International Journal of Engineering & Technology, 7 (4.28) (2018) 480 -483

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

The Use of vegetation to reduce Landslide hazards in Malaysia

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Abstract

The use of vegetation as slope cover becomes an alternative solution for slope stabilization instead of using structural or hard method of engineering techniques. Use of vegetation is a way to reduce the impact of engineering works and increase the landscape quality. Engineers usually are not familiar with engineering properties of vegetation to reduce slope instability and shallow landslide. Therefore, in this research, the soil engineering properties of two tropical species were studied. Eight trees of similar age of *Acacia mangium* and *Macaranga tanarius* were selected along the East-West highway, Malaysia. The direct shear tests were used to analyze the effect of tree roots on soil mechanical properties (soil cohesion and internal friction angle). The results showed that the existence of roots has more impact on the soil cohesion than the soil internal friction angle. In conclusion, slope stability improvement is provided by increasing the additional soil cohesion due to root.

Keywords: *landslides; vegetation roots; soil strength; slope stability; soil cohesion; additional soil cohesion by roots.*

1. Introduction

Use of vegetation in civil engineering is a way to reduce the impact of civil engineering works and increase the landscape quality [1].Vegetation can also increase soil mass strength because of direct influence on the soil. The other engineering function of vegetation on soil consist of interception of rainfall, protection of surface water runoff, protection against foot traffic, increase water infiltration, water uptake by roots, reinforcement of soil by roots, anchoring and buttressing by tap-roots [2]. [1] mentioned the engineering effect of vegetation along highways and railways such as slope stabilization on cuttings, water erosion, and gully erosion control.

On a global scale, slope failures have resulted in approximately 4500 death annually between 2004 and 2010. The highest number of human life losses due to landslides happened in India, China, the Philippines and Nepal [3].

In Malaysia, records somewhere around 1990 and 2009 demonstrate that there were around 2.8 landslides for each year, of which every year 1.7 landslides happened with human fatalities and property misfortune [4].

The information of slope failure occurrences along East-West Highway was mentioned by [4] between 1990 and 2004. He showed that only 4 landslides occurred along East-West Highway. According to another intensive study conducted by [5], between the year 2007 and 2008, 43 shallow landslides occurred along East-West Highway and about 23 landslides without a proper record were found. The researcher's observation shows that in December 2014, after a heavy rainfall which continued for a few days in Malaysia, 26 shallow landslides occurred along the East-West highway.

Due to loss of economy and human lives, numerous studies on man-made slopes have been conducted as well as new rules on the matter have been enforced in Malaysia [5], but studies on the use of vegetation in the aspect of its bioengineering effects to reduce landslide in Malaysia is still insufficient [5]. Many studies around the world have been conducted on root growth, phenology, and root function, but only a few studies have been done on the engineering aspects of roots in holding soil slope [6].

The use of vegetation as slope cover becomes an alternative solution for slope stabilization instead of using shotcrete cover. The reason for using shotcrete is to induce soil suction, but it no longer satisfies the public due to loss of sustainable environment. Live plants reduce rainwater infiltration by evapotranspiration, therefore, increase the shear strength of soil and then reinforce the soil by transferring the soil stress into the root fibers [7].

Slope stability is greatly dependent on soil shear strength increase due to mechanical reinforcement of roots [8; 9]. The increase in soil shear strength can successfully improve slope stability [10; 11]. Therefore, in order to improve our knowledge of tropical plant root properties which are important when investigating the plant effects on mass movement and shallow landslide, soil mechanical properties (soil cohesion and internal friction angle) data of two tropical species are collected to rank their ability to resist the shear stress and shallow slope failure.

Therefore, the aim of this study is to study the soil engineering properties of two tropical plants to increase soil shear strength and reduce shallow landslide along East-West highway, Malaysia.

2. Methodology/Materials

2.1. Study area

The study area is located along the East-West Highway of Malaysia. The East-West Highway is one of the major roads in the northern part of Peninsular Malaysia between N 05° 27′ 32.0″ E 101° 07′ 42.3″ and N 5° 42′ 11.15″ E 101° 49′ 54.74″. The length of the highway is 119 km which links two districts namely Gerik in Perak and Jeli in Kelantan. The climate of the study area is humid and annual mean precipitation is 1957.5 mm.

In this study, investigate species are *Acacia mangium* (Malay name: Mangium) and *Macaranga tanarius* (Malay name: Mahang). The studied species were selected based on the following factors which are the criteria to select slope stability species (Reubens et al., 2007; Stokes et al., 2008):

- Fast growing plant species (*M. tanarius* and *A. mangium*)
- Small species with a low canopy (*M. tanariu*)
- Self-renewal ability (*A. mangium*)
- Nitrogen fixing plants (*A. mangium*) improve soil materials with their nodulation functions; strong resistance; have a beneficial effect on soil resistance and infertility and soil and water conservation.
- *M. tanarius* has been chosen because there is no study about the effect of its root on soil cohesion and also it is the common species in Malaysia [11].

2.2. Sample Preparation

Undisturbed soil samples of rooted and non-rooted soil profiles from *A. mangium* and *M. tanarius* trees were taken by manually pushing the cylinder with a known volume (63.4 mm diameter × 20 mm height). Eight trees of the same age were selected, and a profile with 70 cm depth and 50 cm width for each tree was excavated. Three samples were taken at 30 cm soil depth from each profile (Figure 1).

Fig. 1: Soil preparation for direct shear test

2.3. Laboratory determination

The Strain-controlled direct shear test machine was used (Direct/Residual Shear Apparatus, MCR 2110/1, Geotechnical laboratory, Universiti Sains Malaysia). The undisturbed soil samples were placed in a shear testing device under three different normal loads 10 kg, 20 kg and 40 kg. A lateral displacement was applied at 0.25 mm/min until failure occurred and the peak shear force was noted (Figure 2).

Fig. 2: Strain-controlled direct shear test machine with the shearing box

2.4. Data Processing

First of all, collect 3 soil samples from each profile of trees at 30 cm soil depth, and then carry out the direct shear test under 10, 20 and 40 kg vertical pressure. A lateral displacement was applied at 0.25 mm/min until failure occurred and the peak shear force was noted. When 3 data of peak shear strength are measured, and then plot them to find the relationship between vertical pressure and shear strength, therefore the intercept of the line is soil cohesion and the linear slope is tan ϕ.

The soil engineering properties (soil cohesion and internal friction angle) were measured based on coulomb equation,

$$\tau = \sigma \tan\emptyset + C \tag{1}$$

τ soil shear strength (Kpa)

$\emptyset$ the internal friction angle (degree)

C the cohesion (Kpa)

The normal stress (σ) in KPa, is given by:

$$\sigma = ((9.81m)/1000)/A \tag{2}$$

m is the mass of frame loadings and loads weights (in Kg) (In this study the frame weight is 4.476 Kg).

1 kg $_{force}$ = 9.81 N

A is the soil area (The area of shear box= 0.003157mm^2).

3. Results and Findings

The relationship between vertical pressure and shear strength of two tropical plant species with and without root are shown in figure 3.

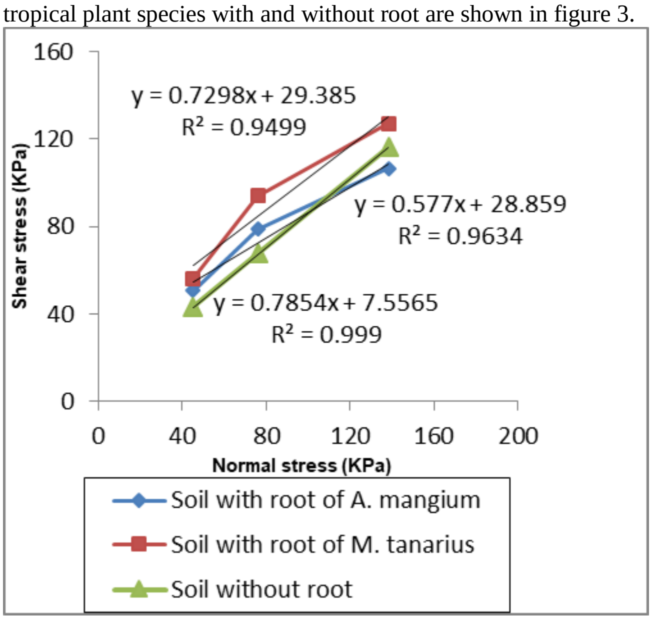

Fig. 3: Shear strength increment of soil–root system with direct shear test

When soil is covered by roots then the composite cohesion comes from not only soil particles but also the interaction between soil and roots. Therefore, the cohesion can be defined as integrated cohesion:

$$C = C_s + C_r \tag{3}$$

Where,

C_s is the soil cohesion

C_r is root cohesion

According to figure 3 and equation 3, the amount of soil cohesion and internal friction angle of both species is:

Table 1: Amount of soil mechanical properties of two species

Soil Sample	C (soil and Root cohesion) KPa	C_r (Root cohesion) (Kpa)	$\emptyset$ (°)
Plain Soil	7.6	-----	38.15
A.mangium	28.9	21.3	30
M.tanarius	29.4	21.8	36.12

4. Discussion and Conclusion

Laboratory and in situ shear tests on root permeated soil blockes have been conducted with a number of researchers around the world [12; 13; 14; 15]. Soil cohesion and internal friction angle of soil samples with and without roots around the world are shown in Table 2.

The information in Table 2 shows that the amount of soil mechanical properties (soil cohesion and internal friction angle) in literature and this research are not the same. The amount of soil cohesion in this research shows a higher value than the other research except [10]. The variability could be explained by the differences in sample size, soil type, and normal stress. The apparent friction angle showed 30 and 36.12 degree in soils with *A. mangium* and *M. tanarius* root, respectively. These results present higher values than those found by [16]; [17]; [18]; [10]; [19].

[10] analyzed the soil shear strength of rooted and non-rooted soil sample of *Robinia pseucdoacacia* with a triaxial compression test and it is found that roots have more impacts on the soil cohesion than the soil friction angle (Table 2). They argue that due to the presence of root, one index of soil shear strength (soil cohesion) increases and the other factor (friction angle) may increase or decrease. They concluded that roots reinforce soil by increasing soil cohesion and changes in soil friction angle have insignificant effects on soil shear strength. [20] state that the friction angle of soil has no significant effect on soil shear strength of three studied species compared to bare soil. The study shows that the cohesion of soil with root is significantly higher than those without root and this amount is significantly higher for *Leucaena leucocephala.* It could be due to the differences in root growth pattern which follows tap root system with long vertical root in *Leucaena leucocephala.* The internal friction angle for the species of *L. leucocephala* is the lowest compared to the other species. This is due to low quantity of total root length of *L. leucocephala*

In contrast to the other authors, [21] and [19] , who investigated the influence of *Alnus incana* and *Leuceana* trees on the shear strength, found only an increase in the internal friction angle of soil (Table 2). [21] stated that an increase in the soil shear strength of moraine with alder trees (*A. incana*) is due to an increase of the internal friction angle of soil from 34.3° to 39.4° without any change in soil cohesion. [19] show that the internal friction angle of soil sample with more roots is larger than that of soil samples without roots; this is due to the roots which increase the friction of the soil and therefore increases soil friction angle. The study found that the existence of the roots destroys the connections of clay particles and therefore diminishes the soil cohesion. He claim that in the direct shear test, the internal friction angle of soil contributes mainly to the root anchorage force. Therefore, roots can increase the friction angle and produce resistance to shear stress.

In addition to the information in Table 2, the other authors such as [14] showed that the existence of *Avena sativa* roots in soil increase the soil internal friction angle compared to non-vegetated soil and in overall increase the soil shear strength.

[22] state that slope stability improvement is provided by increasing the apparent root cohesion and rooting depth. The increase in shear strength because of the roots is reported in various studies is usually attributed to an increase in the apparent soil cohesion c′ [12]; [23]. [23] claim that the soil shear strength increases by increasing soil cohesion due to the presence of the plant roots in the soil and the effect of soil internal friction angle is negligible. They analyzed increased soil shear strength of four different species namely; *Vetiveria zizanoides*, *Leucaena leucocephala*, *Bixa orelana* and *Bauhinia purpurea*. Their results show that shear strength (soil cohesion) increases in *Leucaena leucocephala* more than that of the other species. According to [24], cohesion increases by increasing root amount in the soil, therefore, the differences in soil cohesion may be due to the differences in root profile. On the other hand, soil cohesion increases linearly with an increase in root cross-sectional area at the shear plane. [25] found that the effect of tree roots (Tamarisk and Russian-olive) on soil shear strength increases the soil cohesion without any changes in soil internal friction angle.

[24] also claim that grass roots increase the soil shear strength parameters (both soil cohesion and internal friction angle) of sandy clay loam soils, but for clay soil, it only increases soil cohesion.

The result of this study is in agreement with those who claim that the shear strength of soil increases due to the increase in soil cohesion. Therefore, this research is in agreement with [12]; [23]; [25]; [26]; [20]. According to the results, the soil cohesion of samples with roots for both species is higher than that without roots (Table 1). The results show that the amount of soil cohesion of *M. tanarius* is more than *A. mangium* (Table 1).

In conclusion, the impact of root frameworks on soil shear resistance is achieved through an increase in internal friction angle or apparent cohesion. However, results dependent essentially on species [27]. Slope stability improvement is provided by increasing the apparent root cohesion (additional soil cohesion due to root) [22]. To understand the root function in increasing soil strength, knowledge of the root system is required because this complex biological structure is unknown to the engineers. The use of vegetation as alternative solution needs knowledge of engineering properties and the vegetation interacts with soil, water, and climate, which many engineers are not familiar with the use of vegetation as an engineering material [1].

Due to the lack of knowledge and information regarding the root systems of common tropical species and their effect on soil shear strength, this subject is an important research area for further studies to applicate soil bioengineering techniques instead of civil engineering works in slope stability projects.

Acknowledgement

The authors thank Universiti Sains Malaysia for the financial support through Bridging Grant 304/PJJAUH/6316192/ USM Fellowship, PRGS research grant 1001/PJJAUH/846090 and MOHE grant 203/PJJAUH/6711279.

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Table 2: The soil mechanical properties of different species with and without root in literature and this research

Author	Species	Soil cohesion (KPa)	Internal friction angle (°)	Research method
[23]	*Leuceana Leucocephala* (after six months of growth at 10 cm soil depth)	9.90	48.74	Large direct shear machine
	Leuceana Leucocephala (after six months of growth at 30 cm soil depth)	14.85	40.03	
	Leuceana Leucocephala (after six months of growth at 50 cm soil depth)	23.64	31.38	
	Samples without root	4.57	39.35	
[21]	*Alnus incana*	-0.86	39.39	Triaxial test
	Samples without roots	-0.04	34.35	
[19]	*Leuceana* trees	15.80	6.20	Direct shear test
	Samples without roots	16.20	1.95	
[10]	*Robinia pseucdoacacia* (Horizontal root)	40	26.6	In situ direct shear test
	Robinia pseucdoacacia (Vertical root)	64	23	
	Robinia pseucdoacacia (Cross root)	74	23	
	Samples without root	29	27	
[20]	*Acacia mangium*	6.576	60.9	Large direct shear test
	Dillenia suffruticosa	4.433	61.17	
	Leucaena leucocephala	9.522	57.09	
	Samples without root	2.545	47.49	
This research	*A. mangium* root	28.9	30	Direct shear test
	M. tanarius root	29.4	36.12	
	Samples without roots	7.9	38.15	