LOWLAND TECHNOLOGY INTERNATIONAL Vol. 16, No. 2, 71-80, December 2014
International Association of Lowland Technology (IALT), ISSN 1344-9656

ROOT STRENGTH MEASUREMENTS OF VETIVER AND RUZI GRASSES

Chairat Teerawattanasuk [1], Jindarat Maneecharoen [2], Dennes T. Bergado [3], Panich Voottipruex [4] and Le Gia Lam [5]

ABSTRACT: This paper aims to study effect of roots of vegetation on the stability of soil along slopes and also soil erosion. The effects of root reinforcement depend on the morphological characteristics of the root system, the tensile strength of grass roots, and the spatial distribution of the roots in the soil. The experiments were carried out to evaluate the root tensile strength of two different grasses namely: Vetiver and Ruzi grasses, by conducting the laboratory tensile tests and field direct shear tests. For each type of grass, single root specimens were sampled and tested for their ultimate tensile strength and Young's modulus in the laboratory tests. The results of laboratory tests revealed the significant correlations between root diameter and tensile force or tensile strength and Young's modulus of Ruzi and Vetiver grasses. In addition, large scale field direct shear tests were carried out involving roots of Vetiver and Ruzi grasses to evaluate the contributions of their root systems to the soil shear strength. Vetiver roots contributed higher components of shear strength compared to Ruzi grass. However, it was found that the combination of Ruzi and Vetiver grass roots yielded much better effects than Vetiver grass alone. It can be concluded that the Vetiver grass roots help enhanced the shear strength for soil reinforcement while the short roots of Ruzi grass can help control surface soil erosion.

Keywords: Combination root system, Ruzi and Vetiver grasses, tensile strength, ultimate tensile force, Young's modulus, shear strength.

INTRODUCTION

The presence of vegetation increases soil stability along slopes and also reduces soil erosion. Root strengths are key components for erosion control because roots connect small soil particles and prevent them from being washed away. The significant source that vegetation enhances the stability of slopes is via root reinforcement (Gray et al. 1996). Plant roots improve soil structure and increase the soils organic matter content (Angers et al. 1998). Vegetation root strength and distribution affect shallow mass stability by increasing the shear strength of the soil through root reinforcement (Gray 1998; Reubens et al. 2007). The effect of root reinforcement on the stability of slopes can be evaluated directly in terms of the additional shear strength provided by roots in root-reinforced soils. Roots increase soil shear strength by anchoring a soil layer and by forming a binding network within the layer (Waldron 1997; Waldron and Dakessian 1981; Ziemer, 1981a and b; Tsukamoto and Kusakabe 1984; Sidle 1992; Schmidt 2001). In terms of root strength, many researchers studied in-situ root pull out test, laboratory root tensile test, and shear test of soil blocks reinforced with roots or artificial fibers. Root pull out tests conducted in the field provide data of root tensile strength and root-soil interactions (Schmidt 2001; Wu et al. 1979; Riestenberg 1994; Watson et al. 1999; Norris 2005; Pollen and Simon 2005). However, Schmidt et al. (2001) concluded that root tensile strength data resulting from pull out tests may only have a local value because of spatial variations in vegetation and tensile force and differences in the season when the test were carried out (Makarova et al. 1998). Previous studies indicated exponential (Abe and Iwamoto 1986) and linear (Riestenberg 1994) relationships between the tensile force and root diameter. Then, Riestenberg (1994) concluded that the laboratory tensile force required to break a root of a certain size is always greater than the in-situ root pull-out resistance. The actual behavior of the soil-root system to shearing depends on the roots failure mode, which in turn, influences the ultimate mobilized root tensile strength.

[1] Department of Civil and Environmental Engineering Technology, College of Industrial Technology, King Mongkut's University of Technology North Bangkok, THAILAND, crt@kmutnb.ac.th
[2] Civil Engineering Department, Rajamangala University of Technology Thanyaburi, THAILAND, jindarat4567@hotmail.com
[3] IALT member, School of Engineering and Technology, Asian Institute of Technology, THAILAND, dbergado@gmail.com
[4] Department of Teacher Training in Civil Engineering, King Mongkut's University of Technology North Bangkok, THAILAND, pnv@kmutnb.ac.th
[5] IALT member, Institute of Lowland and Marine Research, Saga University, Saga 840-8502, JAPAN, legialam82@gmail.com
Note: Discussion on this paper is open until June 2015

Roots can react to shearing force in three different ways: stretching, slipping and breaking (Waldron and Dakessian 1981; Abe and Ziemer 1991). In this study, the root tensile strength of two types of grasses, namely: Vetiver (Vetiver Ziznoides (L.) Nash) and Ruzi (Brachiaria Ruziziensis) were measured on root samples using the laboratory root tensile and field tests. The results from these tests are presented and the correlation between the diameter of roots and tensile strength, tensile force and Young's modulus of the two different grass species are presented and discussed.

MATERIALS AND METHODS

Description of Grass Species

The species considered in the present study were Ruzi (Brachiaria ruziziensis) and Vetiver (Vetiver Ziznoidse (L.) grasses. In Thailand, these species can be found growing in a wide range of area from highlands to lowlands in various soil conditions with short rhizomes and massive, finely structured root system. These grasses grow very quickly and commonly used for erosion control and for shallow soil reinforcement. Figure 1 shows the planted grasses to grow roots for laboratory tensile tests.

Vetiver grass (Vetiver Ziznoides (L.) Nash) is a perennial grass belonging to the poacca family. This species appear in a dense clump and grows fast. The clump diameter is about 300 mm. Its size ranges from 500 to 1500 mm. The leaves are erect and rather stiff with 750 mm of length and 8 mm of width. Its root depth can reach 3 to 4 m in the first year (Truong et al. 1995). The deep root system makes the Vetiver plant extremely drought tolerant and very difficult to dislodge when exposed to a strong water flow (Truong et al. 1995, Hengchaovanich 1999). Since Vetiver grass has a deep thick root system which spreads vertically rather than horizontally, its root can reinforce shallow soil slopes. The root system expands sideway up to only 500 mm.

Fig. 1 Planted grasses in PVC mold for laboratory tensile test

"Brachiaria Ruziziensis "is the scientific name of Ruzi grass which has tufted, creeping perennial with short rhizomes forming a dense leafy cover. Clums arise from many-noded creeping shoots and short rhizomes, growing to a height of 1.5 m when flowering. Leaves are soft but hairy, up to 250 mm long and 15 mm wide. Ruzi grass requires light to loam soils of moderately high acidity (pH 5.0 to 6.8) and cannot tolerate strongly acid condition. However, it can tolerate a dry season of 4 months but will die out in extended dry conditions. Having poor tolerance to flooding, it thrives best on well-drained soils and it can grow very fast. Ruzi grasses are widely used to control the erosion.

Tensile Strength

Tensile strength tests were carried out for the Ruzi and Vetiver grasses in order to measure the effects of root reinforcement on soil strength. Root samples were manually dug out and then the soil around the root system was washed out. Laboratory root tensile were conducted on each root sample after growing periods of 2, 4, 6, 8 and 10 months, respectively. Table 1 presents the laboratory test data and the parameter values to establish power law relationship (Eq. 2). The tests were performed using the tensile test apparatus shown in Fig.2. Each root sample (100 to 130 mm length) was cut and weighed. The diameter and length of root was measured (using vernier calipers) at the three points along the root length as shown in Fig.3(a). The two root ends were fixed to the clamps of the machine as shown in Fig.3(b) and the force applied increased every 2 minutes to the root to measure the root tensile strength, TR (MPa) as follows:

$$T_R = \frac{F_{max}}{\frac{\pi D^2}{4}} \quad (1)$$

where F_{max} is the maximum force (N) required to cause tensile failure and D is the average root diameter (mm). Thus, T_R is strongly affected by root diameter. The relationship between T_R and D is generally described by a simple power equation as indicated in Eq. (2) (Gray and Sotir 1996).

$$T_R\ (D) = \alpha \cdot D^{\beta} \qquad (2)$$

where α is the scale factor and β is the rate of strength decrease (empirical constants which vary between plant species). The α and β values are important in making an improved comparison between species. The T_R results vary significantly depending on the method of testing used (Operstein and Frydman 2000). The species listed in Table 1 were tested with the same method. For each species, 39 roots samples with the diameter ranging from 0.30 to 0.70 mm for Ruzi grass and 88 samples with diameter ranging from 0.25 to 2.90 mm of Vetiver grass were tested.

Fig. 2 Grass root tensile test machine

(a) (b)

Fig. 3 Laboratory device for tensile test

(a): Measurement of root diameter, (b): Two root ends were fixed to the clamp of the machine

Table 1 Number of root samples, range of values of root ultimate tensile force, (Tu), root diameter (D), tensile stress (Ti), Young's modulus (Er) and value of correlation coefficient, R of Vetiver and Ruzi grass roots

Species	No. of samples	D (mm)	T_u (mN)	T_i (MPa)	E_r (MPa)	R^2
Vetiver grass (Vetiver Ziznoides (L) Nash)	88	0.25 - 2.90	2255.38 - 33830.7	4.31 - 57.93	43.20 - 2097.35	0.806
Ruzi grass (Brachiaria ruziziensis)	39	0.30 - 0.70	2010.23 - 7207.41	18.73 - 29.13	236.05 - 1609.23	0.898

Shear Strength

To determine the root reinforcement effect of Vetiver and Ruzi grasses, large-scale direct shear tests were performed in the field. The large-scale direct shear test were conducted to investigate the shear strength of weathered clay samples (CL) with and without Ruzi grass and Vetiver grass roots reinforcements. The grass roots were tested at growing periods of 2, 3, 4, 5 and 6 months. The large-scale direct shear apparatus is shown in Fig.4 which consisted of steel frame, steel shear box, hydraulic jack, hydraulic pump, proving ring and dial gauge. The cross-sectional dimensions of the steel shear box were 300 mm x 300 mm with 100 mm in height. The thickness of the steel frame was 10 mm. The maximum capacity of hydraulic jack, hydraulic pump and proving ring are 5, 10 and 1 ton, respectively.

The proving ring used for the measurement of shear resistance was connected to shear box and the steel frame. The horizontal displacement of the shear box was monitored by using a dial gauge and the rate of shearing was made constant by observing the dial gauge reading and controlling the hydraulic pump. The steel frame was placed on the area reinforced with and without Ruzi grass and Vetiver grass which was prepared for testing at

Fig. 4 Field direct shear test equipment

growing periods of 2, 3, 4, 5 and 6 months. Then, the shear box was placed inside the steel frame in which the soil of between the steel frame and shear box was removed at 10 mm depth. The clay samples reinforced with and without Ruzi grass and Vetiver grass were contained inside the shear box in the shear box. Then, the hydraulic jack, hydraulic pump, proving ring and dial gauge were installed together with steel frame and shear box. The shear resistances and displacements were measured and recorded until the clay samples reinforced with and without Ruzi grass and Vetiver grass failed. This procedure were performed at three different normal pressures by using the steel plate (25kg, 50kg and 100kg) to determine the cohesion increment due to Ruzi grass and Vetiver grass.

The Mohr-Coulomb failure criterion model is normally used to evaluate the shear strength of root-reinforced effect on soil. The model assumes that all roots are considered cylindrical, elastic and perpendicular to the shearing plane (acting like laterally loaded piles). Thus, the tension is transferred to the roots as the soil is sheared. The root contribution is modeled as a cohesion term in the Mohr-Coulomb equation, as indicated in the following equation:

$$S = C_s' + \sigma' \cdot \tan \phi' + C_r \qquad (3)$$

where S is the soil shear strength, C_s' is the soil cohesion, σ' is the effective normal stress on the shear plane, ϕ' is the soil friction angle and C_r is the apparent cohesion due to the presence of roots. Assuming that the soil fricton angle is affected little by the presence of the roots [3], the additional root cohesion can be estimated as:

$$C_r = T_R \cdot (\sin(90 - \psi) + \cos(90 - \psi) \cdot \tan \phi') \qquad (4)$$

where T_R is the average mobilized tensile strength of roots per unit area of soil and ψ is the angle of the root at the rupture relative to the failure plane (°).

EXPERIMENTAL RESULTS

Laboratory Tests on Ruzi Grass Roots

In the tensile tests, the elastic modulus in extension, ultimate tensile strength and tensile force were measured. The tensile force increases with increasing diameter (D) as shown in Fig.5(a). The experimental data with rupture in roots was used to evaluate the ultimate tensile strength of roots. In general, 39 roots of Ruzi grass were tested for tensile test. The diameter of the Ruzi grass roots varied between 0.30 and 0.70 mm and the range of the recorded values of ultimate tensile force were from

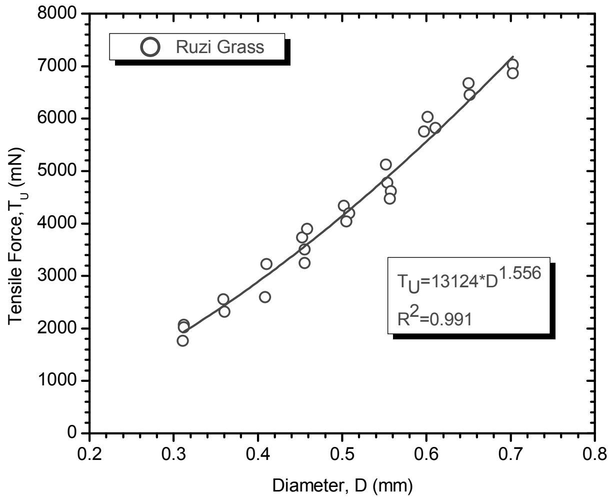

Fig. 5(a) Relationship between root diameter and the tensile forces of Ruzi grass

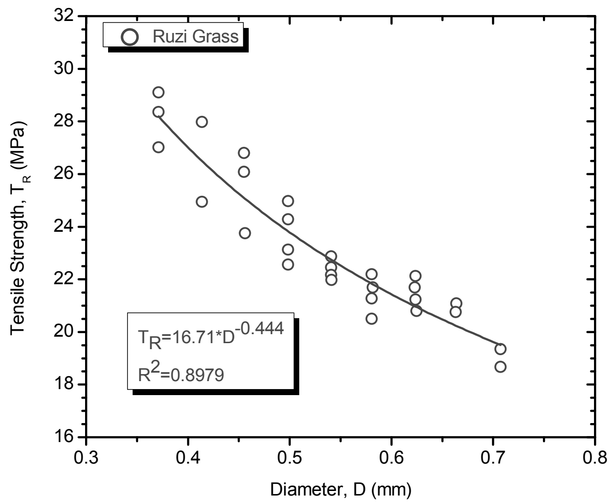

Fig. 5(b) Relationship between root diameter and the tensile strength of Ruzi grass

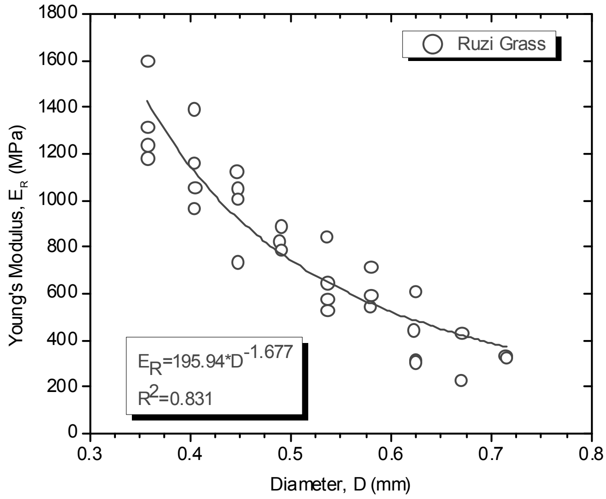

Fig. 5(c) Relationship between root diameter and the Young's modulus of Ruzi grass

7207.41to 2010.23 mN. The relationship between diameter of roots, D, and ultimate tensile force, T_u, of Ruzi grass during growing periods 2 to 6 months as shown in Fig.5a. The mean exponential relationship was established to be:

$$T_U = 13124 \cdot D^{1.556},\ R^2 = 0.991 \quad (5)$$

where T_u is in mN, D is in mm. Additionally, Figure 5b shows the relationship between the tensile strength, T_R, and root diameter, D, for roots of Ruzi grass. The diameter of the Ruzi grass roots varied between 0.30 and 0.70 mm and the range of recorded values of tensile strength, T_R, ranged from 29.13 to 18.73 MPa. The mean exponential relationship was derived to be:

$$T_R = 16.71 \cdot D^{-0.444},\ R^2 = 0.898 \quad (6)$$

where T_R is in MPa and D is in mm. Furthermore, the relationship between Young's modulus, E_R, in tension and root diameter, D, for root of Ruzi grass is shown in Fig. 5c. The range of recorded values of Young's modulus was from 1609.23 to 236.05 MPa and the diameter of the Ruzi grass roots varied between 0.30 and 0.70 mm. The mean exponential relationship was derived as follows:

$$E_R = 195.94 \cdot D^{-1.677},\ R^2 = 0.831 \quad (7)$$

where E_R is in MPa and D is in mm. The inverse relationships for Tu, T_R, and E_R versus D were also found to agree with the results from other researcher (Waldron and Dakessian 1981 and Voottipruex et al. 2008).

Laboratory Tests on Vetiver Grass Roots

Tensile strength tests were carried out on 88 roots samples of Vetiver grass after growing periods of 2, 3, 4, 5, and 6 months, respectively. The tensile force recorded for Vetiver grass (Vetiver Ziznoides (L.) Nash) varied between 2.25 to 33.83 N with the root diameter ranging from 0.25 to 2.90 mm. The relationship between diameter of roots, D, and ultimate tensile force, Tu, of Vetiver grass is shown in Fig. 6a. The mean exponential relationship can be estimated using the following relationships as:

$$Tu = 11951 \cdot D^{1.098},\ R^2 = 0.863 \quad (8)$$

where, Tu is in mN and D is in mm. R^2 is the correlation coefficient. Moreover, the correlation among tensile strength and root diameter of Vetiver grass is indicated in Fig. 6b. The diameter of the Vetiver grass was varied from 0.25 to 2.90 mm and the tensile strength of Vetiver

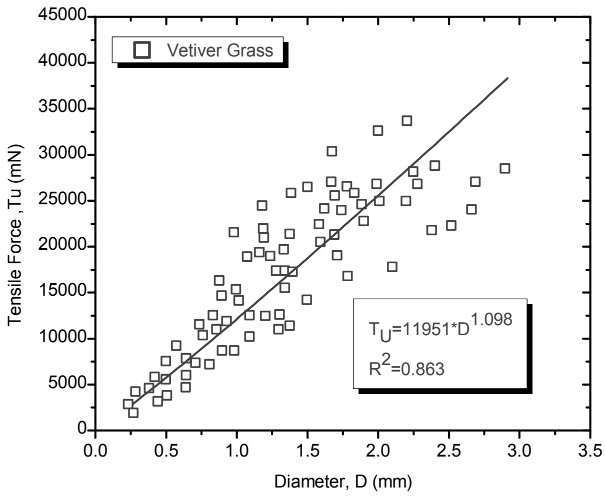

Fig. 6(a) Relationship between root diameter and the ultimate tensile force of Vetiver grass

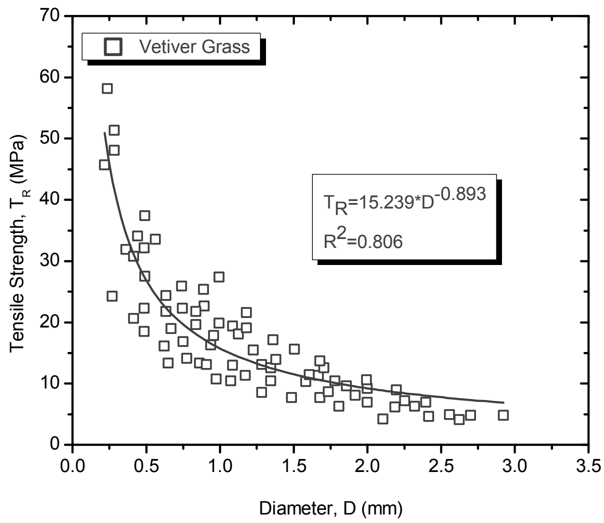

Fig. 6(b) Relationship between root diameter and the tensile strength of Vetiver grass

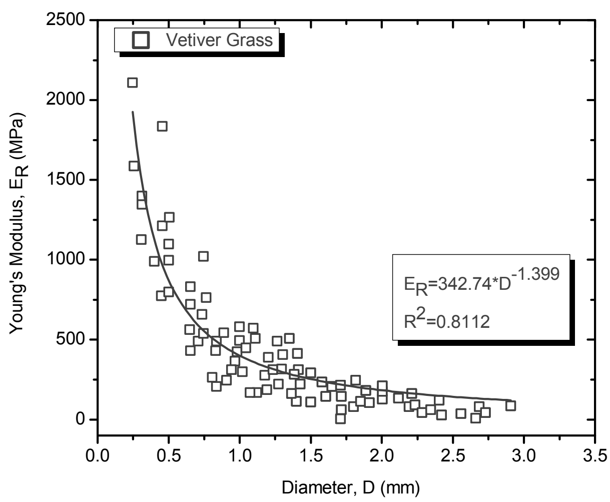

Fig. 6(c) Relationship between root diameter and the tensile strength of Vetiver grass

grass Fig.6b ranged between 4.31 to 57.93 MPa. The corresponding equation was established to be:

$$T_R = 15.239 \cdot D^{-0.893},\ R^2 = 0.806 \tag{9}$$

where, T_R is the tensile strength in MPa and D is the diameter of root in mm. Additionally, Young's modulus were varying between 43.20 to 2097.35 MPa as shown in Fig. 6c. The exponential relationship between the Young's modulus and root diameter was found as follows:

$$E_R = 342.74 \cdot D^{-1.399},\ R^2 = 0.811 \tag{10}$$

where; E_R is the Young's modulus in MPa and D is in diameter in mm. The same relationships for both T_u versus D, and E versus D, were also found by other researcher [24].

Field Direct Shear Tests

Field test provide the contribution, given by the roots systems of Ruzi and Vetiver grasses to soil reinforcement. Data recorded during field experiments were subsequently elaborated, obtaining a shear strength value of each grass roots tested. The relationships between normal stress and shear stress without and with Ruzi and Vetiver grass root reinforcement are plotted in Figs.7 (a, b, c and d). The data demonstrate increasing trends with growing periods except at 6 months when rainy season started. Direct shear tests were carried out also on soil only specimens with shear strength varying from 8.77 to 9.58 kPa (Figs.8a to 8c), in order to estimate the increasing values of soil shear strength between rooted and no-rooted soils. The strengthening effects of the Vetiver and Ruzi roots after 2, 3, 4, 5 and 6 months were observed at Fig.8(a and b). The results show that the range of recorded values of shear strengths in Vetiver rooted soils varied between 11.02 to 17.60 kPa while the rooted soils with Ruzi grass was recorded from 10.04 to 11.14 kPa.

Rooted soils demonstrated increases in soil shear strength by combining Vetiver and Ruzi grass varying from 11.48 to 18.81 kPa. Figure 8(c) shows that the roots of Vetiver grass play an important role in strengthening the soil. By combining Vetiver and Ruzi grasses, greater strengthening of soil reinforcement is provided. The roots interact with the soil to produce a composite material in which the roots are fibres with higher tensile strength and adhesion (Ali 2010).

The shear strength of the soil is therefore enhanced by the root matrix. Root systems lead to an increase in soil strength through an increase in cohesion brought about by their binding action in the fiber/soil composite

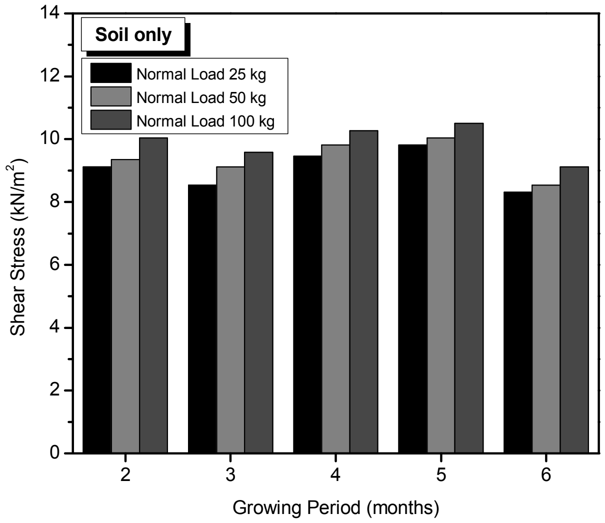

Fig. 7(a) Relationship between shear stress and growing period of the non-reinforced soil

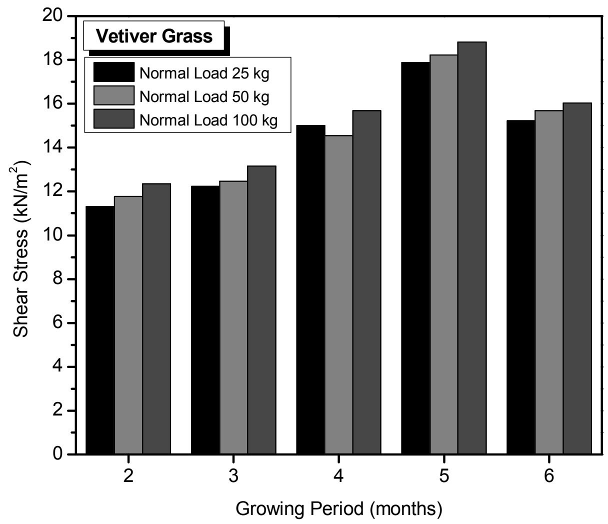

Fig. 7(b) Relationship between shear stress and growing period of the Vetiver grass root reinforcement

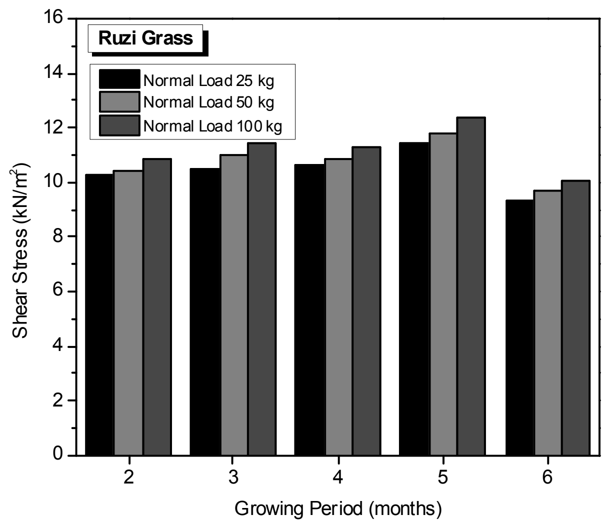

Fig. 7(c) Relationship between shear stress and growing period of the Ruzi grass root reinforcement

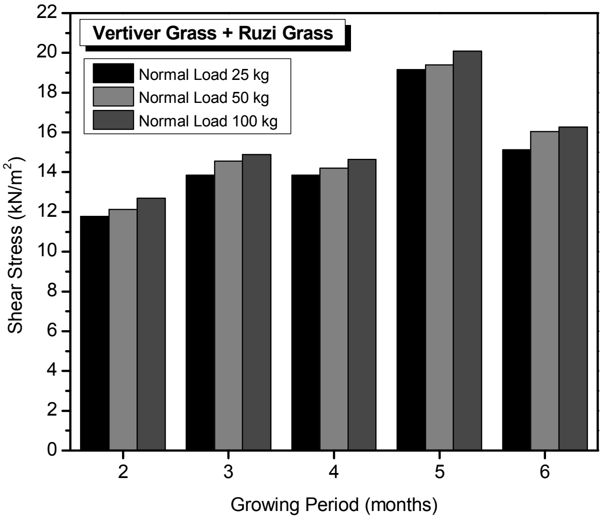

Fig. 7(d) Relationship between shear stress and growing period of the combination of Vetiver and Ruzi grass roots reinforcement

and adhesion of the soil particles to the roots. Tables 2 and 3 summarize direct shear data after 2, 3, 4, 5, and 6 months growth of Vetiver and Ruzi grasses root. The direct shear test data observed that the shear stress increased with growing period of grass roots except during the rainy month in 6. The data combination of Vetiver and Ruzi grasses provides the highest shear stress. The roots of Vetiver and Ruzi grasses contribute significantly to enhancement of soil shear strength.

The results also indicate that the cohesion increases in soil due to penetration of roots. Additionally, it is interest to note that the shear strength of vetiver grass root-reinforced soil is much higher than Ruzi grass and root free soils, as shown in Fig. 8a.

Table. 2 Field direct shear test results of root cohesion (C_r) and soil (C_s) after 2, 3, 4, 5, and 6 months

Cohesion of soil and Ruzi and Vetiver grasses roots (kPa)										
Growing periods (Months)	Soil	Vetiver grass			Ruzi grass			Vetiver + Ruzi grass		
	C_s	C_s	C_r	C_s+C_r	C_s	C_r	C_s+C_r	C_s	C_r	C_s+C_r
2	8.77	8.77	2.25	11.02	8.77	1.27	10.04	8.77	2.71	11.48
3	8.31	8.31	3.58	11.89	8.31	1.96	10.27	8.31	5.37	13.67
4	9.23	9.23	5.19	14.42	9.23	1.15	10.39	9.23	4.38	13.62
5	9.58	9.58	8.02	17.60	9.58	1.56	11.14	9.58	9.23	18.81
6	8.02	8.02	7.04	15.06	8.02	1.15	9.17	8.02	6.98	15.00

DISCUSSIONS

Root tensile strength values, measured in laboratory tests, decreased with increasing root diameters. This relationship can be described by a power law equation (Eq. 2), as widely studied by any authors (Gray and Sotir 1996; Voottipruex et al. 2008; Bischetti et al. 2005;

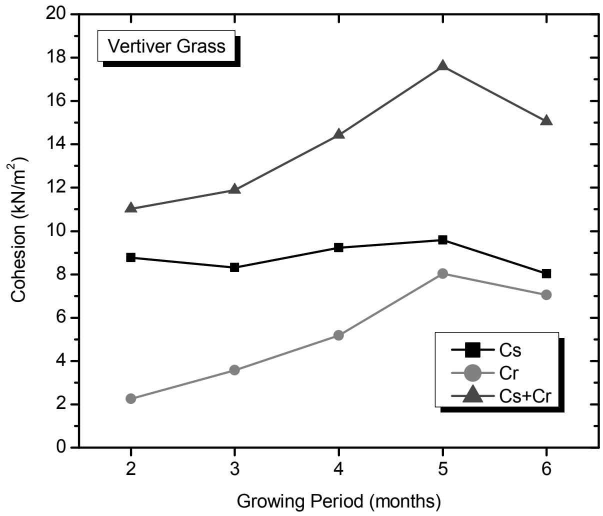

Fig. 8(a) Relationship between growing period of root and the shear strength of Vetiver grass root (Cr) compared to shear strength of soil (Cs)

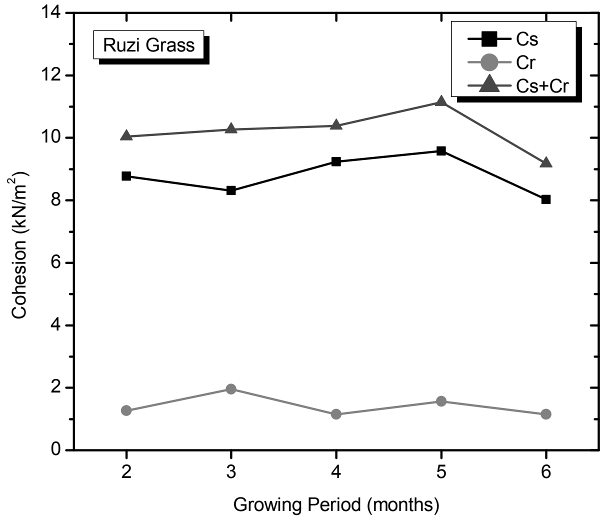

Fig. 8(b) Relationship between growing period of root and the shear strength of Ruzi grass root (Cr) compared to shear strength of soil (Cs)

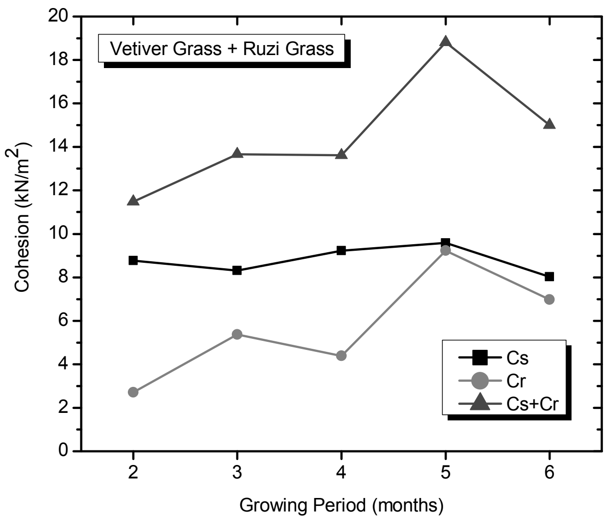

Fig. 8(c) Relationship between growing period of root and the shear strength of Vetiver and Ruzi grass root (Cr) compared to shear strength of soil (Cs)

Mattia et al. 2005; Nilaweera 1994; Tosi 2007). In Eq. (2) α and β are empirical constants depending on type of species: α is the scale factor whereas β is the rate of strength decrease [26]. The tensile strength data from the test for Ruzi grass and Vetiver grass root could be well interpolated by a power law equation (Eq. 2) as shown in Fig.5(b) and Fig.6(b) respectively. Tensile strength data, (Vetiver Ziznoides (L.) Nash) presented in this paper, were compared with those published by previous authors (Voottipruex et al 2008) and for Mediernanean grass and plant species (De Baets et al. 2008). The laboratory test tensile strength data for Vetiver (Vetiver Ziznoides (L.) Nash) measurement from the previous data [24] was varying approximately form 14 to 44 MPa for root diameter ranging from 0.2 to 1.3 mm. The relationship between root tensile strength and diameter can be expressed by:

$$T_R = 16.95 \cdot D^{-0.60},\ R^2 = 0.755 \qquad (11)$$

where T_R is in MPa and D is in mm. The tensile strength reduced with diameter because the diameter of root depended on the sponge shell while the fiber core and strength of root depended only on the inner core of the root.

The Young's modulus of Vetiver grass roots decreased in the range of 420 to 140 MPa with the increase of root diameter and the relationship can be expressed as follows:

$$E = 193.69 \cdot D^{-0.84},\ R^2 = 0.826 \qquad (12)$$

where E is modulus of elasticity of root in MPa and D is root diameter in mm. Tensile strength measured values for Vetiver Ziznoides (Fig.6b) presented a high correlation with diameters ($R^2 = 0.806$), comparable with R^2 value of laboratory tensile strength data measure by previous author [24]. The tensile strength value of Vetiver grass (60 MPa) was higher than tensile strength measured by (Voottipruex et al. 2008) on the same grass species (44 MPa). It is important to consider that the tensile strength of (Voottipruex et al. 2008) is referred a diameter of root (0.2 to 1.3 mm), while tensile strength for Vetiver grass root in the present study referred to diameters of 0.25 to 2.90 mm. In Addition, the elastic modulus value result in this paper was significantly decreased in the range of 2100 to 150 MPa with the increase of root diameter, comparable with the previous data of 420 to 140 MPa. Regardless the root tensile data carried out from present test, we can assume that the high value was due to the strong fiber of the tested root tissue after growing periods of 2, 3, 4, 5 and 6 months. However, there was not much comparable research studies on Ruzi grass root characteristic to compare with the present study.

For the in situ shear tests conducted in this research, shear strength of root reinforced soil increase within the depth of root permeated soil correspond with growing period. The result indicates that the presence of roots has significantly improved the shear strength of soil and it also shows that the effect is mainly on the cohesion. Vetiver grass root is observed to be leading at all growing periods of 2, 3, 4, 5 and 6 months (Fig.8a). Roots of Veitver grass has enhanced the cohesion component of shear strength by 11.02 kPa (2 month), 11.89 kPa (3months), 14.42 kPa (4 months), 17.60 kPa (5 months) to 15.06 kPa (6 months) as compared to the Ruzi grass (Fig.8b) of 10.04 kPa (2 months) 10.27 kPa (3 months), 10.39 kPa (4 months). 11.14 kPa (5 months) and decreased to 9.17 kPa (6 months). The increase in soil strength through an increase in cohesion particularly, is brought about by binding action in the fine roots or soil composition and adhesion of the soil particular to the roots (Styczen and Morgan 1995).

Additionally, combination of Vetiver and Ruzi grasses results in greater development of shear strength for soil reinforcement consisting of 11.48 kPa (2 months) 13.07 kPa (3 months), 13.62 kPa (4 months), 18.81 kPa (5 months) and decreased to 15.00 kPa (6 months) as shown in Fig. 8c. It is noted that the shear strength had decreased at 6 month which may happen for soils at the shallow depth during or after intense rainfall event. According to previous authors (Waldron 1977; Waldron and Dakessian 1981), the interface strength between roots and soil can give an additional cohesion. The overall results suggest that the grass root studied has the potential to play a major engineering role in stabilization slopes and protecting the soil erosion. The root system penetrates the soil mass, reinforced it, bringing about an increase in cohesion and, hence, in soil shear strength. Nilaweera (1994) reported that the increase in cohesion is probably partly due to an increase amount of fiber (fine) roots of the grasses studied. In addition, a fine root mat close to the soil surface may act like a low-growing vegetation cover and protect the soil from erosion.

CONCLUSIONS

The results of laboratory tests on tensile strength of Ruzi and Vetiver grass roots show the importance of root system diameter on tensile strength. Root micromechanical properties, at tissue and fiber levels, can influence its tensile strength behavior. In general root tensile strength values increased with decreasing root diameters while the tensile breaking force values have an opposite trend (tensile force increase with increasing root diameters). The roots of Vetiver grass (Vetiver Ziznoides (L.) Nash) have higher tensile strength than Ruzi grass (Brachiaria Ruziziensis). The tensile strength value registered in this study on Vetiver grass species were comparable to those measured in former studies. The obtained results can be useful in order to mitigate slope failure problems and shallow mass movement. This study shows that roots significantly contribute to the increase in soil shear strength. The contributions mainly arise from the cohesion. The effect varies with increasing depth and age of grass depending on the root length density. While, the Vetiver root result a higher components of both shear strength and shear stress compare to Ruzi grass, the experimental results proved that the combination of Ruzi and Vetier grasses roots yielded greater effects in soil-reinforcements. Subsequently, the longer Vetiver grass roots help enhanced the shear strength for soil reinforcement and shorter Ruzi grass roots can minimize the soil erosion. Thus, the overall results suggested that the roots of vegetation have potential to play a major engineering role in stabilizing slopes and protecting against surface soil erosion.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support provided by King Mongkut's University of Technology North Bangkok under the contract No.2551A11902013.

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