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EFFECTS OF NATURAL FIBRE REINFORCEMENT ON THE SHEAR STRENGTH PROPERTIES OF SOIL

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ABSTRAK

Depending on the material's origin, fiber reinforcement might be classified as waste, synthetic, or natural. Reinforcements made of natural fibers, such plant roots, are biodegradable, environmentally friendly, and have a good impact. Moreover, these fibers are lightweight and extremely rigid, which makes them ideal for improving soil. This research aims to study the effect of plant root reinforcement on the shear strength properties of soils. Soil and root fibres were collected within Universiti Malaysia Sabah Campus before being classified using existing standard. Direct shear box tests were conducted to determine the shear strength of the samples upon mixing with different root types (grass, shrub) at different percentages (0%, 2%, 4%, 6%). Results found that highest cohesion improvement is observed in soil SW-SM and shrub (VH-type) combination. In almost all cases, only insignificance effect is observed in the angle of friction. In conclusion, it was determined that the inclusion of root fibre improves the adhesion and the shear strength properties of the soil.

Kata kunci : Shear Strength; Plant Root; Cohesion; Angle of Friction; Natural Fiber

1. INTRODUCTION

In the tropical region, most of the slope soils are arid and infertile due to lack of buffering capacity and low clay activities which resulted in soil acidity (Osman et al., 2014). Soil acidity has a huge negative impact on fertility, biological activities and plant productivity. There was a great potential to alleviate soil acidity and erosion problems by the use of vegetation and their association with microbes (Osman et al., 2014). Hence, polluted and acidic soil may significantly contribute to restoring the natural environment with proper plantation and management in plants. Besides that, Osman and Barakbah (2011) found that the practice of using vegetation combines an ecological, mechanical and hydrological concept which has been successfully applied to alleviate soil erosion.

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Roots function by controlling the soil water content from exceeding the field capacity (Osman & Barakbah, 2011). Root plants will absorb and circulate the water to atmosphere rather than letting all infiltrates deep into the soil. Rainfall water infiltrates on slope lead to an increase in soil moisture content (Fan & Su, 2008). It then forms a web of network with the soil where the root is the key for this mechanism to operate and has become the main elements which related to shear strength.

The growth of root systems in soils is affected a wide range of soil properties; however, the properties of soils are modified by roots. It has long been appreciated that plants influence the properties of soils and that soil type can, in turn, influence the type of plant that grows. This close association of soils and plants has led to an ongoing debate as to the role of plants in soil formation. Geogory (2006) found that "without plants, no soil can form". This showed that plants can act as both a dependent and independent variable in relation to being a soil-forming factor. However, within a vegetation type, different plant species may have effects which lead to local variations in soil properties and where plants do act as a soil-forming factor.

In order to achieve the objectives of this research, tests have been conducted to determine the shear strength of the interfaces at different type of soil, varied plant type, and also different percentage of plant root. Hence, soil samples are tested based on three different types of soil. Two plant types (shrub and grass) from each location. There are four percentages of plant roots which included 0 %, 2 %, 4 %, and 6 % of plant root based on the plant type. Thus, a total of 24 specimens needed to be prepared.

2. RESEARCH METHODOLOGY

2.1. Desk study and sample collection

A desk study is conducted on the selected location for the collection of soil samples. The three locations are at Kota Kinabalu, Sabah. After the site visit, the soil samples are collected by using disturbed sample method. The soil samples are collected based on the plant type on the ground which included shrub and grass. Soil samples containing plant root will be taken to conduct the tests.

2.2. Soil classification and engineering properties tests

In order to determine the engineering properties of soil samples, soil classification which comprises sieve analysis, Atterberg's limit test, and specific gravity test should be done. Sieve analysis is conducted to determine the grain size distribution of soils. Besides that, Atterberg's limit test which involves cone penetration and rolling hand method to determine the liquid and plastic of soils. In addition, specific gravity test is done to determine the specific gravity of fine-grained and coarse-grained soils. Moreover, standard proctor compaction test will be conducted if the soil is clay to obtain the optimum moisture content maximum dry density.

2.3. Direct Shear Box Test

Upon achieving the basic soil parameters, direct shear box test is conducted to obtain the shear strength parameters. Before the tests being conducted, fibres will be washed in water so as to separate the root. Then, the roots will cut into smaller size and be weighed in order to determine the weight of plant root to be mix with the soil with various plant root percentages.

All the experimental methods are based on five guidelines which include Association of State Highway and Transportation Officials (AASHTO), American Society for Testing and Materials (ASTM), British Standard Classification System (BS), and Unified Soil Classification System (UCSC).

3. RESULT AND DISCUSSION

3.1. Soil Classification

Based on the test results from sieve analysis, Atterberg's limit, specific gravity, three types of soil samples that from Block C, D' Bayu and ODEC had been classified as shown in **Table 1**.

Table 1. Soil Classification Based on AASHTO, USCS, BS and ASTM

Site	Block C	D' Bayu	ODEC
AASHTO	A-2-4(0)	A-2-4(0)	A-3(0)
USCS	SP	SW-SM	SP
BS	SP	SM/SC	SP
ASTM	SP	Unclassified	SP

Based on the classification, it can be observed that the soil is poorly graded in 2 locations (Block C and ODEC) while classified as silty and clayey sand in 1 location (D'Bayu).

3.2. Root Fibre Classification

The classifications of grass type and shrub type in three locations are shown in **Table 2**and **Table 3**, respectively.

Table 2. Observation and Classification of Grass Root Type

Location	Root pattern	Type of root system
Block C	 Grass	 M-type
D' Bayu	 Grass	 M-type
ODEC	 Grass	 M-type

Table 3. Observation and Classification of Shrub Root Type

Location	Root pattern	Type of root system
Block C	 Shrub	 VH-type
D' Bayu	 Shrub	 R-type
ODEC	 Shrub	 H-type

The type of grass root system in all three places is M-type, which indicates that the maximal root development is deep but that 80% of the root matrix occurs within the top 30 cm, according to the root classification given by Styczen and Morgan (1995). Furthermore, the major roots have a small lateral extent and grow massively and lavishly beneath the stump. In the meantime, the VH, R, and H types of shrub root systems are present. The greatest root development in the VH-type is moderate to deep, while the first 60 centimeters include 80% of the root matrix. Furthermore, there is a robust tap root, but the lateral roots spread widely laterally and grow horizontally and copiously. In the R-type, the majority of the main roots extend obliquely or at right angles to the slope, and their lateral reach is large. The maximal root development is deep, with only 20% of the root matrix found in the top 60 cm. H-type roots grow to their maximum at a modest depth (>80% of biomass is found in the top 60 cm), with the majority of the roots extending horizontally and widely lateral.

3.3. Effects of Root Fibre Reinforcement on Cohesion

The analysis data from Figure 1 illustrated that at control condition (0% root fibre), the soil samples from Block C and D' Bayu have the cohesion of 1.81 kN/m^2 and 0.99 kN/m^2 respectively which are relatively higher as compared to soil sample from ODEC which only perform the cohesion of 0.27 kN/m^2. This show that the highest cohesion is observed in soils that contains clay. This can be proven based on the soil classification results, where the soils for Block C and D' Bayu are classified as sand with clay or and silt, whereas the soil from ODEC is classified as poorly graded sand which demonstrate that the clay content for soils from Block C and D' Bayu are comparatively higher as compared to soil sample from ODEC.

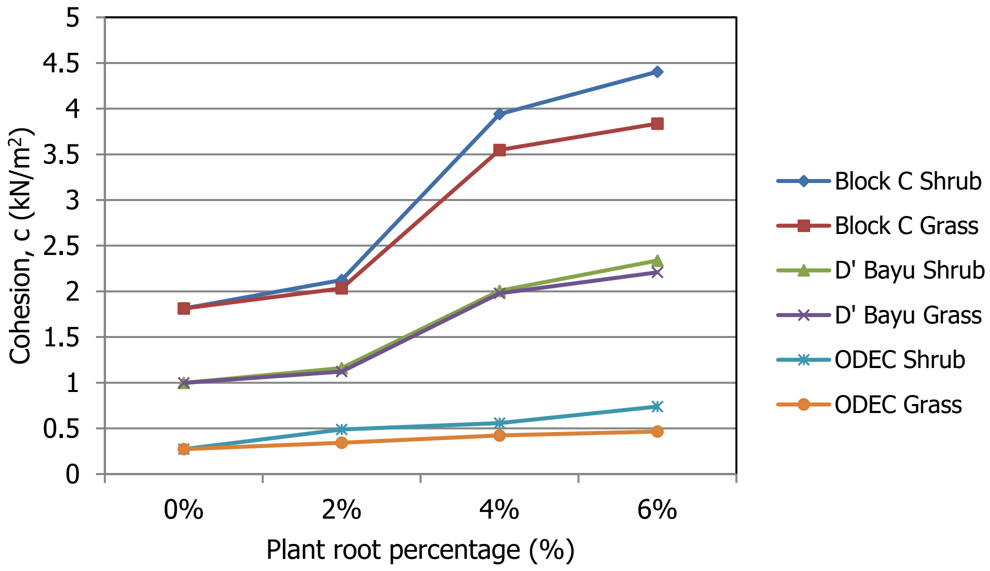

Figure 1. Cohesion Against Plant Root Percentages

In a mixture of sand and clay, it is very challenging to classify the soil into as sand or clay since it possesses both properties of sand and clay (Rathman et al., 2015). It was established by various past researches using reconstituted sand and clay mixture, the researchers concluded that for a clay and sand mixture, the cohesion increases with increasing clay content (Lius and Roger, 2000; Mohammad et al., 2011; Yongshan and James, 2002). Further to this, Shanyoug et al. had found out that the influence of clay content on the engineering properties of sand and stated that the clay content plays an important role on the mechanical response of soils, especially when the soils are subjected to loading.

Furthermore, it is observed that the cohesion for both shrub and grass at 6 % of plant root is relatively higher as compared to plant root of 0 %, 2 % and 4 %. This shows that the presence of roots has positively improved the shear strength of the soil, particularly their cohesion. Plant roots in the soil act very similarly to steel fibers in reinforced concrete and provide resistance to shear and tensile forces induced in the soil (Zhang et al., 2010). Besides that, the increase in cohesion is probably partly due to an increase amount of fiber (fine roots) of the species studied as reported by Nilaweera (1994). In the study of Nilaweera (1994), a fine root mat close to the soil surface may act like a low-growing vegetation cover and protect the soil from erosion.

3.4. Effects of Root Fibre Reinforcement on Angle of Friction

In comparison to the control samples (0% root fibre), the angle of friction for ODEC is comparatively higher than the angle of friction for Block C and D’ Bayu as shown in Figure 2. This is due to the sand particles in the soil sample of ODEC is comparatively higher than soil samples in Block C and D’ Bayu. The analysis data showed that the angle of friction for both shrub and grass decreases as the percentages of plant roots increases. For instance, the angle of friction for shrub at ODEC decreased from 15.39° to 10.28° which showed a reduction of 33 %.

This is because as the plant root percentages increased, there will be more spaces between the soil particles and the roots and hence produced an irregular outline between the surfaces. The regions of contact between the surfaces of the plant roots and soil particles are irregularly distributed; as a consequence, the effective surface of contact is smaller and hence the angle of friction will be reduced. However, Gray and Ohashi (1983) reveal that the presence of root had a little influence in the angle of friction of root-reinforced soil with respect to that of root-free soil. This statement had also been proven by the study of Ali and Osman (2008) which discovered that there is no prominent effect of the root matrix on the angle of friction in the soil.

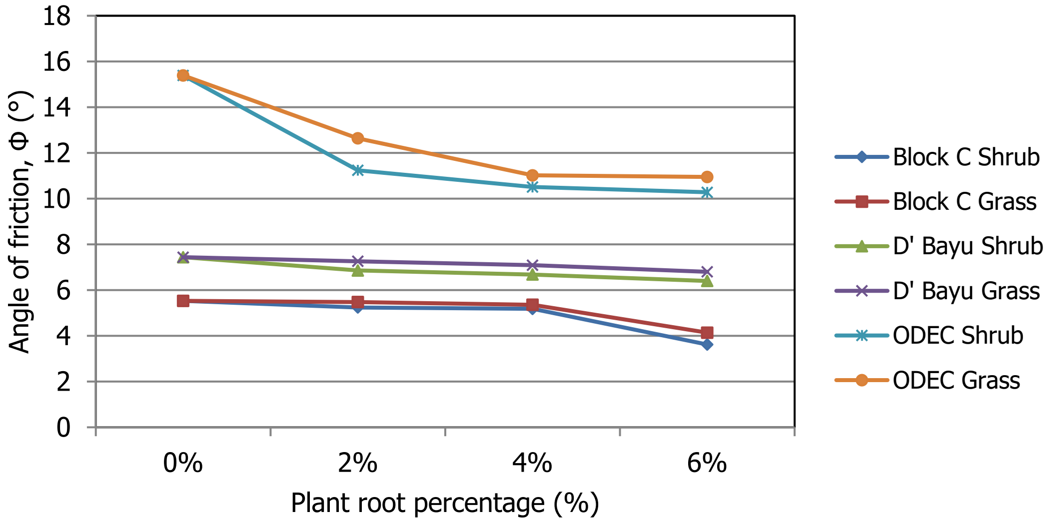

Figure 2. Angle of Friction Against Plant Root Percentages

Besides, the soil of ODEC is classified as poorly graded sand (SP) according to USCS. In contrast, the soil sample from Block C is also classified as SP based on the USCS but the AASHTO system highlighted that its dominant content is clay. Thus, it can be said that the majority particles in soil sample of ODEC are made up of sand. This sand particles which have angularity will possesses more interlocking as compared to others and hence will affect the shear resistance (Muawia, 2013). The values have a very minimal difference as the tests are conducted in small scale apparatus.

According to the study of Abdullah et al. (2011), the angle of friction does not significantly affect the shear strength. In the present study, the differences in angle of friction between the four types were not significant. It was observed that the angle of friction for the shrub of VH-type (Block C) was the lowest compared to the other species. Research found that the angle of friction was influenced by the types and grain size of soil (Dowell and Bolton, 1998). Thus, the differences in angle of friction between species observed may be affected by the architecture of the root presence where shrub from Block C has a large tap root system.

3.5. Effects of Root Types

The results obtained show that shrub for three different locations have higher value in shear strength in terms of cohesion as compared to grass. At 6 % of plant root, the cohesion for shrubs at Block C, D’ Bayu and ODEC are 4.40 kN/m^2, 2.33 kN/m^2 and 0.73 kN/m^2 which are higher than the cohesion for grass at 3.83 kN/m^2, 2.2083 kN/m^2 and 0.46 kN/m^2 correspondingly.

This is due to the root diameter for shrub is larger than the root diameter for grass (Abdullah et al., 2011). The increase in shear strength was due to the presence of vertical tap root in shrubs whereas grass has no single large taproot. Furthermore, shrubs produced longer and more branched roots than grass species (Nyambane and Mwea, 2011). The grasses allocated proportionately more biomass to roots but do not produce deeper roots or better branching pattern. According to studies of Anisuzzaman et al. (2002) and Schroeder (1985), both of them observed that the vertical root helps in plant establishment on slopes as it increases the pullout resistance where surface movement are frequent and it also anchored the soil to improve the resistance. Hence, the plant could help in improve the resistance towards the other forces such as wind and surface runoff which can cause slope erosion or landslide.

Moreover, the results revealed that shrub for Block C exhibits better shear strength properties as it has higher cohesion (4.40 kN/m^2) than the other species. This can be clarified that VH-type shrub from Block C has the most significant effect on reinforcing soil. Horizontal and vertical roots interacting together in VH-type improve soil shear strength in both directions and result in better reinforcing effects. Besides that, the outstanding shear strength performance of VH-type shrub was due to the role of its larger tap root diameter (Abdullah et al., 2011). This can be further support by the studies which discussed that the VH-type plant could display a prominent root system that has an imperative feature for stabilizing slope (Osman et al., 2014). Thus, it can be concluded that the morphology and architecture of the root affect the way root reinforced the soil (Abdullah et al., 2011).

4. CONCLUSION AND RECOMMENDATION

Although the analysis data showed that only one index of shear strength parameter, cohesion is increased and the other one, angle of friction may be decreased due to the presence of plant root, the final effect of roots in soil results in an increase in shear strength of soil. It can be concluded that the overall results indicated all the plants studied have good potential in reinforcing the soil based on their pertaining root and shear strength properties. Furthermore, the plant could help in improve the resistance towards the other forces such as wind and surface runoff which can cause slope erosion or landslide. In short, objectives are achieved by studying the variables that affect the shear strength parameters.

In this study, the plant root percentage that being tested only up to 6 % and it can be observed that the shear strength parameter, cohesion of soil showed an increasing trend. Hence, further research may be needed to study the influence of higher concentration of plant root on the shear strength properties of soil in order to get the optimum percentages of plant root.

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