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A Review on Soil Reinforcement using Different Natural Fibers

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Abstract. The rapid growth of buildings, highways, railways, and other infrastructures has led to an acute shortage of ideal quality construction sites. Consequently, engineers are forced to focus on soil reinforcement techniques to enhance the bearing capacity and settlement characteristics of weak soils. Despite the increasing prominence of ground reinforcement using geosynthetics in the recent years, the rising price and non-eco-friendly nature of these artificial fibers have shifted our attention towards the soil strengthening using natural fibers. From the current studies, it is evident that the ground reinforcement using natural fibers like coir, sisal, jute, and bamboo have exhibited promising results in the fields of geotechnical engineering. This paper mainly explores the potential benefits and application of using different natural fibers as reinforcing materials.

Keywords: Soil, Reinforcement, Natural Fibers

1 Introduction

Currently, the enormous growth of infrastructures has challenged the engineers to adopt various cost effective and efficient ground improvement techniques in order to facilitate construction on poor quality sites. Ground improvement using reinforcing elements have been practiced since the ancient period to deal with the adversities that arise due to developments over problematic weak soils. Lately, the application of geosynthetics in weak soils have attracted the consumers because of its ease of availability and established performance in the geotechnical field. However, considering the environmental and economical perspectives, geosynthetics have possessed certain shortcomings, which has forced the researchers to focus on the use of natural fibers for soil reinforcement. Despite the successful performance of natural fiber reinforcements, these materials are often underutilized due to the lack of detailed studies. The present paper reports a short review on different natural fibers that are locally available and the performance of soil when reinforced with these fibers.

2 Natural fibers

Consequences that are arising due to the overexploitation of non-renewable resources and excessive pollution on the planet has encouraged the use of natural fibers in improving the characteristics of soil in recent times. Natural fibers are cheap and eco-friendly materials that are abstracted from the barks and leaves of plants. The abundant availability of these fibers in developing countries is often unused regardless of its potential benefits in the engineering field. Some of the easily available natural fibers and its effectiveness in improving the bearing capacity of soils are reported below.

2.1 Coir

Coir is a biodegradable cellulose-lignin rich fibrous material obtained from the husks of matured coconut fruits. Coir is considered to be an economical and readily available material with desirable mechanical properties and can withstand harsh environmental conditions when compared to other available natural fibers. Southern Asian countries like India, Ceylon, Indonesia, Philippines are significant contributors of coir fibers in the world. The application of coir fibers continues from enhancing the compressive strength of concrete to improving the performance of weak soil, controlling erosion, and so on. Coir fibers exhibit a tensile strength of 131- 220 Mpa, and it was reported that 80% of the tensile strength of coir fibers is retained even after six months(Rao and Balan 2000)).

The popularity of coir fibers has been initiated since 1991, when Schurholz used coir geotextiles to recover the damaged river bed in West Germany due to flooding. According to the author, coir fibers can withstand intense flooding conditions with less damage. The remarkable durability characteristics are attributed to the high compositions of lignin(40%) and cellulose(54%)(Rao and Balan (2000)). However, the rate of degradation is not a more significant concern if the long term recovery of the sloppy terrain subjected to soil erosion is carried out through vegetative turfing. The well-developed root systems of the vegetation cover will be capable of holding the soil within the degradation period. (Lekha 2004)

From the results presented by Kar. et al., (2014), it is indicated that random distribution of coir fibers in cohesive soils gave promising results. Moreover, the potential of these random coir fibers in increasing the load bearing capacity of soil can be further enhanced with the treatment of fibers with carbon tetrachloride and sodium hydroxide. (Dutta and Gayathri, 2012). Recently the surface modification of coir fibers using nanoparticles and cashew net shell liquid to control microbial attacks have gained prominence. (Anggraini et al. (2016), Sumi. et al. (2018))

Presently, Coir geotextiles are available at different properties and forms to perform various functions depending on the required behavior of the application. Upon the application of Coir Geotextiles in unpaved roads, Vinod and Minu, (2010) confirmed sufficient improvement in CBR value, to decrease the thickness of pavement by eliminating the base course. The inclusion of coir geotextiles can also result in the reduction of excessive settlement and shear failure in soils by an efficient dispersion of load through the reinforcements to the subgrade soil, aiding to a considerable curtailment of pavement layer thicknesses. Substantial reduction in initial cost maintenance cost is possible with the use of coir geotextiles in the pavement. Further studies have indicated that the effect of placement position and forms of coir geotextiles also plays an essential role in improving the load bearing capacity of subgrade soil. From the investigations conducted by Subaida et al. (2009), adequate improvement was noticed with the placement of coir geoxtile layer within the base course layer. Several researchers have studied the efficacy of using different forms of geosynthetics. Lal et al. (2017) carried out the study from an environmental and economic aspect by comparing the performance of planar and 3D form of coir geotextiles in soil. The enhancement in soil strength was more predominant with the use of coir geocells due to the confinement effect offered by the reinforcement.

However, large scale studies are yet required to establish a full fledged use of these coir fibers as an effective soil reinforcement technique.

2.2 Jute

Jute fibers are abstracted from the stems of cellulose rich jute plants that belong to the genus Corchorus, and family Tiliaceae. These plants can grow up to 2.5 m height. Southern Asian countries like Bangladesh, India, China, and Thailand are the rich sources of Jute plants with Bangladesh contributing over 90% of the world's Jute economy. (Tiwari and Kumawat, 2008)

Jute fibers exhibit considerable tensile strength and flexural rigidity due to the presence of high cellulose content. Reinforcement of soil using jute fibers can be considered as a cost effective and economical method, especially in developing countries for unstable slopes, embankments and to facilitate construction on poor quality sites. However, the application of jute fibers is limited in the geotechnical field as a result of wide variations in the mechanical properties shown by these natural fibers.

Virk et al. (2009) have studied the changes in tensile properties of five different Jute fiber lengths and characterized using Weibulls analysis. The authors found, decrement in tensile strength with an increase in fiber length. The presence of weaker links is highly prevalent with the increasing fiber length, leading to the failure. (Pickering et al. 2007). Jute fibers exhibit unique tensile strengths in the range of 393-800 MPa and are proven to be effective in improving the strength of the soil. (Kozlowski, 2012).

Generally, the incorporation of jute fibers into the soil matrix for soil reinforcement is accomplished in two methods, either by the random distribution of jute fibers or through oriented distribution by the provision of woven jute mats into the soil layers.

The potential of jute fibers in improving the subgrade characteristics is studied by Agarwal and Sharma (2010) by conducting a series of Proctor and CBR tests on soil mixed with jute fibers at varying lengths, diameters, and quantities. The author concluded that subgrade thickness could be reduced by the incorporation of optimum percentages of jute fibers with desirable properties. An increase in the CBR value of soil was noticed by Akhtar Hossain (2015), with an increase in length and diameter of jute fibers at 1.2%. Both the authors concluded that an increase in optimum moisture content and a reduction in maximum dry density was observed in the experimental investigations.

Md. et al. (2016) compared the performance of subgrade soil reinforced with jute geotextiles at varying depths to the unreinforced subgrade soil through a series of CBR tests. Appreciable improvement was observed with the inclusion of jute geotextiles, and further enhancement was noted when the reinforcements were placed at the bottom layers. Hossain et al. (2019) experimentally investigated that slope failures due to erosion in Bangladesh can be effectively controlled by using an overlay of open meshed jute geotextiles on the slopes.

However, a detailed investigation is yet required to understand the potential of jute fibers for soil reinforcement in geotechnical engineering.

2.3 Sisal

Sisal is a quickly growing plant that extends up to 1 m in height and 28 mm wide. It is mostly spotted in Southern American countries like Brazil, Venezuela, and African countries like Tanzania, Kenya, Madagascar. Sisal fibers extracted from the fresh leaves of Agava plants have considerable strength, durability, tensile strength due to the presence of high cellulose composition. Sisal fibers possess a tensile strength of 468-700 MPa and Young's modulus of 9.4-22 GPa.

Mattone (2005) confirmed that the addition of sisal fibers was successful in enhancing the tensile behavior and shrinkage characteristics of the soil matrix. Researchers have studied the compatibility of different natural fibers with each other, and the results presented were promising enough for the practical application in the sites. When coir fibers were used in conjunction with sisal fibers, Ghavami et al. (1999) noted that along with an increase in compressive strength, natural fibers imparted considerable durability to the soil. Furthermore, the authors have pointed out that stabilizing agents like cement is exceptionally compatible with sisal fibers in improving the durability characteristics of the soil.

Prabakar and Sridhar (2002) noticed a significant enhancement in the shear strength parameters of soil by conducting a compaction test and triaxial compression test on soil samples reinforced with sisal fibers at varying percentages and fiber length. Linear reduction in maximum dry density was observed with an increase in fiber length and fiber percentages. The author stated that significant improvement in shear stress was observed at an optimum fiber length of 20 mm and the fiber content of 0.75%, beyond which no increase was observed due to ineffective interlocking of sisal fibers with the soil matrix.

The effect of polymers in boosting the performance of sisal reinforced sand was studied by Wei et al. (2018). The author stated that polyurethane polymer played a vital role in strengthening the interparticle cohesion of sand along with the mechanical interaction of sisal fibers with soil matrix. Wu et al. (2014) analyzed the performance of randomly distributed sisal fibers in silty clay soil collected from the Quingdao district, China.

The fibers were added at 0.5, 1, 1.5%, and 5, 10, and 15 mm fiber lengths. The authors observed considerable bearing capacity improvement at fiber composition of 1% and a fiber length of 10 mm.

However, among the natural fibers, limited studies are carried out on the soil reinforcement using sisal fibers. Extensive studies regarding the durability characteristics of sisal fibers in soil and its adaptability to harsh environments are yet to be conducted to exploit these fibers fully. Moreover, the researches are constrained within the random distribution of sisal fibers in soil without focusing on the effect of oriented sisal fibers(planar reinforcements) in the soil matrix.

2.4 Bamboo

Bamboos are fast-growing plants that belong to the genre of bambusoideae. These plants can extend up to 4.5 to 12 meters due to their unique rhizome dependent system. Bamboos exhibit a notable specific strength of 549.4-1089.9 MPa/gm/cm^3 and have a tensile strength of 500-1000 MPa. Despite the remarkable mechanical and engineering properties of bamboo culms, their demand is limited in the market when compared to the manmade fiber geotextiles. This is due to inadequate technical information regarding the functionally reliable raw materials that are locally available in our country and because of the infrequent use of these fibers in the present construction field. According to the studies conducted by Agarwal et al. (2014), the inclusion of Bamboos in concrete has resulted in higher failure load and energy absorption capacity when compared to PCC and RCC. Researchers have experimentally pointed out that the incorporation of bamboo in concrete imparted an increased tensile, flexure, and impact strength. (Mansur and Aziz, 1983; Ghavami, 1995, 2005; M. M. Rahman, M. H. Rashid, M. A. Hossain, 2011; Mark and Russell, 2011; Terai and Minami, 2011; Khan, 2014; Ramaswamy and Mathew, 2019; Mali and Datta, 2020). Thus through research investigations, it is validated that bamboos are successfully capable of replacing steels in concrete. The abundant availability and desirable engineering properties of these natural fibers have encouraged the researchers to extend their application to the civil engineering field.

Currently, bamboo is substituted for other artificial fibers in reinforcing soft soils to enhance its load bearing capacity and increase stiffness. Toh et al. (1994) have reported the performance of Geotextile Bamboo Fascine mattresses in soft soils at slime ponds situated near the outskirts of Kuala Lumpur, Malaysia. The author has concluded that Bamboo fascine mattresses were not only successful in preventing the intermixing of soils but also played a significant role in controlling the excessive differential settlement of soft ground and thereby improving its bearing capacity. Further studies have indicated that, along with the tensile and bending stiffness of the bamboo reinforcements, its placement pattern also plays a significant role in controlling the load settlement behavior of soil. Khatib et al. (2005) have directly used bamboo culms at square and parallel patterns on soft clays overlaid by the geotextile layer to investigate the bearing capacity improvement. The author reported an increment of 127% in load carrying capacity with the provision of the reinforcement layer. However, the square pattern of bamboo culms proved to be more beneficial than parallelly placed bamboo culms. Later on, the application of bamboo reinforcements had achieved higher dimensions when the researchers initiated the use of bamboo mats, bamboo grids, and bamboo cells to replace its commercial counterparts like geotextiles, geogrids, and geocells considering the environmental and economic aspects. When comparing the performance of bamboo reinforcements with geosynthetics Hegde and Sitharam (2015) pointed out that the ultimate bearing capacity of clay bed reinforced with bamboo cell and the bamboo grid was 1.3 times greater than clay bed reinforced with geocell and geogrid. The authors observed that minimal surface deformation was noticed with the inclusion of 3D reinforcements(bamboo cells and geocells) when compared to the planar reinforcements(bamboo grids and geogrids). Asaduzzaman and Islam, (2014) observed, multi-layers of bamboo reinforcement is more effective in improving the bearing capacity of clay bed than single layer reinforcement. Ahirwar and Mandal, (2018) studied the performance of different aperture shaped bamboo grids to understand the effect of varying configuration, for its efficient application in weak soils. The authors concluded that tri-directional (Hexagonal) bamboo grids exhibited superior results when compared to the bi directional (Square) due to the confinement effect offered by the ribs and joints in the grids, owing to the smooth distribution of vertical stress.

To study the effect of treatment in bamboos, Maulana et al. (2018) compared the performance of treated and untreated bamboo grids in peat soils for supporting embankments of varying heights. According to the authors, treated Bamboo grids exhibited insignificant improvement in bearing capacity when compared to untreated Bamboo grids. The results were comparable to the experimental investigations conducted by Hegde and Sitharam (2015).

Therefore, through researches, it is concluded that bamboo fibers have potential application in geotechnical engineering and is capable of replacing artificial fiber reinforcement.

3 Conclusions

This paper briefly reports the different approaches of incorporating natural fibers into the soil and the effectiveness of various forms of natural geotextiles in problematic soils that are presently used. The development in certain countries is often hindered due to the rise of geotechnical problems and the scarcity of ideal quality sites. Natural fibers are affordable and readily available in these developing countries, and studies have shown that it has high potential in resolving geotechnical related issues. Moreover, the replacement of geosynthetics by natural fibers can control the environmental conditions of a country and can play a dynamic role in improving economic growth. Authors conclude that the performance of natural fibers are feasible enough to be applied on roads, embankments, slopes to maintain soil stability.

However, extensive and detailed researches are still required to prove the reliability of practicing natural fiber reinforcements in soil because of the declination observed in their consumption. This paper aims to shortly review the commonly used natural fiber intrusions in soils, and more researches are to be conducted in this area to explore the underutilized natural fibers that have suitable physical and engineering properties.

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