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Geotechnical Behaviour of Expensive Soil Mixed With Water Hyacinth Powder and Musa Fiber

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Abstract: Expansive soils can create serious problems in construction because they expand and shrink when the moisture content changes, leading to cracks and instability in structures. In this study, an attempt has been made to improve the properties of such soils by using natural and eco-friendly materials, namely Water Hyacinth (W.H) and Musa fibers. Different proportions of these fibers (0%, 5%, 10%, and 15%) were mixed with the soil, and a series of laboratory tests such as specific gravity, Atterberg limits, Proctor compaction, and direct shear tests were carried out. The results show that adding these natural fibers helps in improving the soil behavior. The liquid limit decreases while the plastic limit increases, which means the soil becomes less plastic and more stable. Compaction test results indicate that the maximum dry density increases with the addition of fibers, and the optimum moisture content changes depending on the mix. The shear strength of the soil also improves significantly, reaching the highest value at 10% fiber content. However, when the fiber content is increased to 15%, there is a slight reduction in strength, possibly due to improper mixing or excess fibers. Overall, the study suggests that using Water Hyacinth and Musa fibers is an effective, low-cost, and environmentally friendly method for stabilizing expansive soils. Among all the mixes, 10% fiber content is found to be the most suitable for achieving better strength and stability.

Keywords: Expansive soil, Soil stabilization, Natural fibers, Water hyacinth fiber, Musa fiber, Atterberg limits, Compaction characteristics, Maximum dry density, Optimum moisture content, Shear strength, Eco-friendly materials, Sustainable engineering.

1.Introduction

Expansive soils are one of the most problematic types of soils encountered in geotechnical engineering, as they undergo significant volume changes with variations in moisture content. These changes often lead to cracks, settlement, and damage to structures such as pavements, foundations, and buildings. Stabilizing such soils is therefore essential to ensure safety, durability, and long-term performance of civil engineering projects.

In recent years, there has been growing interest in using natural and sustainable materials for soil stabilization instead of conventional chemical additives. Natural fibers are gaining attention due to their low cost, easy availability, and environmentally friendly nature. Among these, Water Hyacinth (W.H), an invasive aquatic plant, and Musa fibers, obtained from banana plants, have shown promising potential in improving soil properties. Utilizing these materials not only enhances soil performance but also helps in managing agricultural and environmental waste.

The present study focuses on improving the engineering properties of expansive soil by adding varying percentages (0%, 5%, 10%, and 15%) of Water Hyacinth and Musa fibers. A series of laboratory tests were conducted, including specific gravity, Atterberg limits, Proctor compaction, and direct shear tests, to evaluate the changes in soil behavior with fiber addition.

The main objective of this study is to analyze the effect of natural fiber reinforcement on the strength and consistency characteristics of expansive soil and to determine the optimum percentage of fiber content that provides maximum improvement. This research aims to promote the use of eco-friendly stabilization techniques as a sustainable alternative in geotechnical engineering applications.

2. Literature reviews

Ramesh et al. (2016) studied different natural fibers like coir, jute, sisal, and banana fiber in soil stabilization. They conducted strength tests to evaluate performance. The results showed that banana fiber performed the best among all fibers. This is due to its high tensile strength and better bonding ability. It significantly increased soil strength and reduced deformation.

Johnson et al. (2016) used natural fibers along with biological materials in soil. Their study focused on improving soil properties and stability. They observed a reduction in plasticity and cracking in soil. The fibers helped in increasing cohesion between particles. Overall, soil became stronger and more stable.

Deepa & Roshan (2016) compared natural fibers with synthetic fibers in soil. Their results showed that both types provide similar strength improvement. However, natural fibers are more economical and eco-friendly. They also reduce environmental impact. Hence, natural fibers are preferred for sustainable construction.

Hussain et al. (2017) used water hyacinth ash as a stabilizing material in soil. They found that it reduces plasticity of soil. The ash also increased soil density. This led to improvement in overall strength. Thus, it is an effective waste material for stabilization.

Balaji & Kumar (2017) studied the use of water hyacinth powder in soil. They observed better bonding between soil particles. This improved inter-particle friction and cohesion. As a result, soil strength increased. The method is simple and cost-effective.

Kulkarni et al. (2017) analyzed the effect of water hyacinth on soil water absorption. They found a reduction in liquid limit values. This indicates improved soil consistency. Workability of soil also increased. Hence, it is suitable for construction applications.

Yadav et al. (2017) added banana fiber to soil and studied its effects. They conducted CBR and UCS tests. Results showed a significant increase in strength. Cracking in soil was also reduced. Therefore, banana fiber is effective in stabilization.

Prakash & Kumar (2018) used musa (banana) fiber in soil reinforcement. They observed improvement in shear strength. Compaction characteristics were also enhanced. Soil became denser and stronger. This shows the efficiency of banana fiber in soil improvement.

Patil et al. (2018) studied the effect of different fiber contents in soil. They found that about 0.5% fiber gives optimum results. Strength increases up to this limit. Beyond that, strength decreases due to excess fiber. Hence, optimum dosage is important.

Das & Banerjee (2018) used agricultural waste fibers for soil stabilization. They observed reduction in swelling behavior. Soil strength improved significantly. The method is also economical. It promotes use of waste materials.

Lakshmi et al. (2018) used water hyacinth fiber in soil. They found reduced plasticity in soil. Stability of soil improved. Strength parameters increased. It is an eco-friendly stabilization technique.

Fernando et al. (2018) conducted microscopic analysis of treated soil. They observed better bonding between particles. Pore spaces were reduced significantly. This resulted in higher strength. Soil structure became more compact.

Vishnu et al. (2019) used water hyacinth fiber in soil stabilization. They found an increase in CBR values. Plasticity index was reduced. Soil strength improved considerably. It is suitable for pavement applications.

Karthik et al. (2019) used water hyacinth ash in soil. They observed chemical reactions that improved soil properties. Density of soil increased. Strength also improved significantly. It acts as a stabilizing agent.

Nisha & Shaji (2019) studied fiber-reinforced soil behavior. They found that fibers reduce cracks in soil. Soil stiffness also increased. This improves durability. It is useful in construction works.

Singh & Murthy (2019) used banana fiber for soil stabilization. They observed reduction in shrinkage. Durability of soil increased. Soil performance improved under stress. It is a reliable reinforcement method.

Sharma & Rao (2020) studied the flexibility of fiber-reinforced soil. They found that soil becomes less brittle. It can withstand more deformation. Failure chances are reduced. This improves engineering performance.

Chandrasekaran et al. (2020) conducted UCS tests on reinforced soil. They observed increased compressive strength. Soil became less brittle. Load-bearing capacity improved. This enhances structural stability.

Jacob & Mathew (2020) studied wetting and drying cycles in soil. They found improved durability with fiber addition. Soil resisted damage from environmental changes. Cracks were reduced. This increases lifespan.

Gairola et al. (2020) studied fiber interaction in soil. They found improved interlocking between particles. This increased soil strength. Stability also improved. It is beneficial for engineering applications.

3. Materials and Methodology

3.1. Materials

3.1.1 Expansive Soil (Black Cotton Soil)

Expansive soil, commonly called **Black Cotton Soil**, is a fine-grained clay soil that exhibits large volume changes when its moisture content varies. When water increases, the soil **swells**, and when water decreases, it **shrinks**, causing structural instability. This soil is problematic in construction due to its unpredictable behaviour, low bearing capacity, and high plasticity.

Figure1:Black cotton soil sample collected from Allavaram, East Godavari District.

Table1: Index properties of untreated expansive clay soil

Property	**Typical Range**	**Description**
Colour	Dark black/grey	Due to presence of montmorillonite minerals
Moisture Content	5-25%	Depends on local environmental conditions
Specific Gravity	2.60-2.75	Depends on local environmental conditions
Liquid Limit(LL)	40%-120%	Very high due to high plastic clay
Plastic Limit(PL)	20%-50%	igh plastic nature
Plastic Index(PI)	20-70	Highly plastic and expansive
Free swell Index	50-120%	Shows swelling potential
Optimum Moisture Content(OPT)	12-25%	High water demand for compaction
Maximum Dry Density(MDD)	1.4-1.7g/cc	Low density due to clay structure

3.1.2.Water Hyacinth Fiber (W.H)

Water Hyacinth (*Eichhornia crassipes*) is an aquatic plant with fibrous roots and stems. The fibers extracted from this plant are lightweight, biodegradable, and have good bonding characteristics. They help reduce shrinkage and improve soil structure when mixed with expansive soil.

Figure2:Water Hyacinth

Table2:Properties of Water Hyacinth (W.H)

Property	**Description**
Appearance	Light brown, porous fiber
Moisture Content	10-15%
Density	0.7-1.2g/cm^3
Fiber Length Used	10-20mm
Cellulose Content	40-50%
Lignin Content	10-15%
Tensile Strength	Moderate
Water Absorption	High (hydrophilic)

3.1.3.MUSA FIBER (BANANA FIBER)

Musa fiber (Banana fiber) is obtained from the pseudo-stem of banana plants. It is a natural, strong, biodegradable fiber with excellent flexibility. When used in expansive soil, it helps in increasing strength, reducing plasticity, and improving compaction behavior.

Figure 3: Musa Fiber(banana fiber)

Table 3: Properties of Musa Fiber

Property	**Description**
Colour	Pale yellow / brown
Density	1.3 – 1.5 g/cm³
Fiber Length Used	10–20 mm
Cellulose Content	60–65%
Lignin Content	5–12%
Tensile Strength	400–600 MPa
Moisture Absorption	Medium
Diameter	80–250 microns

3.2.Methodology

3.2.1.Specific gravity

In the density bottle method, a clean and dry density bottle of 50 ml capacity is taken, and its empty weight (W1) is recorded. A small quantity of oven-dried soil passing through a 4.25 mm sieve is carefully placed inside the bottle and weighed again (W2). Distilled water is added to the bottle up to the top, and the mixture is stirred thoroughly to remove all trapped air bubbles. The bottle filled with soil and water is weighed (W3). Then, the bottle is emptied, cleaned, and filled only with water to determine its full weight (W4). Using these values, specific gravity is calculated with the standard formula. This test is repeated for soil mixed with fibers to examine variations due to stabilization.

Figure 4: Specific gravity test setup(density bottle method).

3.2.2.Atterberg Limits

3.2.2.1.Liquid Limit Test

In this test, a portion of soil passing through a 425-micron sieve is mixed with water to form a uniform paste. This paste is placed in the Casagrande cup and levelled using a spatula. A groove is cut at the center using the standard grooving tool. The cup is repeatedly dropped at a height of 10 mm using the mechanical crank until the groove closes for a length of 12 mm. The number of blows required to close the groove is recorded. A small sample is taken from the closed groove and its water content is determined. The same procedure is repeated for different moisture contents to obtain multiple readings. A flow curve is plotted between the number of blows and water content, and the water content corresponding to 25 blows is taken as the liquid limit.

Figure 5: Liquid limit test

3.2.2.2.Plastic Limit Test

A representative soil sample passing through a 425-micron sieve is taken and mixed with water until it becomes plastic enough to be shaped. A small portion is rolled on a glass plate into a thread of 3 mm diameter using the fingers. If the thread crumbles before reaching 3 mm, more water is added. If it does not crumble, water content is reduced. The water content at the point where the soil thread just begins to crumble is noted as the plastic limit. This test is repeated for soil mixed with different fiber percentages to study variations in plastic behavior.

Figure 6: Plastic limit test

3.2.3.Standard Proctor Compaction Test

In this test, about 3–4 kg of soil is taken and mixed thoroughly with a known quantity of water. The wet soil is compacted inside a standard Proctor mold in three equal layers, each layer receiving 25 blows from a hammer of 2.6 kg falling from a height of 310 mm. After compaction, the collar is removed, and the excess soil is trimmed. The mold with compacted soil is weighed to determine the bulk density. A small sample is taken to measure moisture content. The same procedure is repeated for increasing water contents until a peak dry density is observed. A compaction curve is then plotted between dry density and moisture content to determine OMC and MDD. The test is repeated for different stabilizer percentages (0%, 5%, 10%, 15%) to study improvements in compaction behavior.

Figure 7: Proctor Compaction Test

3.2.4.Direct Shear Test

In the Direct Shear Test, the soil sample is first prepared by mixing expansive soil with Water Hyacinth Fiber and Musa Fiber at required percentages of 0%, 5%, 10%, and 15%. The prepared mixture is placed inside a square shear box, which is divided horizontally into an upper and lower half. A porous stone and a metal grid are placed on both top and bottom of the sample to ensure uniform load distribution. The sample is compacted gently to avoid disturbance. A normal load is then applied vertically on the top of the sample using the loading frame. Once the normal load is set, the horizontal shear load is applied gradually by moving the lower half of the shear box. As the load increases, the soil begins to slide along the predetermined shear plane. The proving ring records the shear force, and the dial gauge measures horizontal displacement. The test continues until the specimen fails or reaches maximum shear stress. The same procedure is repeated for different normal stresses to obtain multiple readings. From these values, a shear stress versus normal stress graph is plotted, and the shear strength parameters, cohesion (c) and angle of internal friction (ϕ), are calculated for each fiber percentage. This helps in evaluating the improvement in shear strength due to the addition of natural fibers.

Figure 8: Direct Shear Test

4.RESULT AND DISCUSSION

4.1.SPECIFIC GRAVITY TEST

The specific gravity of the soil was determined by using the density bottle method. From the experimental observations, the specific gravity values obtained are 2.04 for 0%, 2.08 for 5%, 2.14 for 10%, and 2.20 for 15%. The results show that the specific gravity of the soil increases gradually as the percentage increases. This indicates that the addition of the material increases the density of the soil particles. Therefore, it can be concluded that the soil becomes slightly denser with the increase in percentage, which results in higher specific gravity values.

Table 4: Specific Gravity Test For W.H- MUSA Mix(%) Proportions

Mix (%)	Specific Gravity (%)
0%	2.04
5%	2.08
10%	2.14
15%	2.20

4.2.ATTERBERG LIMITS TEST

4.2.1.Liquid Limit Test:

From the results, it is observed that the liquid limit decreases as the percentage of additive increases. The natural soil (0%) has a liquid limit of 41%. When 5% additive is added, it decreases to 38%. At 10% and 15%, the liquid limit further decreases to 35% and 32%.This shows that the addition of water hyacinth and musa fiber reduces the plasticity and swelling nature of expansive soil, which improves the stability and engineering properties of the soil.

Table 5: Liquid Limit Test For W.H- MUSA Mix(%) Proportions

Mix (%)	**Liquid Limit (%)**
0%	41%
5%	38%
10%	35%
15%	32%

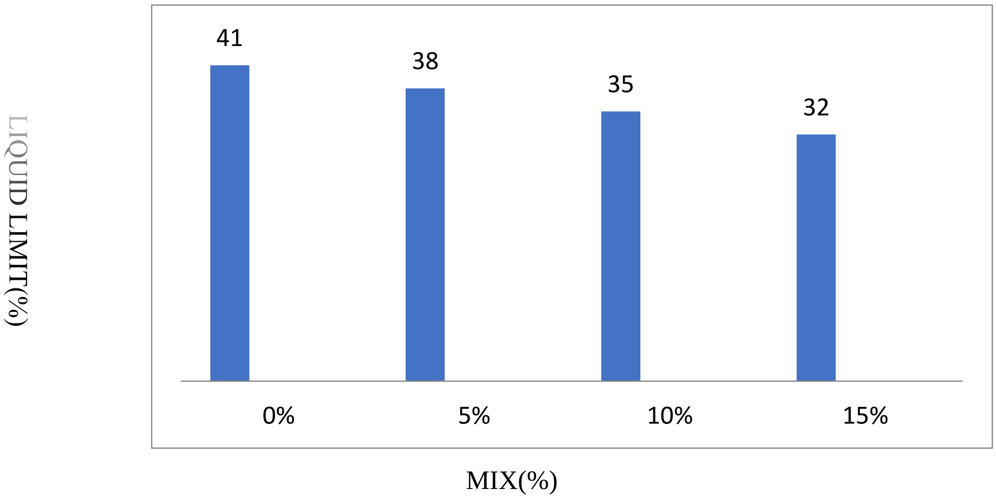

Figure 9: Liquid Limit Test

4.2.2.Plastic Limit Test:

From the results, it is observed that the plastic limit increases as the percentage of additive increases. The natural soil (0%) has a plastic limit of 26%. When 5% additive is added, it increases to 31%. At 10% and 15%, the plastic limit further increases to 37% and 42%.This shows that the addition of water hyacinth and musa fiber improves the plasticity characteristics of the soil, making the soil more stable and less prone to cracking.

Table 6: Plastic Limit Test For W.H- MUSA Mix(%) Proportions

Mix(%)	Plastic Limit(%)
0%	26%
5%	31%
10%	37%
15%	42%

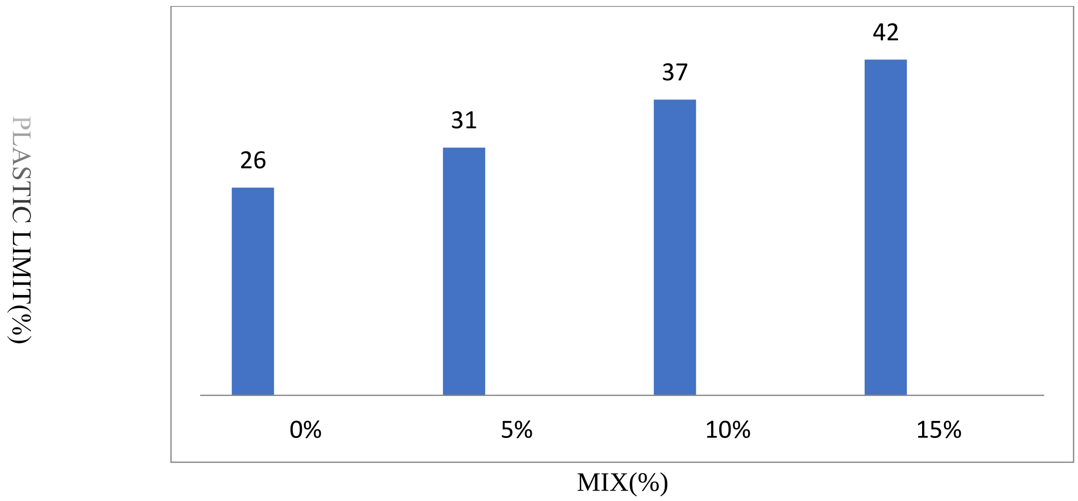

Figure 10: Plastic Limit Test

4.3.Proctor Compaction Test:

From the results, it is observed that the Optimum Moisture Content (OMC) increases with the addition of additives up to 10% and then decreases slightly at 15%. The natural soil (0%) has an OMC of 11.32%. When 5% additive is added, it increases to 13.2%, and at 10% it further increases to 16.9%. At 15%, the OMC slightly decreases to 13.33%.The Maximum Dry Density (MDD) increases gradually with the increase in additive percentage. The MDD value increases from 1.66 g/cc at 0% to 1.69 g/cc at 5%, 1.72 g/cc at 10%, and 1.73 g/cc at 15%.This shows that the addition of water hyacinth and musa fiber improves the compaction characteristics and stability of the soil.

Table 7: Proctor Compaction Test For W.H- MUSA Mix(%) Proportions

MIX	OMC(%)	MDD(g/cc)
0%	11.32%	1.66
5%	13.2%	1.69
10%	16.9%	1.72
15%	13.33%	1.73

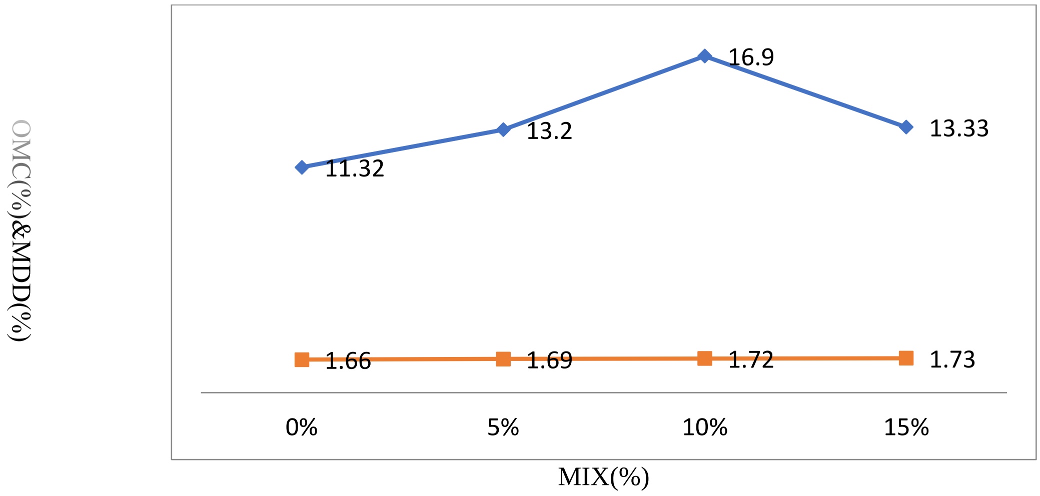

Figure 11: Proctor Compaction Test

4.4.Direct Shear Test:

From the Direct Shear Test results, it is observed that the shear strength of the soil increases with the addition of Water Hyacinth and Musa fiber up to 10% and then slightly decreases at 15%. The natural soil (0%) shows shear stresses of 28, 52, and 74 kN/m² at normal stresses of 50, 100, and 150 kN/m² respectively. When 5% admixture is added, the shear strength improves significantly, giving 40, 75, and 105 kN/m² for the same normal stresses. The highest improvement is observed at 10% fiber content, where the shear stresses reach 48, 90, and 125 kN/m², indicating maximum enhancement in frictional resistance and bonding between soil particles. However, at 15% addition, the shear strength slightly reduces to 43, 82, and 115 kN/m², which may be due to excessive fiber content causing poor mixing and reduced interlocking. Overall, the results show that the addition of Water Hyacinth and Musa fibers improves the shear strength of expansive soil, with 10% being the optimum percentage for achieving maximum stability and shear resistance.

Table 8: Direct Shear Test For W.H- MUSA Mix(%) Proportions

Normal Stress	**0%**	**5%**	**10%**	**15%**
50	28	40	48	43
100	52	75	90	82
150	74	105	125	115

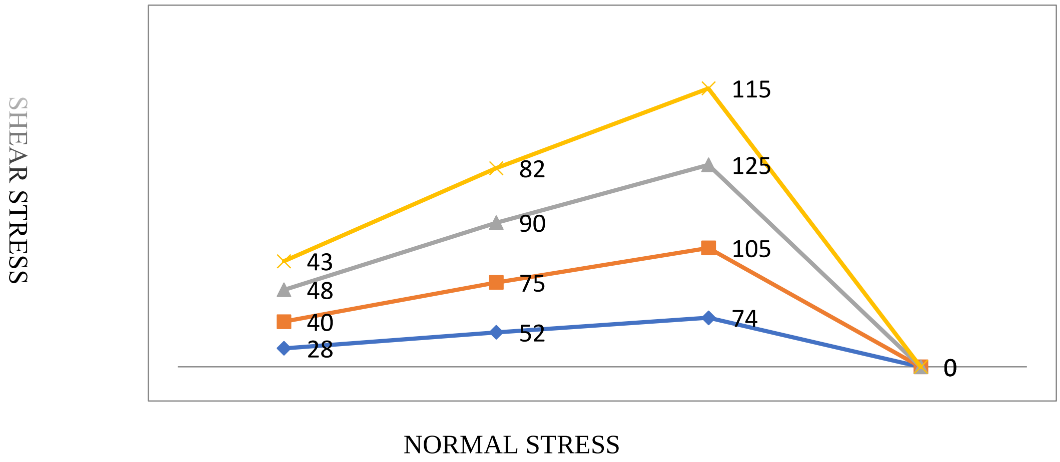

Figure 12: Direct Shear Test

5.Conclusion:

This study was carried out to improve the behavior of expansive soil by using natural fibers such as Water Hyacinth and Musa (banana) fibers. Expansive soils usually swell when wet and shrink when dry, making them weak and unstable for construction. The test results showed that adding fibers improved the soil's moisture behavior, compaction, and density. The Optimum Moisture Content increased and the Maximum Dry Density improved up to 10% fiber content. The Direct Shear Test also proved that the soil became stronger and more resistant to shearing when fibers were added, with the best performance recorded at 10% fiber addition.

Overall, the combination of 5% Water Hyacinth and 5% Musa fiber gave the most effective results, showing maximum improvement in strength and stability compared to natural soil. These natural fibers are cheap, biodegradable, and eco-friendly, making them a good alternative to chemical stabilizers. The findings of this project show that Water Hyacinth and Musa fibers can significantly enhance the engineering properties of expansive soil, making it more suitable for use in construction works such as roads, embankments, and foundations in weak soil areas.

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