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Full Length Research Paper

Influence of tensile force of agave and tea plants roots on experimental prototype slopes

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The study is aimed to determine the influence of tensile force of roots of agave (*Angustifolio marginata*) and tea (*Acalypha siamensis*) plants on landslide in prototype slopes. The plants of agave and tea were planted in different prototype slopes and the corresponding tensile forces were measured with the installed strain gauge *in-situ*. The study found that the tensile force of tea plants increase with increased root diameter inside the prototype slopes with angle which ranged from 30 to 40°. But, the tensile force of agave roots decreased slightly with increased slope angle. Again, the tensile force increased significantly with increased width-height ratios of agave leaves. The plant agave and tea showed significant results to protect the experimental prototype slopes. Regression relationship between tensile force and root's diameter of tea and agave plants has been established. Further research can bring positive impact in using such plants in actual natural slopes in order to prevent the landslides.

Key words: Tensile force, agave and tea plants, roots, slope, landslides.

INTRODUCTION

Slope failures can be attributed to several factors such as climatic conditions, geological features, topography, plant or a combination of these factors (Basile et al., 2003). Plant has long been considered to improve slope stability and several pioneering works have been done (Schiechtl, 1958; Endo and Tsuruta, 1969; Wu et al., 1979; Bibalani et al., 2006; De Baets et al., 2008; Normaniza et al., 2008). Plant can enhance the stability of a slope by root reinforcement. The plant factor can be a significant factor in protecting slopes. Wu et al. (1979) suggested that the root reinforcement from plant increases slope stability. Genet et al. (2005) and Bischetti et al. (2009) found significant statistical differences of tensile strengths between the considered species of plants. According to Bischetti et al. (2009), the root tensile strength for *Castanea sativa* and *Ostrya carpinifolia* decreases considerably with root diameter.

Few laboratory studies (Endo and Tsuruta, 1969; Waldron, 1977; Waldron and Dakessian, 1981) related to protective effects of plant roots on shallow landslide have been conducted. A longer root mobilizes maximum tensile strength than a shorter root. Greenway (1987) and Gray and Sotir (1996) showed that the differences between root strength of different species of the same family can be very large. Similarly, there are large differences of tensile strength between roots of different species growing in different locations and climate.

The role of tensile forces of plant roots on slope can be judged in experimental proto-type slope. Generally, the shallow sliding of a soil mass results in a number of tensile cracks on the slope surface at an early stage. In rooted soil, a number of roots are found crossing these tensile cracks from both sides. The roots from the stable mass invade downwards and help to hold the sliding soil mass against further down-slope movement, through their tensile properties and root-soil bonds. The roots from the sliding side, in contrast, anchor the mass to the stable mass to prevent further movement. When tensile cracks occur, the soil itself tends to limit their extent to a certain degree with its own tensile strength if the soil mass is penetrated by lateral roots. It may obtain an

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Abbreviations: USM, University Sains Malaysia; **Δs**, additional cohension.

Figure 1. Agave (*A. marginata*) plants.

additional tensile strength due to the traction effect of these roots. In the case of soil creep, the tensile cracks likely to occur, and the roots will act in the same way. In an area of vertical cross-section within the tensile cracks, the moving-resistant force per unit area exerted by the roots hold the rooted soil-mass against lateral movement. The roots of the plants were impregnated inside the slope. Despite these root actions, the slope failed. Hence, the role of such plants in providing additional strength to the slope angle is not clear, or the plant's roots are not adequate in protecting the landslide. It is obvious that the roots of different plants act differently on the slope angle. There may be some plants which can provide more strength to the slope angle by extending their roots and form a rigid root nets. Investigation on slope with and without plants shows increase in the shear strength attributed by the root. Tensile test of plant roots done on the prototype slope can provide tensile strength data for soil-root interaction. The actual behavior of the soil- root system to shearing depends on the failure mode of roots, which in turn, influences the ultimate mobilized tensile strength of roots. Roots can respond to shearing force in three different ways: stretching, slipping and breaking (Waldron and Dakessian, 1981; Ennos, 1990). Waldron and Dakessian (1981) claimed that slippage of roots limits their contribution to strength of fine soil. Riestenberg (1994) and Norris (2005) concluded that the number of branches and root morphology influences the stress-strain relationship and finally resists failure.

Roots produce a clear cohesion through reinforcement which promotes stability for shallow soil slope. The value of the root as cohesion is difficult to predict and plant growth habit varies widely even within species that grow in different environments. Burroughs and Thomas (1977) hypothesized that forest landslides occur within areas of low root reinforcement or in areas where the root strength declined substantially due to decay. In Malaysia, shallow landslides occurred during rainy days of each year and decomposed residual soils along the hill slopes despite the considerable amount of tree type vegetation cover. Mostly large trees can not contribute in protecting the shallow surface slides. Shrub or grass type plants can be judged important for shallow landslides in Malaysia. Lateh et al. (2009) found that agave plants on slope considered worth in providing cover on soil slope. These plants can restrain rain water from infiltrating into soil and reduce erosion. The characteristics of leaf, roots and sizes of agave (*Angustifolio marginata*) can reduce erosion, increase shear strength and prevent slope failures (Figure 1). It is assumed that the tea plants among others can also be regarded useful in protecting the shallow slides. The investigation of the effect of root of agave plant (*A. marginata*) and tea plant (*Acalypha siamensis*) on stability of slope can be important in mitigating the shallow landslides. This paper aimed to determine the influence of tensile force of roots of agave (*A. marginata*) and tea (*A. siamensis*) plants on prototype soil slopes within an experimental setup.

MATERIALS AND METHODS

Properties of the soil used for the experiment

Physical and strength properties of the soil materials for the model and prototype slope are given in Table 1.

Tensile force test

Tests for tensile force of root of plant agave (*A. marginata*) and tea (*A. siamensis*) were conducted in the prototype slope with angle ranges from 30 to 40° as well as in the pots with a base frame angled 0, 30, 40, 50°. A tripod equipped with strain gauge instrument as a recorder was used. The tests on the tea (*A. siamensis*) plants with same size and diameter were performed. The tests on agave (*A. marginata*) plants were conducted with the same width-height ratio of leaves and same root diameter. Tensile force test conducted in saturated conditions. The study was conducted on an experimental field setup inside the campus of University Sains Malaysia (USM). Test arrangements in the prototype slope and in the pots were shown in Figure 2.

Root architecture

Roots of sample plants agave and tea were obtained manually by pulling the plant in a pot. Then roots were washed to remove soil so that the root architecture can be observed (Figure 3) for agave (*A. marginata*) and for tea (*A. siamensis*). Root's of agave plant is longer than the height of the leaves. However, the root system of tea plant spreads laterally more than vertically and it covers more lateral area than the agave plant. Roots of agave plant grow vertically more than that of tea plant. This observation clearly represents the difference between root branching pattern of tea and agave plants.

Table 1. Soil property for experiment model.

Property	Soil in pot	Soil in prototype slope
Specific gravity (SG)	2.661	2.661
Dry density (γ_{dry}, kN/m^3)	13.439	16.292
Porosity (n)	0.403	0.303
Index plastic (IP, %)	31.65	31.65
Fines then < 0.063 mm (%)	51.68	51.68
Internal friction angle (Ø)	33°	29°
Cohesion (c, kPa)	17.5	20

Figure 2. Tensile force measurement of plant roots on experimental prototype slope (a) and pots (b).

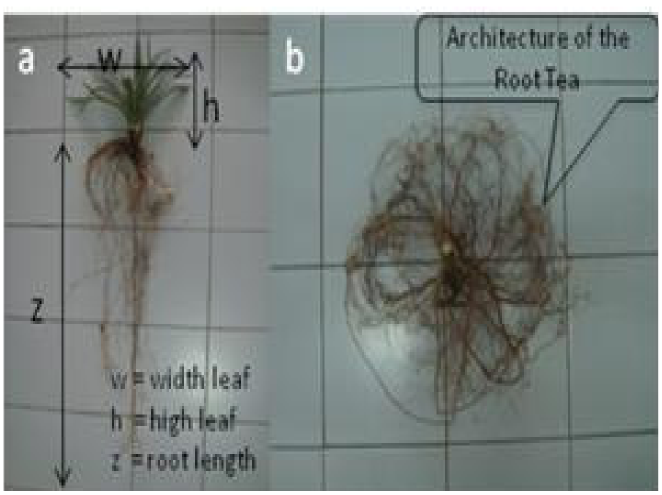

Figure 3. Root architecture of a, Agave (*A. marginata*); b, tea (*A. siamensis*) plant in pots.

Root reinforcement estimation

The presence of plant roots in soil acts as reinforcement through cohesion effects and enhances the stability of slopes (Schmidt and Kazda, 2001; Van Beek et al., 2005). Roots, as the reinforcement of soil (Wu, 1976) are widely used to estimate the additional cohesion (Δs). Such Δs need to be estimated in order to account the presence of roots in the soil (Gray and Sotir, 1996; Roering et al., 2003; Bischetti et al., 2005). In this case, the soil shear strength is reinforced by the root's strength, τ calculated by Morh-Coulomb equation as follows:

$$\tau = c + \sigma \tan\varnothing + \Delta s \quad (1)$$

where c is soil cohesion, Δs is additional cohesion due to the presence of roots, σ is the normal stress on the shear plane and Ø is the soil apparent friction angle. Shear force is developed on the soil when the soil moves and the force are translated into tensile strength in the roots. Mobilization of tensile strength in the root can then split into tangential and normal components. Assuming roots are elastic and initially oriented perpendicularly to the slip plane, fully mobilized in tension and that is unaffected by root reinforcement (Waldron, 1977; Greenway, 1987). Δs can be defined as:

$$\Delta s = t_r (\sin\delta + \cos\delta \tan\varnothing) \quad (2)$$

where t_r is the average mobilized tensile strength of roots per unit area of the soil and δ is the angle of root distortion in the shear zone. Sensitivity analyses show that values of (sinδ + cosδ tanØ) can be approximated as 1.2 for 30° < Ø < 40° and 48° < δ < 72° (Wu, 1995). Using these approximations, Equation (2) can be simplified as:

$$\Delta s = 1.2\, t_r \quad (3)$$

To calculate the Δs of root system that grown in the prototype slope and pots, the equation becomes:

$$\Delta s = 1.2 \frac{\sum t r_i \cdot n_i \cdot a_i}{A} \quad (4)$$

Where t_{ri} is root tensile strength (kPa), n_i is the number of roots in a diameter class, $_i$ is root diameter class, a_i is the root cross-sectional area (m^2) and A is the reference area of soil occupied by roots (m^2). The following formula was then used to calculate t_r (Bischetti et al., 2005).

$$t_r = \frac{F_{max}}{\pi \left(D^2 / 4 \right)} \quad (5)$$

where F_{max} is the maximum force (kN) required to pull the root and D is mean root diameter (mm).

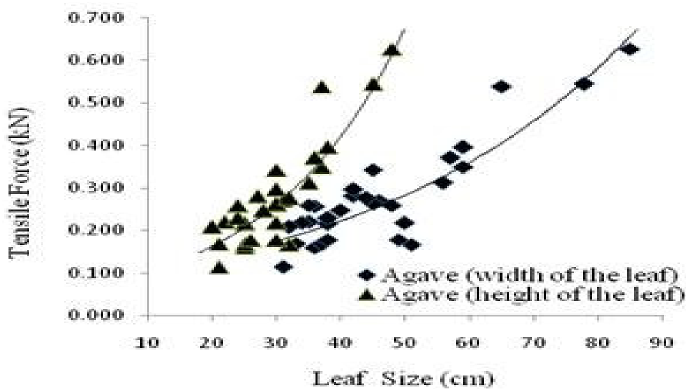

Figure 4. The relationship between the tensile force and the size of agave leaves.

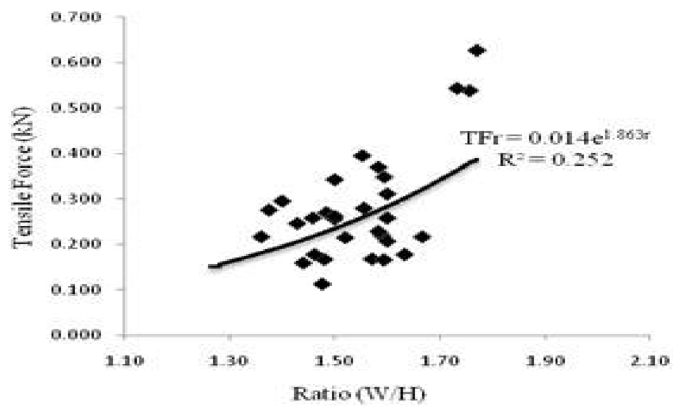

Figure 5. The relationship between tensile force and the width-height ratio of agave leaves.

RESULTS AND DISCUSSION

The tensile strength of roots

Results of tensile strength tests of Agave (*A. marginata*) and tea (*A. siamensis*) roots are described as follows:

Tensile force of agave roots

Tensile forces of agave roots with different leave's sizes and with different root's diameters were determined. From the results of the relationship between the tensile force (kN) with leaf size (cm) indicates that tensile force is directly proportional to the height and width of leaf (Figure 4). Tensile strength increased significantly with the increase of width-height ratio of the agave plant (Figure 5). The regression fitting for the relationship found as,

$$TFr = 0.014e^{1.863r} \quad (6)$$

where TFr is the root tensile force of agave plant, r is the ratio of width-height of leaves, *e* is the regression exponential and $R^2 = 0.252$.

The influence of tensile force with diameter of root against slope

Plants planted on prototype slope were tea (*A. siamensis*) with the root architecture shown in the Figure 3b. Tensile force was tested with different root diameter and the results showed that the tensile force of plant tea increased significantly with the increasing root diameter. The vertical roots penetrate the slip surface to work against failure. This situation assumes that the tensile strength of roots becomes fully mobilized if the roots are deeply embedded into the soil. The following equation represents the relation between tensile force and root of tea plant.

$$TFr = 0.023d^2+0.051d + 0.069 \quad (7)$$

where TFr is the root tensile force of tea plant, d is the diameter of the root tea, this is a polynomial regression curve with $R^2 = 0.932$ (Figure 6). The results obtained for the considered plants are in agreement with many other authors (Bischetti et al., 2005; Genet et al., 2005) and confirm the validity of the general power law equation for the relationship between root tensile strength and root diameter.

Figure 7 showed that higher inclination of tea root inside the pots have smaller increase in tensile strength. But higher inclination of agave root with width-height (W/H) ratio of 1.52 resulted reduced tensile strength.

Figure 8 depicts the relationship between the diameter of the roots of tea plant and tensile force on the prototype slope or in pots. Results showed that the tensile force increases significantly with the increase of diameter of the root in the prototype slope compared to that in the pots. The linear regression line for this relationship was found as,

$$TFr = 0.172d – 0.066 \quad (8)$$

where TFr is the root tensile force of tea plant, d is the diameter of the root tea and $R^2 = 0.968$ (Figure. 8).

Thus, this study can provide better understanding about the tensile force developed in the roots in order to protect natural slopes. The present study suggests further research on actual landslide cases to have the clear picture of impact of plant roots in preventing shallow landslides.

Conclusion

A number of tensile force tests on the roots of agave (*A. marginata*) and tea (*A. siamensis*) in experimental prototype slope have been conducted. The results

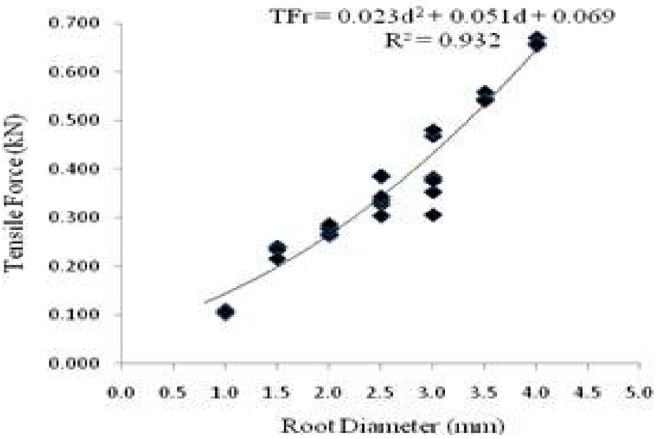

Figure 6. The relationship between tensile forces and the diameter of tea plant root.

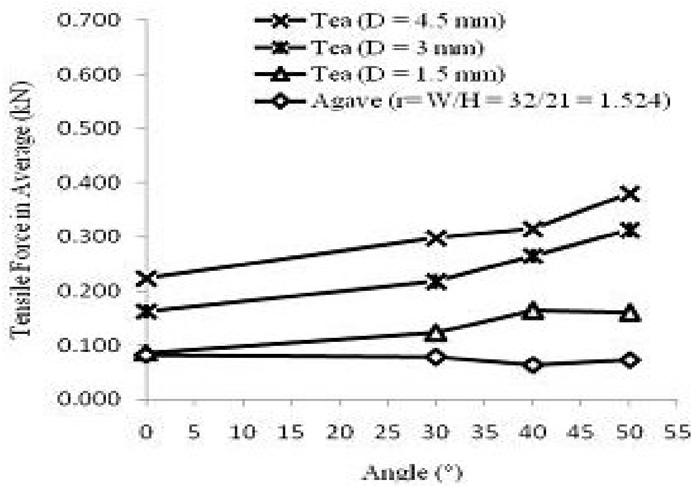

Figure 7. The relationship between the base frame angle slope of the pot and the tensile force.

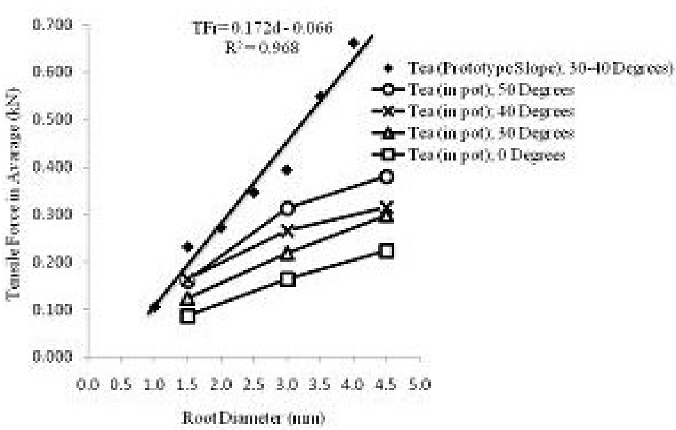

Figure 8. The relationship between the diameters of the roots and tensile force of tea plant for different inclinations of roots.

showed that the tensile force of tea plant root increased with increasing root diameter with a slope angle ranging from 30 to 40°. However, tensile force of agave roots decreased slightly with increasing slope angle. It also showed that the tensile force increased significantly with increasing width-height ratio of agave leaves. Agave plant showed a significant result to protect the experimental prototype slopes. Tea plant roots with an increased diameter also played an important role in preventing landslides in the prototype slope. Further research could bring significant results in using the plant on the slope of the real world to prevent landslides.

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