AN INVESTIGATION OF *ACACIA MANGIUM* AND *MACARANGA TANARIUS* ROOT PROPERTIES AND ITS RELATION TO SOIL STRENGTH AND SLOPE STABILITY ALONG THE EAST-WEST HIGHWAY, MALAYSIA

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by

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Setting goals is the first step in turning the invisible into the visible

Tony Robbins

I dedicated this thesis to my parents, sisters and my little brother

For their love, support and encouragement

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This thesis is only a beginning of my long journey.

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KAJIAN SIFAT AKAR *ACACIA MANGIUM* DAN *MACARANGA TANARIUS* SERTA PERKAITANNYA DENGAN KEKUATAN TANIH DAN KESTABILAN CERUN DI SEPANJANG LEBUH RAYA TIMUR-BARAT MALAYSIA

ABSTRAK

Kestabilan cerun sangat bergantung kepada kekuatan ricih tanih disebabkan pengukuhan mekanikal akar. Kenaikan dalam kekuatan ricih tanih dapat memperbaiki kestabilan cerun. Pengaruh akar tumbuhan bagi meningkatkan kekuatan ricih tanih merupakan sumbangan utama dalam penyelidikan ini. Bagi penyelidikan ini, dua spesis pokok iaitu *Acacia mangium* dan *Macaranga tanarius* di sepanjang lebuh raya Timur-Barat Malaysia telah dipilih. Nisbah kawasan akar dan kekuatan tegangan pada jarak dua batang pokok diperoleh menggunakan kaedah pengorekan. Jelekitan tanah tambahan disebabkan oleh akar dikira menggunakan model serenjang ringkas. Bagi menyelidik sumbangan akar terhadap kekuatan tanih, ujian ricih terus tak terganggu sampel tanih dengan akar dan tanpa akar dijalankan. Pada masa yang sama, sifat fizikal tanih seperti kandungan air, graviti tertentu tanih dan saiz partikel tanih ditentukan menggunakan kaedah piawai. Hasil kajian menunjukkan bahawa tiada perbezaan di antara nisbah kawasan akar spesis tetapi terdapat perbezaan signifikan dalam nisbah kawasan akar dengan jarak batang pokok. Hasil kekuatan tegangan akar menunjukkan jumlah kekuatan tegangan akar adalah secara signifikan lebih tinggi dalam *A. mangium* berbanding *M. tanarius* dan jumlah ini berkurangan secara signifikan dengan jarak batang pokok. Hasil pengukuhan akar menunjukkan tiada perbezaan signifikan di antara spesis dan jarak batang pokok. Ujian fizikal tanih menunjukkan dengan kenaikan lembapan tanih, jumlah kekuatan ricih tanih menyusut. Hasil kajian menunjukkan terdapat kolerasi positif di antara kekuatan ricih tanih dan ketumpatan pukal tanih. Ujian kotak ricih tanah menunjukkan kewujudan akar dalam tanah meningkatkan kekuatan ricih tanah dan nilai kekuatan yang lebih tinggi bagi sampel tanih yang mempunyai akar *M. tanarius*. *M.tanarius* boleh meningkatkan kekuatan ricih tanah hampir 11% hingga 44% dan kekuatan richih tanah bagi pokok *A. mangium* boleh meningkat hampir dari 7% hingga 27%. Kesimpulannya, aspek kekuatan tegangan akar, *A. mangium* menunjukkan jumlah kekuatan yang lebih tinggi berbanding *M. tanarius* tetapi dalam aspek pengukuhan akar, sifat mekanikal tanah dan kekuatan ricih tanah, *M. tanarius* menunjukkan jumlah yang lebih tinggi berbanding *M. tanarius.* Oleh itu, ia menunjukkan bahawa penanaman campuran kedua-dua jenis spesis dalam kawasan kajian dapat mencegah ketidakstabilan cerun dan membantu memulihkan kawasan selepas gelongsoran tanah. Perbandingan pengukuhan akar diantara keputusan eksperimen (ujian kotak ricih) dan model (dikira) menunjukkan bahawa model terlebih/tersasar dalam meramal pengukuhan akar kerana semua akar tidak pecah dalam kegagalan ricih. Keputusan menunjukkan bahawa model lebih tepat dalam mempertimbangkan *A. mangium* berbanding *M. tanarius* disebabkan kekuatan tegangan tinggi akar dan pada masa yang sama lebih banyak akar dapat memberi lebih tegangan dalam zon ricih.

AN INVESTIGATION OF *ACACIA MANGIUM* AND *MACARANGA TANARIUS* ROOT PROPERTIES AND ITS RELATION TO SOIL STRENGTH AND SLOPE STABILITY ALONG THE EAST-WEST HIGHWAY, MALAYSIA

ABSTRACT

Slope stability is greatly dependent on soil shear strength due to root mechanical reinforcement. An increase in shear strength of soil can successfully improve slope stability. The influence of the vegetation roots to increase soil shear strength is the main contribution of this research. For the purpose of this research, two species, namely *Acacia mangium* and *Macaranga tanarius* along East-West highway of Malaysia were selected. Root area ratio and root tensile strength at two distances from tree stem were obtained with excavation method. Additional soil cohesion due to roots was calculated with a simple perpendicular model. In order to investigate the contribution of roots to shear strength of soil, direct shear test of undisturbed soil sample with and without root were carried out. At the same time, the physical properties of soil, such as moisture content, soil specific gravity and soil particle size were determined using standard methods. The results showed that there is no meaningful difference in root area ratio of the studied species but there is significant difference in root area ratio between distances from tree stems. The results of root tensile strength showed that the amount of root tensile strength is significantly higher in *A. mangium* than *M. tanarius* and this amount decreases significantly with the distance from tree stem. Root reinforcement results showed that there is no significant difference between species and distances from tree stems. The soil physical test showed that with the increase of soil moisture the amount of soil shear strength decreases. The results showed that there is a positive correlation between soil shear strength and soil bulk density. The soil shear box test results showed that the existence of roots in soil increases soil shear strength and this amount is higher in soil sample with *M. tanarius* root. *M. tanarius* trees can increase the shear strength of soil about 11% to 44% and *A. mangium* trees can increase about 7% to 27%. In conclusion, in the aspect of root tensile strength, *A. mangium* showed higher amount than *M. tanarius*, but in the aspect of root reinforcement, soil mechanical properties and soil shear strength, *M. tanarius* showed higher amount than *A. Mangium*. Therefore, it shows that the mix culture of both species in the study area could prevent slope instability and help to recover the area after sliding. The comparison of root reinforcement between experimental (shear box test) results and model (calculated) showed that the model over-predicts the root reinforcement due to the fact that all of the roots are not broken in shear failure. The results showed that the model is more accurate in considering *A. mangium* than *M. tanarius* due to higher root tensile strength and at the same time more roots provide more tensile resistance in shear zone.

CHAPTER 1 : INTRODUCTION

1.0. Introduction

Vegetation plays an important role in stabilising slope through its root by increasing soil cohesion (Cancienne, 2008). Two mechanical parameters of soil which are key matters to gripping the soil particles are known as soil cohesion and internal friction angle. Roots do not affect the internal friction angle, but improve soil cohesion by gripping the soil and increase the cohesion between soil particles. For investigating additional soil cohesion by vegetation roots, tensile strength of individual roots and root density of whole roots in soil are the key matters. Wu (1976) and Waldron (1977) investigated the theory for analysing additional soil cohesion by the existence of vegetation roots in the soil. The hypotheses of the theory consist of:

- The tensile strength of the roots is fully mobilised;
- Internal friction angle is not affected by the presence of roots in the soil (root reinforcement);
- Roots are completely flexible and oriented perpendicularly across the soil shear zone;
- All roots rupture simultaneously;
- Root cohesion is more affected by root area ratio rather than root tensile strength;
- Thickness of shear zone is restricted to a narrow one (Schmidt, 1999).

Many authors around the world have used this theory as it is considered a simple one and the required data can be easily gathered. In 2005, Simon and Pollen noted that Wu and Waldron model (WW, 1976) overestimate the root cohesion due to the fact that all of the roots cannot rupture at the same time during soil failure.

Therefore, they came up with a new theory on the concept of progressive failure of the roots during soil failure, in which the rupture of the roots depends on the root diameter and their tensile resistance to the failure. Even though their theory finds more actual data, many authors around the world are still using the model (WW, 1976).

1.1. Study background

Plants can meaningfully improve slope stability and avoid soil slippage in two ways, through hydrological mechanisms by dropping pore water pressure (Gyssels, Poesen, Bochet, & Li, 2005) and over mechanical reinforcement of soil by roots (Nilaweera & Nutalaya, 1999; Burylo, Hudek, & Ray, 2011; Askarinejad & Springman, 2015). In soil covered with flora, as the soil water transfers into plant roots, adverse suction or pressure is applied by the roots to the soil due to a decline of the soil water potential. Plants and soil both collaborate in this process which impact on the soil water content (Mafian, Huat, & Ghiasi, 2009). Slope stability is greatly dependent on soil shear strength increase due to mechanical reinforcement of roots (Gyssels & Poesen, 2003; Chok, Jaksa, Kaggwa, & Griffiths, 2015). Increase in soil shear strength can successfully improve slope stability (Pollen, 2007; Zhang, Chen, Liu, Ji, & Liu, 2010).

Plant root affords further cohesion to the soil and root-permeated soils are much stronger than soils alone to survive soil damage procedures such as mass movements. Root density, depth and tensile strength are the most influential factors of roots leading to soil fixation (Genet et al., 2008). Soil reinforcement due to the roots is influenced by numerous variables, including root systems such as root distribution with soil depth, root distribution over root diameter classes and root tensile strength (Nicoll & Ray, 1996; Stokes & Guitard, 1997; Li, Sun, Yang, Xiong, & Cui, 2007; Sun, Li, Xiong, Yang, & Cui, 2008; Loades, Bengough, Bransby, & Hallett, 2010; Stokes, Atger, Bengough, Fourcaud, & Sidle, 2009; De Baets et al., 2008; Burylo et al., 2011), root number, root diameter or rooting depth (Wu, McKinnell, & Swanston, 1979), root system architecture (Dupuy, Fourcaud, & Stokes, 2005) and pullout resistance (Nilaweera & Nutalaya, 1999). The roots in the soil reply inconsistently to load, depending on the root diameter and material of soil. Roots are strained in a way parallel to the load, and absorbing tension loads (Ammann, Boll, Rickli, Speck, & Holdenrieder, 2009).

It has been defined that there is a relation between root system resistance, and the number of roots, in addition to the changes in diameter and root angle (Sun et al., 2008). Roots can extend between 10-20% before breaking whereas soil can stretch less than 2% before breaking (Coder, 2010). It is commonly accepted that roots are strong in tension, but fragile in compression (Abdi, Majnonian, Genet, & Rahimi, 2010; De Baets et al., 2008). Conversely, soil is strong in compression, but fragile in tension (Pollen, 2007; De Baets et al., 2008; Abdi, Majnonian, Genet, et al., 2010). Thus, the existence of roots in the soil creates a reinforced complex in which stress is moved to the roots through the loading of the soil in shear zone in a way that is similar to the concrete structures reinforcement by steel and fiberglass (Abdi, Majnounian, Genet, et al., 2010). It is well documented in many researches that higher tensile strength is produced by fine roots (De Baets et al., 2008; Preti & Giadrossich, 2009). Therefore, it is concluded that a large number of small roots will contribute more to soil reinforcement as compared to a small number of thick roots

(De Baets et al., 2008). Information on a wide range of root tensile strength and root density produce key knowledge that is necessary in root-soil assessment analysis and this can be beneficial when selecting plant species for erosion control (Abdi, Majnounian, Genet, et al., 2010).

Interaction between tree roots and soil must resist environmental forces to keep a tree upright. There are different kinds of roots with different sizes which play some roles in anchorage. Tree roots as their structural and biological functions are suppressed by soil and soil microbial materials. Root number, root diameter, root density per soil volume, and associated root cross-sectional area are the index value in tree anchorage, and a composite of all these factors is root biomass (Stokes et al., 2008). There is some influence of vegetation on slope stability, such as the effect of root system strength in holding the soil on the slope face and the influence of the vegetation on the hydrology of each site (Maguigan, 2012); though both Sidle and Ochiai (2006) and Maguigan (2012) noted that “the root system is generally more significant in stabilising the slope”.

1.2. Vegetation and its engineering effects on soil strength

Soil stabilization is one of the least recognized influences of roots in woody shrubs and trees, and reinforcement of sloping ground. A summary of engineering influences of vegetation used to stabilise sloping ground (Norris & Greenwood, 2006) include:

- Additional effective cohesion due to the vegetation
- Tensile reinforcement force by the existence of roots
- Soil strength changes due to moisture removal by the vegetation
- Pore water pressure changes due to the existence of roots

Table 1.1 shows several plant characteristics with regards to its function in different usage. In the function of plant reinforcement, the vegetation which has these characteristics has the potential for soil stabilisation such as: deep root system, rapid root growth, high root/shoot ratio, leaf transpiration potential and propagation (Stokes et al., 2008).

Table 1.1: “Desirable plant characteristics for functions of vegetation” (after Gray and Sotir 1996, as cited in Stokes et al., 2008).

Function	Desirable Plant Characteristics
Capture and restrain	Strong, multiply, and flexible stems; rapid stem growth; ability to re-sprout after damage; ready propagation from cuttings and root suckers
Cover and armor	Extensive, tight, and low canopy; dense, spreading, surface growth; fibrous root mat
Reinforce and support	Multiple, strong, deep roots; rapid root development; high root/shoot biomass ratio; good leaf transpiration potential
Improve habitat	Shade and cover to moderate temperatures and improve moisture retention; soil humus development from litter; nitrogen fixation potential, ability to growth in different soil condition

1.2.1. Soil properties and tree root anchorage

The structure and features of the soil have an important effect on tree root anchorage. For example, rooting depth is influenced by soil structure, which is a great part of the anchorage strength (Ray & Nicoll, 1998; Cucchi et al., 2004).

The roots are strong in tension, while soils, on the other hand, are weak in tension, and strong in compression. Soil reinforcement is a combined effect of soil and roots. At the point when shearing the soil, as a result of shear stresses that develop in the soil, roots activate their strength in the soil grid and then shear stresses are exchanged to the root tensile resistance (De Baets et al., 2008).

The symmetry of the structural system of roots influences on the stability and soil holding capacity of trees on sloping and horizontal sites (Stokes et al., 2008). Plants protect the surface from rain plash and their roots help to bind the soil (Norris et al., 2008). When an area of a slope is cleared of vegetation, there is a gradual decline in soil strength due to root decay over time and the loss of evapotranspiration effects (Ziemer, 1981; Norris & Greenwood, 2006). Naturally, characterised sorts of plants are more qualified than others for particular stabilisation goals (Stokes et al., 2008).

Soil mechanical properties (soil cohesion and internal friction angle) and root architecture are the most important factors in tree anchorage. On the other hand, based on the research conducted by Rahadjo et al. (2014) it is concluded that tree anchorage is not affected by soil shear strength. They found that on the weakest soil, according to soil engineering properties (soil cohesion and internal friction angle), the highest maximum overturning force takes place.

1.3. Problem Statement

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 (Stokes et al., 2014).

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 (Komoo, Aziz, & Sian, 2011). Table 1.2 presents the information on landslide occurrences in Malaysia between 1990 and 2009 (Komoo et al., 2011).

Table 1.2: A summary of major landslide occurrences in Malaysia between 1990 and 2009 (Komoo et al., 2011)

Year	Total death	Total landslide	Events with fatality
1900-1979	70	4	Perak: 3
1980-1984	No data	No data	No data
1985-1989	2	1	Sabah: 1
1990-1994	53	7	Selangor:2; Pahang: 1
1995-1999	109+302*	21	Sabah: 5; Pahang: 2; Perak: 2; Kuala Lumpur: 1
2000-2004	57	14	Selangor: 4; Sabah: 2; Perak: 1; Pahang: 1; Johor: 1; Sarawak: 1
2005-2009	28	13	Selangor: 4; Sabah: 3; Pahang: 1; Sarawak: 1

*The Greg Tropical Storm in Keningau, Sabah

The information of slope failure occurrences along East-West Highway was mentioned by Jaapar (2006) between 1990 and 2004. He showed that only 4 landslides occurred along East-West Highway (Table 1.3).

Table 1.3: Detailed information on landslide occurrences along East-West Highway (Jaapar, 2006)

Date	Location	Fatalitis (No.)	Injuries (No.)	After effects
22.12.1993	Km 9, 20, 24, 25 and 26 of East- West Highway, Kelantan	0	0	No record
31.12.1993	Km 59.5, East-West Highway, Kelantan	1	3	A car damaged
11.11.1994	Km 32, East-West Highway, Kelantan	0	0	Road closure for several days. Ten people stranded
15.11.1994	Km 33, East-West Highway, Kelantan	0	0	Road closure for several days

According to another intensive study conducted by Lateh, Tay, Khan, Kamil, and Nazirah (2013), between the year 2007 and 2008, 43 shallow landslides occurred along East-West Highway and about 23 landslides without proper record was 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. Based on observation on the East-West Highway, it shows that *Acacia mangium* and *Macaranga tanarius* cover slopes along the highway and this could be positive to slope stability.

According to Table 1.1, Stokes et al. (2008) stated several criteria of slope plants which are found in *A. mangium* and *M. tanarius*; such as: rapid stem growth (Kadir, Kadir, Cleemput, & Rahman, 1998), nitrogen fixation plant (Jeyanny, Lee, & Rasidah, 2011) and ability to grow in different soil conditions (Kadir et al., 1998) in *A. mangium*. Factors such as small tree with low canopy and ability to grow in a variety of soil types were found in *M. tanarius* (World Agroforestry Center, 2002). Therefore, these two species are considered as suitable species for slope stability.

Due to loss in 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 (Jaapar, 2006), but studies on the use of vegetation in the aspect of its bioengineering effects to reduce landslide in Malaysia is still insufficient (Ali, 2010). Many studies around the world have been conducted on root growth, phenology and root function, but only few studies have been done on the engineering aspects of roots in holding soil slope (Cazzuffi, Corneo, & Crippa, 2006).

Maximum root reinforcement on a slope is an essential element to stabilise slope especially in tropical countries and the management of protected forests (Schwarz, Cohen, & Or, 2012). However, there is inadequate data of root system or root dynamics in Malaysia, as Schmidt et al. (2001) claimed, the growth habits of trees are highly changeable even within the same species growing in different environments in slope stability projects. Therefore, in order to upgrade our knowledge on root properties as well as for erosion control and prevent slope instability, collecting data in a different environment is necessary.

For a long time, tropical plant root information has been very limited. Recently, a few studies have been conducted in investigating tropical root properties and their effects on slope stability. Some of these studies include:

- Osman and Barakbah (2006) investigated the relation between root length density (RLD) and soil water content on slopes along the North-South Expressway. They found positive effects of these two factors on slope stability.

- Root reinforcement, soil shear strength and root profile of *Leucaena leucocephala* was investigated by Osman, Faisal, and Barakbah (2008). They recommended *L. Leucocephala* as a prominent slope plant due to its great capacity of root reinforcement and water absorption.
- Ali (2010) studied the root tensile strength and pull-out resistance of three tropical plants namely; *Acacia mangium, Leucaena leucocephala* and *Melastoma malabathricum* on different stem sizes.
- Osman, Abdullah, and Abdullah (2011) compared the effects of two different tropical plants namely; *Leucaena leucocephala*, *Acacia mangium* on slope stability in different stem sizes. In this study, root tensile strength and pull-out tests were analysed.
- Osman and Barakbah (2011) studied the effects of plant succession on slope stability. Four experimental plots consist of grasses (G), *Leucaena leucocephala* (LL), plots with four shrub species (SS) and plots with *L. leucocephala* and shrubs (LLSS) were considered. In their study, (RLD) and root strength were analysed and the result showed the effects of mixed culture on slope stability.
- Lateh, Bakar, Khan, and Abustan (2011) studied the effects of root reinforcement of Agave and tea plants to slope stability on prototype slope. Their work suggested that further research should investigate the effects of root reinforcement on real slope position.

However, the number of tropical species studied remains very limited. None of the above works studied on slope stability problems which consider additional soil cohesion due to the existence of roots of *Acacia mangium* and *Macaranga tanarius*. There is no information about root growth pattern of *M. tanarius* and its influence on slope stability are found in literature as well as there is also no study on the effects of vegetation on soil shear strength and soil stabilization along the East-West Highway.

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, root properties information (root area ratio and root tensile strength) and soil mechanical properties (soil shear strength) data of two tropical species (root system of different species may have different characteristic and therefore different adaptability to the environment and thus have different mechanical properties (Schmidt et al., 2001)) are collected to rank their ability to resist the shear stress and shallow slope failure.

Root tensile strength, density and root depth show significant differences with species. On the other hand, tree succession would affect the magnitude of root strength in areas capable of slope instability. Several studies (Ali, 2010; Roering et al., 2003) have been shown the effect of local vegetation on slope failure occurrence. Studies on linking the distribution of trees around slope failure with estimation of root strength will improve the unstable areas (Roering et al., 2003).

Despite the importance of root distribution in soil reinforcement process, very few studies describe the spatial variability of root distribution with regards to growth conditions around tree trunk (Abernethy & Rutherfurd, 2001; Hales, Ford, Hwang, Vose, & Band, 2009; Ji, Kokutse, Genet, Fourcaud, & Zhang, 2012). Genet, Stokes, Fourcaud, and Norris (2010) mentioned that gap happened between trees where root distribution reduced and the slope stability decrease significantly as the number of trees decreased. Danjon, Barker, Drexhage, and Stokes (2008) also mentioned that with increasing distance from tree trunk the amount of soil reinforcement by roots decrease and the highest soil reinforcement occurs close to the tree stem, and this amount is negligible at a distance more than 1 meter from tree stem. Therefore, in this research root information (Root area ratio, root tensile strength and root reinforcement) were calculated at two distances from tree trunk to describe the root distribution and root reinforcement with distance from tree stem.

A number of authors around the world (Operstein & Frydman, 2000; Wu, 2007; Ali & Osman, 2008) claims that roots could enhance soil shear strength according to the root-soil direct shear test, therefore, it is believed that cohesion correlated positively with root content, but there is little correlation between internal friction angle and root amount. Endo and Tsuruta (1969) argued that the increase of cohesion of soil is positively correlated with root amount. However, other authors such as Jiao, Wang, Xie, Zhang, and Guo (2010) believed that soil shear strength increases with the enhancement of internal friction angle, in which there is a positive correlation between soil internal friction angle and root amount, and also soil cohesion is negatively correlated with root amount.

In order to answer this question that the presence of roots in soil column effect on soil shear strength, and make clear the properties and mechanics of *Acacia mangium* and *Macaranga tanarius* root reinforcement of soil, the direct shear test of undisturbed soil sample with and without roots were carried out in the study area to determine the characteristics of cohesion and internal friction angle of soil under different variables. In addition to direct shear test, simple perpendicular model (WW, 1976) was used to analyse the root reinforcement of tree roots. Then the values from direct shear test (Measured) and simple model (Calculated) were compared to understand if the model describes well the roots natural behavior of tested species.

Literature gap: The number of plant species that can be studied is still too many; especially the mechanical characteristics of tropical plant root systems which have not been fully studied. Further research is needed to study about the root system of different species in different environment and analyse their mechanical properties as a function to indicate the root reinforcement. This study is interested to work on soil reinforcement due to vegetation roots and helps to fill the gap and produce more information and data on the root and soil mechanical properties of tropical plant species.

1.4. Research Objectives

There are a number of factors such as soil depth, root tensile strength, the internal friction angle and root cohesion that show why a certain site is more prone to slope failure. Due to vegetation roots that provide impressive cohesion to the soil, the reinforcement of roots can significantly increase the stability of slopes (Chok et al., 2015). Therefore, knowledge on the effective cohesion due to root tensile strength and root area ratio in different species across the landscape could meaningfully improve the knowledge of additional soil cohesion due to specific vegetation roots and it would also be useful for planting in erosion control purpose.

One of the limiting factors in the use of biotechnology of environmental engineering is lack of knowledge about the characteristic of the root systems. Therefore, knowledge on morphological and mechanical properties of root system of different plant species is an effective parameter to select an appropriate slope stability species. The main aim of this study is to investigate the effect of vegetation roots of two broadleaf species on soil shear strength.

Specific research objectives are:

- To investigate root area ratio, root tensile strength, root tensile force and root reinforcement according to species and distance from tree stem.
- To evaluate the relative increase in soil shear strength of two tree species in tropical forest.
- To compare additional soil cohesion due to root with model (Calculated) and direct shear test (Experimental).

1.5. Research Questions

- Do species and distance from tree stem affects root area ratio, root tensile strength, root tensile force and root reinforcement?
- Does the existence of *A. mangium* and *M. tanarius* root system in soil increase the soil shear strength?
- Does the root reinforcement model (calculated) explain the root natural behavior better compared with experimental test?

1.6. Research Hypothesis

- There is no significant difference in root area ratio, root tensile strength, root tensile force and root reinforcement by species and distance from tree stem.
- There is no significant difference between shear strength of rooted and non-rooted soil.
- There is no difference between root cohesion derived from calculated model and direct shear test.

1.7. Significance of the Study

Utilization of bio-engineering on slopes and road cuttings depict the use of vegetation to the protection of river banks and slopes. Bio-engineering combines an understanding of engineering principles with knowledge of vegetation and its interaction with soil.

Surface movement and shallow or deep instability cause slope failure. Surface movement in upland zones is normally caused by excessive rain or frost, furthermore can occur in cuttings. For shallow instability which is the most essential issue within 2m of the ground surface in clay soils and cutting sections, vegetation can be helpful. Grass roots regularly extend out to 0.5 meters below ground level and shrub and tree roots extend about 2 to 3 meters underneath the surface. The presence of vegetation can significantly effect the water level in the soil and also the pore pressure of water in the soil (Greenwood, Norris, & Wint, 2006). Vegetation has two main effects on the slope stability with hydrological effect and mechanical effects. By hydrological effect, vegetation can increase the capacity of water infiltration and reduce the water content in the soil and also with evapotranspiration increase the effective soil cohesion and the effective soil cohesion enhances by increasing in reinforcement effect (Gyssels et al., 2005). In mechanical effect the presence of vegetation roots crosses the potential failure slip surface, provides a tensile force which is an additional restrain on the potential slip (Nilaweera & Nutalaya, 1999; Burylo et al., 2011; Gyssels & Poesen, 2003). Use of vegetation for slope stabilization as the construction cost to compare conventional, has lower initial construction cost and it needs just regular observation and maintenance. It is so difficult to measure visual appearance, but it can be recognized by the public. Bio-engineering offers an alternative solution instead of using a conventional massive structure for slope stability and shallow landslide (Leung, Yan, Hau, & Tham, 2015).

In particular, this study is mainly related to the study of the mechanical effects of two types of tropical plants and their roots contribution to soil shear strength. For this reason, some information such as; a) plant properties consist of diameter at breast height, b) root distribution and root mechanical properties (tensile strength) c) soil geotechnical properties, such as soil particle size, soil bulk density, soil moisture and d) soil mechanical properties (soil cohesion and internal friction angle) are gathered.

1.8. Summary

This chapter explains the influences of vegetation on slope stability and slope failure occurrence as natural disaster in a global scale and in Malaysia. Slope failures become one of the serious natural disasters in Malaysia. Due to the fact that in humid tropical and sub-tropical regions, there is a relationship between rainfall and slope failure. Most of the slope failures are caused by heavy rainfall in wet season due to the loss of negative pore water pressure and matric suction. Although the use of vegetation to reduce slope failure is common around the world during the last decades, but in Malaysia there is still a lack of such studies on the use of vegetation to reduce slope instability. In Malaysia, there is a limited study on root properties and vegetation root effects on slope stability. This raises the question why research on the effect of root mechanical characteristics on slope reinforcement is limited.

CHAPTER 2 : LITERATURE REVIEW

2.0. Introduction

The use of live 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 (Leung et al., 2015). 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.

This chapter presents previous studies and researches on root physiology and engineering parameters of root system which focus on slope stability and the effect of root mechanical properties on slope stability.

2.1. Engineering parameters of root system

2.1.1. Root physiology and root reinforcement

Plant roots typically have three important functions and they are usually located underground. Primary roots include root caps, lateral roots and root hair (Figure 2.1). The main functions of all of types of roots are to 1) absorb water, minerals and nutrients, 2) transport these materials inside the plant, and 3) anchor the plant into the soil (Pratt, Jacobsen, Ewers, & Davis, 2007). The wide variations in root system, both inter species and intra species, is due to genetic and environmental conditions which affect material and architectural characteristics of the root system (Duckett, 2014).

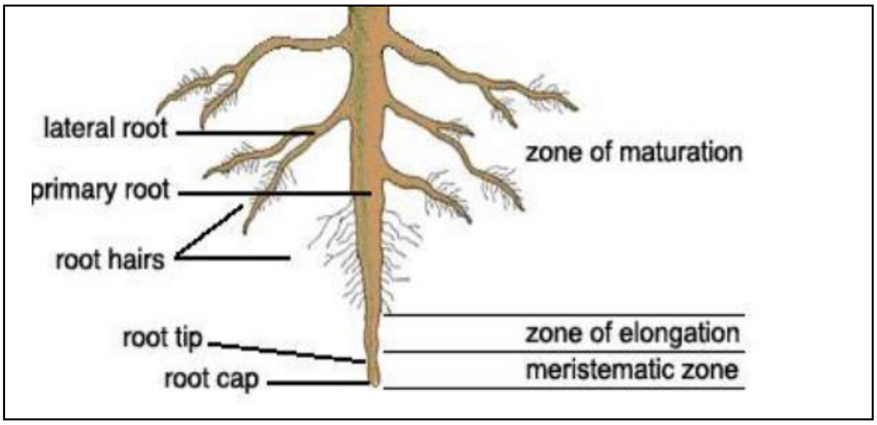

Figure 2.1: Root physiology (Duckett, 2014)

A description of the architecture of root systems is required in the studies dealing with root systems. During the twentieth century, qualitative methods were used for assessing root system architecture. However, in the last 40 years, quantitative methods were developed in plant architecture analysis. Since the end of 1990s, coarse root architecture was measured by new devices and techniques such as volume location techniques and semi-automatic 3D digitizing. Furthermore, for modeling procedures, full 3D root system analysis is used. In addition, topology and geometry root data are needed to obtain a full 3D architecture. Topology data are needed for understanding and investigating the influence of slope and wind on root architecture. Roots geometry is used to understand symmetrical and asymmetrical coarse root system structures which are important for the use of vegetation to stabilise slope. Root architecture can be achieved by classifying individual roots in several types of roots (Danjon & Reubens, 2008). Parr and Cameron (2004) show that environmental factors such as; nutrient variations, physical barriers and soil water status are typically associated with root asymmetrical development. Spatial variation of water and nutrient in soil cause root asymmetry and clustering (Soethe, Lehmann, & Engels, 2006).

Chiatante, Scippa, Di Iorio, and Sarnataro (2003) claim that on plane soil, plant root systems show a normal symmetrical architecture while in steep areas due to the response to the mechanical force to overturn, plant root systems show an asymmetrical architecture. This asymmetrical root architecture helps plants to increase stability on steep slopes by changing the mechanical force distribution in the soil. This hypothesis is supported by "self-loading" theory on slopes whereby roots growing in the up-slope are under tension and tend to be elongated whereas roots growing in the down-slope are under compression and tend to be shortened. The root system which has asymmetrical architecture due to growth on slope is called "bilaterial fan shape".

The root system architecture of *Pinus sitchensis* on horizontal and sloping terrain was studied by Nicoll et al. (2006). For the purpose of this study, nine trees per direction (upslope, down slope and across-slope) on the slope area and nine trees on the horizontal part of the site are excavated in random directions. The results show that there is a linear relationship between root volume and stem volume. The location of root volume on horizontal and on slopes shows different variations. More root mass is in the windward sectors for trees on the slope, but for trees on the horizontal the highest root mass is on the leeward sectors.