	Water Content (%)	Dry Density (g/cc)	Dry Density (kN/m3)
1	3461	5290	1829	1.848219636	5	1.760209177	17.26765203
2	3461	5440	1979	1.999795877	10	1.817996252	17.83454323
3	3461	5640	2179	2.201897532	15	1.914693506	18.7831433
4	3461	5676	2215	2.23827583	20	1.865229859	18.29790491
5	3461	5604	2143	2.165519235	25	1.732415388	16.99499495

Table No.2 :-bare soil sample

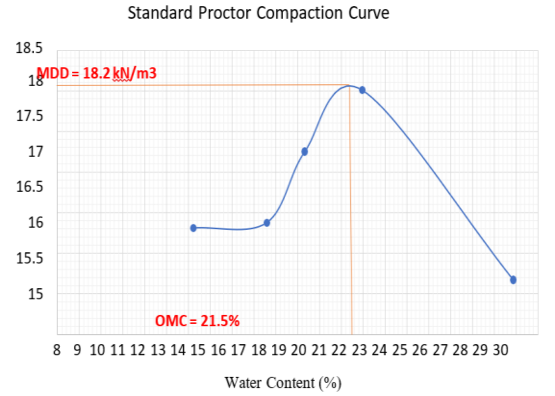


The result after performing the compaction test on bare soil the optimum moisture content (OMC) value is 15.5% and maximum dry density (MDD) value is 18.8 KN/m3.

2. Bare soil sample + 0.5 % luffa fibre test result

Sr.no.	Mass of empty mould (g)	Mass of mould + soil (g)	Mass of soil(g)	Bulk density (g/cc)	Water content (%)	Dry density (g/cc)	Dry density (kn/m3)
1	3461	5340	1879	1.89874505	14.236	1.662124943	16.30544569
2	3461	5403	1942	1.962407071	17.597	1.668756066	16.37049701
3	3461	5537	2076	2.09781518	19.34	1.757847478	17.24448376
4	3461	5676	2215	2.23827583	21.965	1.835178806	18.00310408
5	3461	5498	2037	2.058405357	28.89	1.597024872	15.66681399

Table no.3:- Bare soil sample + 0.5 % luffa fibre

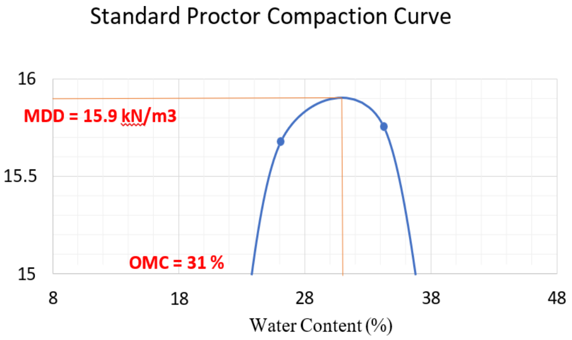


The result after performing the compaction test on bare soil with mixing of 0.5% of luffa fibre the optimum moisture content (OMC) value is 21.5% and maximum dry density (MDD) value is 18.2 KN/m3.

3. Bare soil sample + 1.0 % luffa fibre test result

Sr.no.	Mass of empty mould (g)	Mass of mould + soil (g)	Mass of soil(g)	Bulk density (g/cc)	Water content (%)	Dry density (g/cc)	Dry density (kn/m3)
1	3461	5190	1729	1.747168808	21.87	1.433633223	14.06394191
2	3461	5455	1994	2.014953501	26.08	1.598154744	15.67789804
3	3461	5595	2134	2.15642466	34.28	1.605916488	15.75404075
4	3461	5410	1949	1.969480629	39.13	1.415568626	13.88672822
5	3461	5370	1909	1.929060298	41.37	1.364547144	13.38620749

Table no.4:- Bare soil sample + 1.0 % luffa fibre

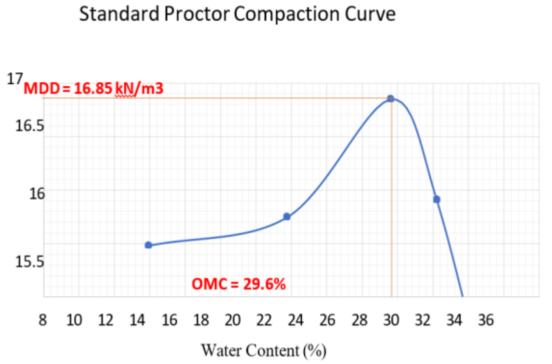


The result after performing the compaction test on bare soil with mixing 1.0 % of luffa fibre the optimum moisture content (OMC) value is 31% and maximum dry density (MDD) value is 18.355 KN/m3.

4. Bare soil sample + 1.5 % luffa fibre test result

Sr no.	Mass of empty mould (g)	Mass of mould +soil (g)	Mass of soil (g)	Bulk density (g/cc)	Water Content (%)	Dry density (g/cc)	Dry density (kn /m3)
1.	3461	5240	1779	1.797694222	13.94	1.577755154	15.47777806
2.	3461	5395	1934	1.954323005	21.76	1.605061601	15.7456543
3.	3461	5630	2169	2.19179245	27.62	1.717436491	16.84805198
4.	3461	5550	2089	2.110951788	30.19	1.621439272	15.90631925
5.	3461	5285	1824	1.843167095	33.85	1.377039294	13.50875547

Table no.5:- Bare soil sample + 1.5 % luffa fibre



The result after performing the compaction test on bare soil with mixing 1.0 % of luffa fibre the optimum moisture content (OMC) value is 29.6% and maximum dry density (MDD) value is 16.85 KN/m3.

Plastic Limit Test

The plastic limit is the minimum water content at which the soil can be rolled into a thread of 3 mm diameter without crumbling. Procedure: Take about 20 g of air-dried soil, add water to prepare a plastic mass, roll into a thread on a glass plate, and determine moisture content when the thread starts cracking at 3 mm diameter.

Fibre content	Mass of empty container (gm)	Mass of container +wet soil (gm)	Mass of container + dry soil (gm)	Water content (%)	Plastic Limit (Wp) %
Bare soil	31.36	56.00	49.84	22.83	22.83
Bare soil +0.5% fibre	28.45	47.07	43.58	23.09	23.09
Bare soil +1.0% fibre	27.73	49.59	45.36	23.98	23.98
Bare soil +1.5% fibre	35.48	57.97	53.75	23.12	23.12

Table no.6:- Plastic Limit

Liquid limit test

The liquid limit is the minimum water content at which a pat of soil cut by a groove of standard dimension will flow together for 12 mm under an impact of 25 blows in the Casagrande device. Procedure: Mix soil with water, place in cup, cut groove, and count blows required to close groove for 12 mm. Repeat at different water contents (15–35 blow range).

Bare Soil Sample

Sr no.	No. of blows (N)	Mass of empty cup (g)	Mass of empty cup + wet soil (g)	Mass of empty cup + dry soil (g)	Water content (%)
1	25	32.36	92.38	77.16	33.97
2	45	33.25	83.10	71.88	29.04
3	80	29.12	85.82	73.5	27.76
4	5	40.44	109.88	94.04	37.23

Table no.6:- Bare Soil

The liquid limit of the bare soil sample is 32 %

2. Bare Soil Sample + 0.5% Luffa Fibre

Sr no.	No. of blows(N)	Mass of empty cup (g)	Mass of empty cup + wet soil (g)	Mass of empty cup + dry soil (g)	Water content (%)
1	70	26.42	57.04	50.21	28.7
2	7	31.98	83.7	69.27	38.69
3	5	22.32	71.77	59.95	29.47
4	30	33.5	85.2	73.15	34.45

Table no.7:- Bare Soil Sample + 0.5% Luffa Fibre

The liquid limit of the bare soil sample with mixing of 0.5 % of luffa fibre is 31.81%.

3. Bare Soil Sample + 1.0 % Luffa Fibre

Sr no.	No. of blows (N)	Mass of empty cup (g)	Mass of empty cup + wet soil (g)	Mass of empty cup + dry soil (g)	Water content (%)
1	40	50.28	114.6	99	32.01
2	6	33.98	99.86	80.67	38.94
3	72	27.14	77.13	65.75	29.47
4	23	29.28	94.10	77.20	35.26

Table no.8:- Bare Soil Sample + 1.0 % Luffa Fibre

The liquid limit of the bare soil sample with mixing of 1.0 % of luffa fibre is 32.73 %.

4. Bare Soil Sample + 1.5 % Luffa Fibre

Sr no.	No. of blows (N)	Mass of empty cup (g)	Mass of empty cup + wet soil (g)	Mass of empty cup + dry soil (g)	Water content (%)
1	75	30.5	82.45	70.5	29.87
2	28	32.2	88.37	74.2	33.75
3	50	28.9	78.69	66.9	31.01
4	8	31	102.15	83.25	36.17

Table no.9:- Bare Soil Sample + 1.5 % Luffa Fibre

The liquid limit of the bare soil sample with mixing of 1.5 % of luffa fibre is 34.19 %

The consistency limits results are critical for understanding the plastic behaviour of silty clay soil sample. Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI) and Consistency Index (Ic)

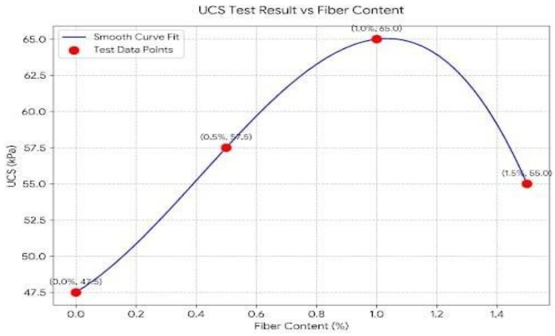
Soil Sample	Plastic Limit (Wp)	Liquidity Limit (Wl)	Plasticity Index (Ip)
Bare Soil Sample (0 % fibre)	22.83	32	9.17
Bare Soil Sample+ 0.5% Fibre	23.09	32.82	9.73
Bare Soil Sample+ 1% Fibre	23.98	33.92	9.94
Bare Soil Sample+ 1.5% Fibre	23.12	32.70	9.58

Table no.10:- Index Properties Of The Atterberg Limit Test

From the above A limit test results, the bare soil sample (0% fibre) shows a plastic limit of 22.83%, liquid limit of 32% and plasticity index of 9.17%, indicating low to medium plastic nature with limited cohesion. On adding 0.5% fibre, the plastic limit increases slightly to 23.09% and liquid limit to 32.82%, with plasticity index rising to 9.73%, which reflects a small improvement in soil plasticity and bonding characteristics. Further increase to 1% fibre content gives the plastic limit as 23.98% and liquid limit as 33.92%, resulting in the highest plasticity index of 9.94%, showing better interaction between soil particles and fibres, thereby improving cohesion. However, at 1.5% fibre content, the plastic limit decreases to 23.12% and liquid limit to 32.70%, with plasticity index reducing to 9.58%, indicating that excess fibre disturbs the soil structure and reduces effectiveness. Thus, the trend shows that plasticity and cohesion increase up to 1% fibre and then decrease beyond that. Since higher plasticity index higher the cohesion strength.

Cohesion

Cohesion is the force that holds particles together even without any external pressure and provides resistance against separation. It depends on consistency limits like liquid limit and plasticity index, where higher plasticity usually indicates stronger bonding. As these limits vary, cohesion also changes. Increased cohesion improves shear strength and leads to higher compressive strength, while lower cohesion reduces resistance and weakens the overall strength behavior under load.



Soil Sample	UCS (KPa)
Bare Soil Sample (0 % fibre)	47.5
Bare Soil Sample+ 0.5% Fibre	57.5
Bare Soil Sample+ 1% Fibre	65
Bare Soil Sample+ 1.5% Fibre	55

From the test, it is clearly seen that the UCS strength increases as fibre content is added up to a certain limit. The bare soil shows a UCS of 47.5 kPa, which gradually increases to 57.5 kPa at 0.5% fibre. The maximum strength of 65 kPa is achieved at 1% fibre content, indicating optimum reinforcement. Beyond this point, at 1.5% fibre, the UCS decreases to 55 kPa as shown in both graph and data. This reduction may be due to excess fibre causing poor bonding within soil structure. Hence, 1% fibre content can be considered as the optimum value for improving soil strength.

IV.DISCUSSIONS

The soil under study is mainly fine-grained, consisting of about 60.64% silt with some clay, 39.13% sand, and very little gravel, indicating a matrix sensitive to moisture variation and relatively low inherent strength. With a specific gravity of 2.26 and natural water content of 14.40%, the soil shows suitability for improvement through fibre reinforcement. When natural fibre was introduced, noticeable changes occurred in consistency limits. The liquid limit, plastic limit, and plasticity index initially increased, reaching peak values at around 1% fibre content, suggesting higher water demand due to the hydrophilic nature of fibres.

At lower additions (0.5%–1%), fibres absorbed moisture and improved soil plastic behavior, but beyond this (1.5%), a slight reduction in limits was observed as fibres began replacing active fine particles. A similar trend was seen in strength characteristics. Cohesion increased significantly from 38 kPa in untreated soil to a maximum of 52 kPa at 1% fibre, showing improved interparticle bonding and resistance due to fibre bridging.

The unconfined compressive strength followed the same pattern, rising from 47.5 kPa to 65 kPa at optimum fibre content, indicating better stress distribution and delayed failure. However, excess fibre (1.5%) reduced both cohesion and UCS, likely due to poor bonding and fibre clustering. Overall, the results indicate that around 1% fibre content is optimal, beyond which performance declines.

V. CONCLUSION

The present study focuses on the stabilization of soil using natural luffa fibre and evaluates its effect on various engineering properties of soil through laboratory testing. The soil used in the investigation is predominantly fine-grained, consisting of about 60.74% fines, 39.13% sand, and negligible gravel, indicating low natural strength and high sensitivity to moisture variations. The natural moisture content of the soil is found to be 14.40%, and the specific gravity is 2.26, confirming its suitability for stabilization. The compaction characteristics of untreated soil show an optimum moisture content (OMC) of 15.5% and maximum dry density (MDD) of 18.8 kN/m³. With the addition of 0.5% luffa fibre, the OMC increases to 21.5% and MDD slightly decreases to 18.2 kN/m³. At 1% fibre content, the OMC further increases to 31%, while MDD shows variation due to fibre interference in compaction. For 1.5% fibre content, the OMC is 29.6% and MDD reduces to 16.85 kN/m³, indicating that excess fibre reduces compaction efficiency.

The Atterberg limits test results indicate that the plastic limit of untreated soil is 22.83% and liquid limit is 32%, giving a plasticity index of 9.17%. With 0.5% fibre, the plastic limit increases to 23.09% and liquid limit to 32.82%. At 1% fibre content, the plastic limit reaches 23.98% and liquid limit 33.92%, resulting in the highest plasticity index of 9.94%. However, at 1.5% fibre, both limits decrease slightly, indicating reduced effectiveness.

The cohesion of soil increases significantly with fibre addition. The untreated soil shows a cohesion of 38 kPa, which increases to 46 kPa at 0.5% fibre and reaches a maximum of 52 kPa at 1% fibre content. At 1.5% fibre, the cohesion decreases to 44 kPa due to excess fibre content affecting soil bonding.

Similarly, the unconfined compressive strength (UCS) of soil improves with fibre addition. The UCS of untreated soil is 47.5 kPa, which increases to 57.5 kPa at 0.5% fibre and reaches a maximum value of 65 kPa at 1% fibre content. However, at 1.5% fibre, the UCS reduces to 55 kPa, indicating a decline in strength beyond the optimum level.
Overall, the results clearly show that the addition of luffa fibre enhances soil properties by improving interlocking, bonding, and resistance to deformation. The fibre absorbs moisture and increases water demand, leading to higher OMC values. At the same time, it reinforces the soil matrix and improves strength characteristics up to an optimum level.

However, beyond 1% fibre content, the performance of soil decreases due to fibre clustering, reduced soil contact, and poor compaction. Excess fibre disrupts the soil structure and reduces the efficiency of reinforcement.

Thus, it can be concluded that 1% luffa fibre is the optimum content for soil stabilization, providing maximum improvement in strength and stability. The use of luffa fibre is economical, biodegradable, and environmentally friendly compared to conventional stabilizers like cement and lime.

Therefore, luffa fibre can be effectively used in geotechnical engineering applications such as road subgrades, embankments, and foundation soils, contributing to sustainable construction practices.

REFERENCES

[1] Mohamad Shakri Mohmad Shariff, Mohamed Ahmed Hafez, Nazaruddin Abdul Taha, Nor Faiza, Abdul Rahman, Munira Mohammad, (June-2025)
Enhancing Soft Soil Strength by using Jute Fiber and Human Hair Fiber as Reinforcing Materials. Journal: Journal of Advanced Research in Applied Mechanics, Vol. 138, pp. 191- 202, ISSN 2289-7895

[2] Talha Zafar, Mohd Asif Ansari,Atif Husain,(2023) Soil stabilization by reinforcing natural and synthetic fibers. Journal: Materials Today: Proceedings; DOI: 10.1016/j.matpr.2023.03.503, Volume 78,

[3] M H Zulkafli, M N Noorasyikin and L F Roslan, (2024) Stabilization of soft soil with rice husk and coconut fiber. published in IOP Conference Series: Earth and Environmental Science, Volume 1347, issue 1, Article 012058

[4] Radha Palpi Boruah, Aditya Kumar Anshu (March 2025) Utilizing Vetiver and Bamboo Fibers to Enhance Soil Stabilization in Arunachal Pradesh. Journal of Civil Engineering, Vol. 12 Issue 3, pages. 226–234,

[5] Mukund P. Chougale, Kunal Tukaram Korade, Saurav Jaywant Shinde, Aarti Tukaram Upade, Shivani Subhash Sarokte (May 2023) Study on Soil Stabilization by Using Natural Fiber for Artificial Lake Liner. Journal of Research in Engineering, Science and Management (IJRESM), Vol. 6 No. 5, May 2023, pages. 32–34.

[6] Prabakaran Ellappan, Vijayakumar Arumugam, Nithya Muthukumaran (2020) Influence of Natural Fibers in Strengthening of Black Cotton Soil. Journal:- IOP Conference Series, Materials Science and Engineering, Volume 955 (2020)

[7] Mithilesh Kumar , Md Hussain , Kumar Vikas , Sanjay Prasad, Rajnish Kumar Upadhyay (April 2023), An Experimental Study On Stabilization Of Clayey Soil Reinforced With Banana Fiber. Journal:- Educational Administration, Theory and Practice, Volume 29, Issue 4 (2023), pages 1587–1597.