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Natural Fiber-Reinforced Soil: A Brief Review Paper

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ABSTRACT

The majority of building and civil engineering projects start on undeveloped soils. Before taking any further action, a thorough site inspection is required to determine the current condition of the site. Finding a location with optimal soil conditions can be difficult. One of the most commonly used methods for treating undeveloped soil is to incorporate natural fiber to reinforce soil, also known as natural fiber-reinforced soil. The purpose of this review article is to look at how different natural fibers reinforced soil. A review of studies suggests that reinforcing soil with natural fibers is a low-cost and effective stabilizing technique with several benefits. This paper is intended for geotechnical engineers in improving undeveloped soils with natural fibers, as well as researchers conducting future research.

Keywords: undeveloped soil, fiber-reinforced soils, natural fiber, stabilizing technique.

INTRODUCTION

The majority of buildings and other civil engineering construction projects commence on undeveloped ground. Prior to commencing any further actions, it is imperative to conduct a thorough site inspection to ascertain the current condition of the site. Finding a place with optimal soil qualities can be challenging. Potential alternate remedies to address this situation include:

1. Avoid the site. Relocate the intended construction project to an alternative location.
2. Replace the unsuitable soils. Once the soil parameters have been obtained, it can be decided that the soils are inadequate and should be replaced with more suitable soils.
3. Attempt to alter the current soil composition. This process is referred to as ground modification.

Categorized ground improvement, alteration, or stabilization into four distinct groups [1]:

First, Mechanical modification. Soil density can be increased through the use of external mechanical forces, which involve various methods such as static compaction, dynamic compaction, or deep compaction utilizing heavy tamping.

Second, Hydraulic modification. Another technique can be applied such as hydraulic modification is by using geosynthetics. Groundwater is expelled from the subsurface through the use of drainage systems or wells. Groundwater levels can be reduced by extracting water from trenches or boreholes in soils that are coarse-grained or lack cohesion. However, for soils that are fine-grained or cohesive, a long-term application of external pressure (preloading) or electrical loads (electrokinetic stabilization) is necessary.

Third, Physical and chemical modification. An instance of this technique involves the process of soil stabilization through the physical incorporation of additives into the upper layers of soil at a certain depth. Additives encompass a range of substances, including natural soils, industrial by-products, waste materials, and other chemical compounds, which have the ability to interact with the soil. Previously, we have already explored other applications such as ground alteration by grouting and thermal

Fourth, Modification by inclusions and confinement. This group is regarded as enhancing the stability of soil through the use of materials, such as meshes, bars, strips, fibers, and textiles that possess tensile strength. Stable-earth retaining structures can be created by enclosing a site using concrete, steel, or cloth materials. Conventional pile foundations, although occasionally referred to as "compressive reinforcement," are not included in this category. The primary objective of pile foundation is not to reinforce the soil, but rather to transfer the load to a more robust or deeper layer.

Soil reinforcement is a ground enhancement technique that involves the use of synthetic or natural additives to enhance the characteristics or attributes of the soil. Several reinforcement strategies can be employed to address challenging soil conditions. Therefore, the methods for strengthening the earth can be classified into various groups based on different perspectives. Figure 1 illustrates many methods of ground improvement, particularly the reinforcing of a site or ground [2]. Figure 2 presents a summary of ground or site improvement methods based on soil grain size.

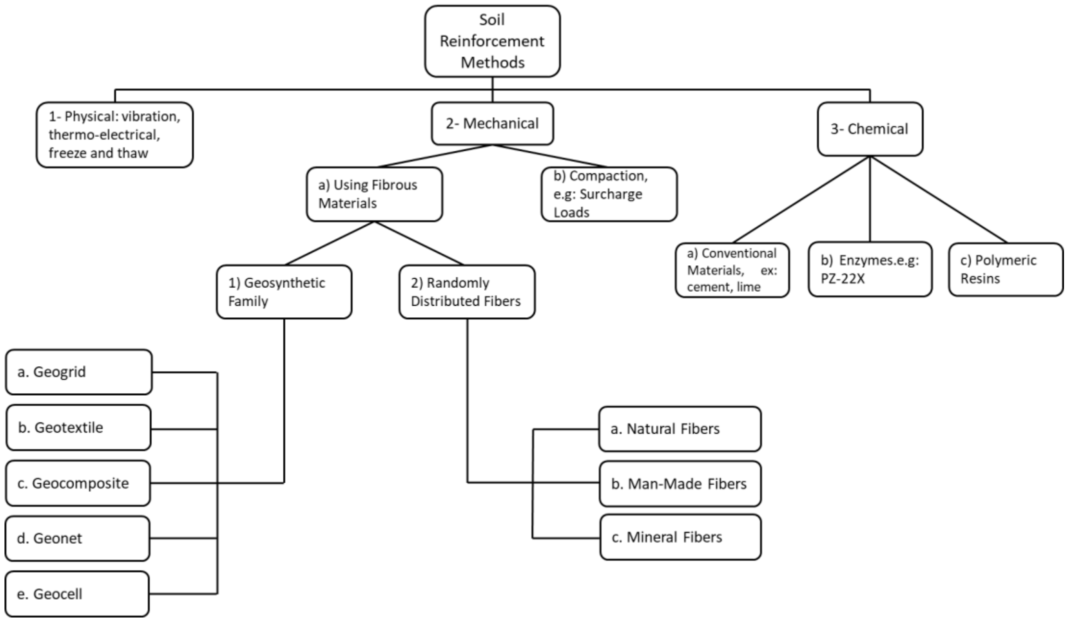

Figure 1. Several Methods of Soil Reinforcement [2]

Reinforced Soil

The reinforced soil is originally defined as a soil which is strengthened by a material able to resist tensile stresses and which interacts with the soil through friction and/or adhesion. Subsequently, the meaning of soil reinforcement was broadened, and this term is now also used for other mechanical and structural methods of soil improvement, such as compressive reinforcement by confinement and encapsulation.

The main purpose of soil reinforcement is to increase the stability or soil strength [3]-[12], improve bearing capacity and reduce settlements and lateral deformation. The wider definition of soil reinforcement also includes erosion control methods and stress transfer via anchors and piles. This term becomes complicated since many materials used to improve engineering properties of soil, for example geotextiles that can be used for multiple purposes (e.g., strengthen structural behavior, control groundwater flow and separate different soil layers during construction). Another material is even from the root and natural geotextiles from Bamboo, that it can also increase strength of the soil structures [13].

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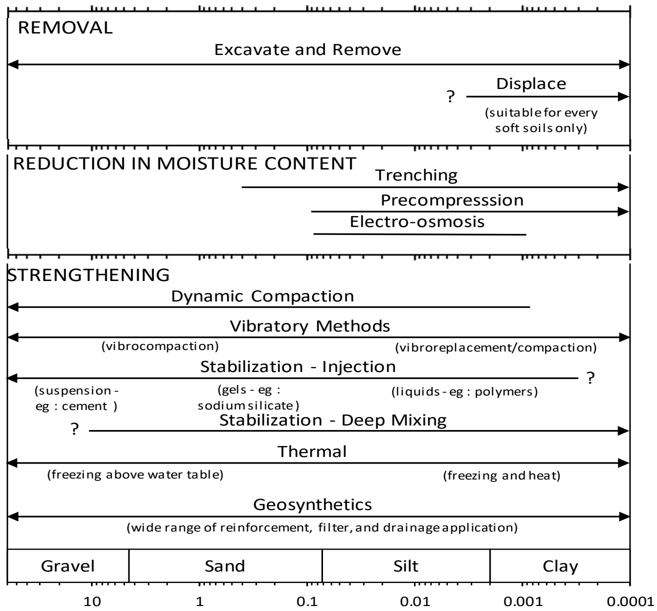

Figure 2. Ground Modification Methods based on Soil Grain Size [14]

Soil reinforcement is not a new concept. The ancient ziggurats found in Iraq, which are more than 3000 years old is one of early examples of soil reinforcement application. Reed-reinforced earth levees were constructed along the Tiber River by the Romans. The modern uses of soil reinforcement appeared in the 1960s with the development of Reinforced Earth retaining walls and geotextile stabilization of haul roads and access roads.

Fiber Reinforced Soil

Another solution to reinforce soil is by using fiber. It has been a solution to stabilize thin soil and localized repair of failed slopes. Unlikely geosynthetics, another reinforcement method using fibers is applied by distributing the fibers randomly. Fibers which can be used either natural fibers or synthetic fibers. Figure 3 shows the review of more than 100 researches of soil reinforcement by using natural fibers [2].

To prepare sample or specimens of fiber-reinforced soils to be tested in laboratory, it can be mixed either manually or mechanically by using mixing machine. Whatever the mixing method used, many researches implicitly assume that the fibers will be randomly distributed in the soil mass. That orientation distribution would give the soil strength isotropy.

Effects of fiber-reinforced soil are relatively similar to geosynthetics-reinforced soil for both coarse-grained and fine-grained soils, such as increasing bearing capacity and soil strength [3]-[12]. There are some common natural fibers [2]:

Coconut (coir) fiber

It is from matured coconut, or or coconut husk, normally 50-350 mm long and contains mainly cellulose, pectin, tannin, lignin and other water soluble substances. Due to high lignin content, it will be degraded slowly than other natural fibers. Because of that, the coconut fiber can be long-lasting, around 4-10 years of service life. Typically, it has much tensile strength when wet. This fiber is produced mostly in South Asian countries, like Indonesia, Philippines and India. Reinforcing soil by coir fibers can increase tensile strength and reduce the settlement. Also, durability of stabilized soil blocks were increased with the addition with coconut coir [15].

Palm fibers

This fiber, which has low elasticity modulus and tensile strength, is extracted from decomposed palm trees. Soil reinforced with palm fibers has greater unconfined compressive strength (UCS) as shown in Figure 4, CBR and shear strength parameters [12].

Fiber Type				Length (mm)	Optimized fiber percentage	Fiber special property	Soil types used in the literature	Conclusions	References
Coir Fibers				Randomly distributed: 10–500 mm and 50 mm	1% by weight with aspect ratio of 20	– Retains much of its tensile strength when wet	– Black cotton	– Fibers decrease the MDD of the soil while increase the OMC	[42–53]
D (µm)	SG (g/cm³)	*E* (GPa)	UTS (MPa)			– Low tenacity but high elongation	– Lateritic soil	– The compressive and tensile strength of the composite soil increases up to 1% of coir conten	
10 - 20	1.15 - 1.33	4 - 5	250			– Keeps 80% of its tensile strength after 6 months of embedment in clay	– Clay	– Fiber–soil–cement block has low thermal conductivity	
Sisal Fibers				10, 15, 20 and 25; 20 mm: optimized	0.75%	– Traditional use as a reinforcement for gypsum plaster sheet	– Clay	– Fiber imparts considerable ductility and slightly increases the compressive strengt	[54–57]
D (µm)	SG (g/cm³)	*E* (GPa)	UTS (MPa)			–60% to 70% of water absorption.	– Silty sand	– The shear strength of the composite soil is increased non-linearly with increase in length of fiber up to 20 mm and 0.75% fiber content	
25 - 400	1.2 - 1.45	26 - 32	560						
Palm Fibers				15, 20, 30, 40 and 45; 30 mm: optimized	0.5%	– Low cost, plenitude in the region, durability, lightweight, relative strength against deterioration	– Silty sand	– Fiber increases the UCS, CBR and shear strength parameters (C and U) of the soft soil	[58–63]
D (µm)	SG (g/cm³)	*E* (GPa)	UTS (MPa)						
25 - 60	1.3 - 1.46	0.55	21 - 60			– Low tensile strength and modulus with very high water absorption		– 3% palm fibers improve the compressive strength of composite bricks.	
Jute Fibers				5, 10, 15 and 20; 10 mm: optimized	0.8%	– Used for producing porous textiles which are widely used for filtration, drainage, and soil stabilization	– Clay	– Fiber reduces the MDD while increases the OMC. CBR value is increased more than 2.5 times compared to the plain soil CBR value	[68–70]
D (µm)	SG (g/cm³)	*E* (GPa)	UTS (MPa)						
10–50	1.44–1.46	22	453–550			– Soft clay (expansive soil)			
Barley-Straw Fibers				Randomly distributed: 10–500 mm	1%	– Widely cultivated and harvested in all over the world	– Clayey silty soil	– Fiber decreases shrinkage, reduces the curing time and enhances compressive strength if an optimal reinforcement ratio is used. Flexural and shear strengths are also increased and a more ductile failure can be obtained	[63–78]
D (µm)	SG (g/cm³)	*E* (GPa)	UTS (MPa)			– Commonly used in producing composite soil blocks	– Clayey sandy soil		
1000–4000	2.05	-	-				– Silty sand		

Figure 3. Summary of Previous Researches on Natural-Fibers to Reinforce Soil [2]

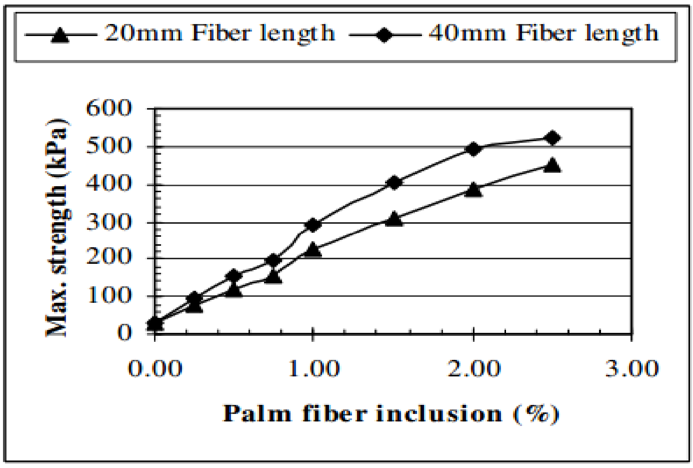

Figure 4. Relationship between Maximum Strength and Inclusion of Palm Fibers [12]

Jute

Jute is one of natural fibers grown in India, China, Pakistan, Bangladesh and Thailand. [10] conducted study about effect of jute fiber inclusion on CBR improvements. The contents of Jute fiber were determined by dry weight of soil, which are 0.25% to 1% (interval of 0.25%). Other variation used is dimension of the fiber (the length and diameter). The lengths were 30 mm up to 90 mm with the interval of 30 mm, while two diameters were considered: 1 mm and 2 mm. Tests results, indicate that the CBR value of soil was increased as the inclusion of jute fiber (0%-1%). Maximum increase is 200% at 1% jute fiber inclusion with the diameter of 2 mm and 90 mm length. Incorporating jute fiber along with black carbon can increase the CBR value, dry density and Optimum Moisture Content (OMC) of the reinforced soil [16].

Benefits and Challenges of Soil Reinforcement Using Natural Fibers

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Soil reinforcement using natural fibers has gained significant attention due to its potential to improve soil properties in an environmentally friendly and cost-effective manner. Natural fibers such as coconut, jute, and palm fibers have been extensively studied for their ability to enhance soil strength, reduce deformation, and improve overall stability. However, like any ground improvement technique, the use of natural fibers for soil reinforcement has both advantages and limitations. The following section outlines the key benefits and challenges associated with this approach, providing a balanced overview based on current research.

Benefits

1. Cost-effective, locally available, and eco-friendly [8], [10], [17].
2. Improves soil strength [2], [4], [5] and reduces swelling and shrinkage properties [2].
3. Less susceptible to weather conditions compared to cement, lime, and other chemical stabilization methods [17], [21].
4. Fiber reinforcement can inhibit tensile crack propagation and alter the failure mechanism after initial formation [2], [12].
5. The lightweight and readily available nature of glass fiber demonstrates its potential for long-term soil improvement [18], [19].

Challenges

Despite extensive research on the effects of using fibers to improve soil, there are currently no established scientific procedures or standards, particularly for field applications [2], [20].

CONCLUSION

Fiber-reinforced soil is an effective ground improvement method that uses both natural and synthetic additive materials to enhance soil properties. The primary objective of this technique is to increase soil stability, strength, bearing capacity, and to reduce settlement and lateral deformation, making it a valuable solution for addressing problematic soils. Various types of fibers, including natural fibers such as coconut, palm, and jute, as well as synthetic fibers like polypropylene and polyester, offer diverse solutions depending on soil conditions and project requirements. This review provides a brief overview of the use of fibers in soil reinforcement, highlighting both its economic and technical benefits. The technique not only plays a crucial role in improving soil quality but also holds significant potential for developing more environmentally friendly and cost-effective ground improvement methods. As research in this field continues to evolve, it is expected to lead to more efficient and applicable solutions, contributing significantly to the advancement of sustainable infrastructure development.

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