iTS Institut Teknologi Sepuluh Nopember
PROGRAM PASCASARJANA
JURUSAN TEKNIK SIPIL

45

PROSIDING

SEMINAR NASIONAL Teknik Sipil VIII 2012

ISBN 978-979-99327-7-8

"Pembangunan Berkelanjutan Transportasi dan Infrastruktur"

Surabaya, 2 Februari 2012

EFFECT OF THE ROOTS DENSITIES ON THE SHEAR STRENGTH OF ROOT-REINFORCED SOIL

Agus Setyo Muntohar

Department of Civil Engineering, Universitas Muhammadiyah Yogyakarta, Indonesia
Tel. +62-274-387656. Email: muntohar@umy.ac.id

ABSTRACT

Vegetation on slope was introduced as an alternative technique to prevent the slope failures. Many factors may affect the increases in the shear strength of the root-reinforced soil. This research was undertaken to investigate the effects of the shear strength of soil with the variations of root densities. In this research, a series of laboratory tests was conducted on undisturbed and disturbed samples of soil reinforced with *Imperata Cylindrica*. The root area ratio (RAR) was estimated from 0.07% to 1.18%. The main laboratory test conducted was direct shear test. The specimen size was in square size of 50 mm by 50 mm and 25 mm of thickness. The relationship between root densities and shear strength of soil was developed. The experimental results revealed that the vegetation roots improved significantly the soil shear strength. The maximum shear strength of the soil increased linearly with the increases in fiber content of the roots. The maximum shear strength was depending on the applied normal stress. A higher normal stress, higher maximum shear strength was obtained. Thus, fibrous root vegetation was playing a significant role in stabilizing the slope.

Keywords: root reinforcement, root density, shear strength.

1 INTRODUCTION

Landslides are known severe natural disasters in the world where take place at hilly site or mountainous area. This disaster caused severe damage on the property and loss of live. Several countermeasures techniques can be applied to prevent slope failures e.g. retaining wall, ground anchor, reinforced structure, bioremediation, etc. In general practices, retaining walls are built to prevent slope movement. However, the construction cost of retaining walls is very high and it is made up of concrete where it is considered as a non environmental friendly material. Nowadays, global warming is the issue of the environmental degradation and thus several alternatives method had been developed in the construction industry to replace the concrete retaining wall to protect the environment by applying vegetation on slopes. Vegetation is the most natural method for protecting slopes because it is relatively easy to establish and maintain and is visually attractive. However, vegetation alone should not be seriously considered as a countermeasure against severe slope erosion and failures where an infrastructure is at risk. At such locations, vegetation can best serve to supplement other countermeasures (Figure 1). Vegetation can effectively protect a slope or embankment below the design water line in two ways. First, the root system helps to hold the soil together and increases the stability by forming a binding network. Second, the exposed stalks, stems, branches and foliage provide resistance to flow, causing the flow to lose energy by deforming the plants rather than by removing soil particles. Vegetation is generally divided into two broad categories: (1) grasses, and (2) woody plants (trees and shrubs). A major factor affecting species selection is the length of time required for the plant to become established on the slope. Grasses are less costly to plant on an eroding bank and

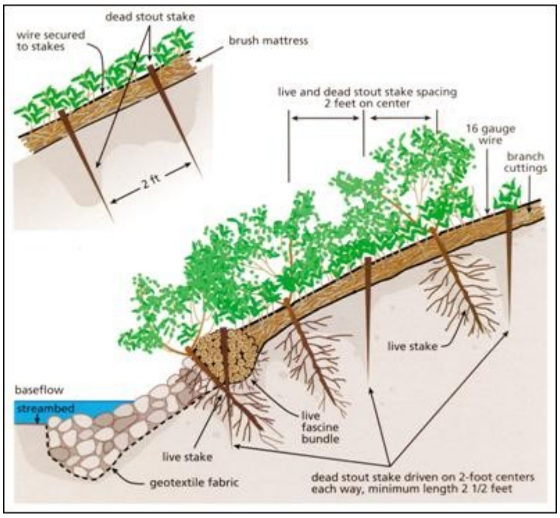

Figure 1 Biotechnical remediation of slope (modified from Gray & Sortir, 1996)

require a shorter period of time to become established. Woody plants offer greater protection against erosion because of more extensive root systems; however, under some conditions the weight of the plant will offset the advantage of the root system. On high slopes, tree root systems may not penetrate to the toe of the slope. If the toe becomes eroded, the weight of the tree and its root mass may cause a slope failure.

Woody and herbaceous vegetation is commonly used to prevent surficial soil erosion (Coppin & Richards, 1990). Its influence on the processes of mass stability is less well appreciated although it is generally accepted that vegetation affects slope stability through six primary mechanisms (Gray & Leiser, 1982) including (1) root reinforcement of the soil, (2) soil moisture modification, (3) buttressing and soil-arching, (4) surcharge weight of trees, (5) root wedging, and (6) wind-throw. A comprehensive reviews have been made (Gray & Leiser, 1982; Greenway, 1987; Coppin & Richards, 1990; Styczen & Morgan, 1995; Wu, 1995) with a general consensus that the positive effects on slope stability far outweigh the negative. The magnitude of root reinforcement depends on morphological characteristics of the root system (e.g. root distribution with depth, root distribution over different root diameter classes), root tensile strengths, root tensile modulus values, the interface friction between roots and the soil and the orientation of roots to the principal direction of strain (Greenway 1987). This paper focuses only on root reinforcement of the soil. This research was undertaken to investigate the effects of the shear strength of soil with the variations of root densities.

1.1 Root-soil reinforcement system

Soil is strong in compression but weak in tension, while roots are weak in compression but strong in tension. Therefore when soil and roots are combined the resultant soil-root matrix produces a mass which is much stronger than either the soil or the roots on their own. The roots act by transferring the shear stresses developing in the soil to the tensile resistance in the roots, and also by distributing stresses through the soil, so avoiding local stress build-ups and progressive failures. Investigators of root reinforcement in soil have generally found that roots have failed in tension and therefore posit that root systems have a negligible influence on the frictional component of soil

ISBN 978-979-99327-7-8

strength (Endo & Tsurata, 1969; O'Loughlin, 1974a,b; Waldron, 1977; Gray & Megahan, 1981; Waldron & Dakessian, 1981; O'Loughlin et al, 1982; Riestenberg & Sovonick-Dunford, 1983; Abernethy & Rutherfurd, 2001). That is, the confining stresses within the soil are large enough to surpass the critical confining stress for a given root length, thereby allowing mobilization of the required frictional bond between the soil and the root that prevents the root from pulling out of the soil intact. The shear zone must also be wide enough to allow roots crossing it to deflect, elongate, and develop their maximum tensile strength, rather than failing in shear, as would be the case with a thin shear zone (a few millimeters wide) where the roots are held rigidly by the soil on either side (Burroughs & Thomas, 1977). These observations have been used to demonstrate that root reinforcement of soil is best approximated by an increase in apparent soil cohesion that varies in proportion to the concentration of roots within the soil. Figure 2 illustrates the Mohr-Coulomb envelopes for reinforced and unreinforced soils with root. The critical confining stress varies for different soil-fiber systems and is a function of such properties as tensile strength and modulus of the fibers, length/diameter ratio of the fibers, and frictional characteristics of the fibers and soil (Gray & Ohashi, 1983).

1.2 Soil-root interactions model

The Mohr-Coulomb equation is normally used to evaluate the shear strength of root-reinforced soils based on three assumptions: (1) roots penetrate vertically into the soil subjected to shear. A shear zone with a thickness of Z, which remains unchanged during shear, is developed. (2) Roots are flexible, linearly elastic, and uniform in diameter. (3) The friction angle ϕ, of soils is not affected by roots (Waldron, 1977; Waldron & Dakessian, 1981). Simple force equilibrium models, as shown in Figure 3(a), were developed to compute the additional shear strength, ΔS, for vertical roots, and the equation is given as (Wu et al., 1979; Waldron and Dakessian, 1981):

$$\Delta S = t_R\left(\sin\theta + \cos\theta\tan\phi\right) \quad (1)$$

where t_R is the mobilized tensile force in roots per unit area of soil, $\theta = tan^{-1}\ x/z$ is the angle of the root in relation to the vertical after shear distortion, z is the thickness of the shear zone, x is the shear displacement, and ϕ is the internal friction angle. The mobilized force in roots is dependent on elongation and fixity of roots in soils. The tensile strength of roots can be mobilized if roots stretch deep enough or the embedment

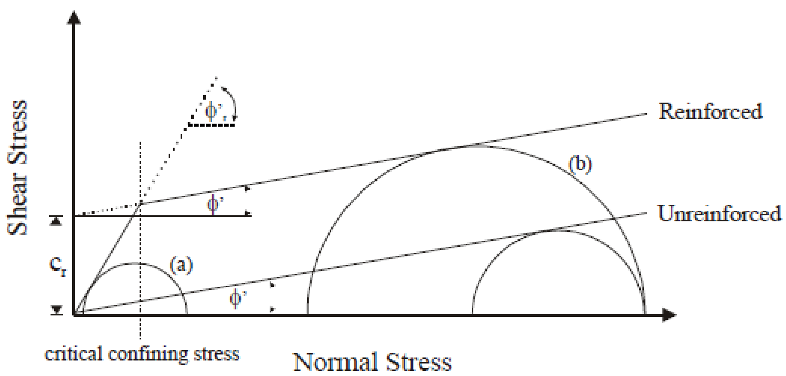

Figure 2 Mohr-Coulomb envelopes for reinforced and unreinforced soils with circles describing failure by (a) slippage and (b) reinforcement rupture (after Hausmann, 1976).

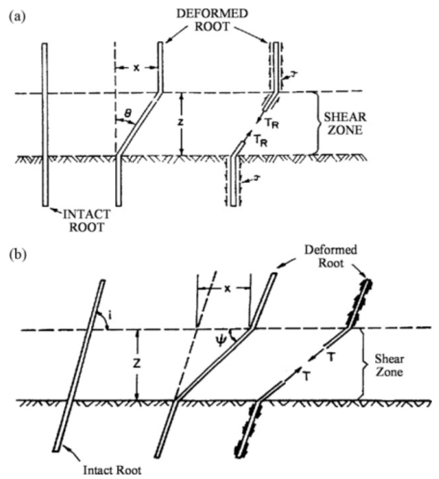

Figure 3 Root-reinforcement models: (a) perpendicular root-reinforcement model; (b) inclined root-reinforcement model (Gray and Lieser, 1982).

length of roots in soils is sufficient to prevent from pulling out. The mobilized tensile force in roots per unit area of soil, t_R, can be computed by Equation (2).

$$t_R = T_R \frac{A_R}{A} \quad \text{.....................................} (2)$$

where T_R is the tensile stress developed in roots, A is the area of the soil shear surface, A_R is the total cross-sectional area of all roots crossing the shear surface, and A_R/A is defined as the root area ratio (*RAR*). The value of the term (sin θ + cos θ tan ϕ) in Equation (1) is relatively insensitive to normal variations in θ (=40–90°) and ϕ (= 25–40°). Thus, Wu et al. (1979) proposed an average value of *1.2* for this term, i.e. $\Delta S = 1.2t_R$.

2 EXPERIMENTAL PROGRAM

2.1 Materials and Test

In this research, a series of laboratory tests was conducted on the disturbed samples of soil reinforced with cogon grass (*Imperata Cylindrica*) or "ilalang" in local word. The sample of the grass is shown in Figure 4. The main laboratory test conducted was direct shear test. The specimen size was in square size of 50 mm by 50 mm and 25 mm thickness. The relationship between root densities and shear strength of soil was developed. In this research, the direct shear test was conducted in saturated condition as avowed in ASTM D3080. Since landslide commonly occurs during the rainfall, to demonstrate this condition, the specimen was soaked for16 hours under water immersion before performing the test. Three different normal stresses were applied and they are 50 kPa, 100 kPa and 150 kPa.

2.2 Determination of the root area ratio and density

The fibrous root content was defined as the ratio of dry mass of fibers and dry mass of soils. It was conducted according to ASTM D1997. After completing direct shear test for each of the specimen, the soil was oven dried to obtain the dry mass of the

 ISBN 978-979-99327-7-8

(a) (b)

Figure 4 (a) Sample of the *Imperata Cylindrica* grass in the field and (b) root architecture

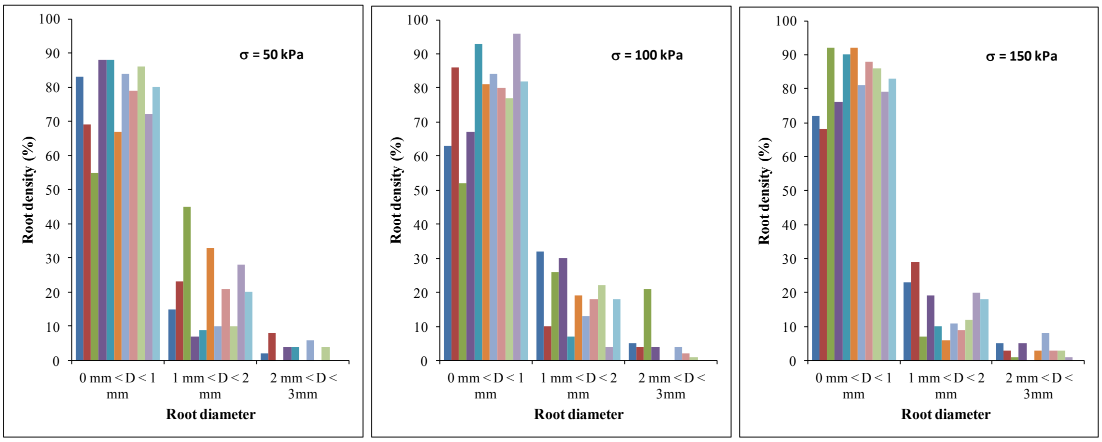

Figure 5 The distribution of the root size (D_R) used in the experiment

soils then lastly the dry soil was removed to obtain the dry mass of the fibers. The fiber content can be obtained by the Equation (3).

$$RAR = \frac{m_R}{m_d} \times 100\% \quad \text{.......................................}(3)$$

where, m_R is mass of fibrous roots, and m_d is mass of dry soil. In this study, the root area ratio (RAR) was estimated from 0.07% to 1.18%.

The density or distribution of root size was calculated after the fiber content test by classifying the roots into three categories which was smaller than 1 mm (finer root), in between 1 to 2 mm (medium root), and larger than 2 mm (thick root). The percentage distribution of roots can be estimated by Equation (4). The density of the root samples is illustrated in Figure 5.

$$D_R = \frac{\sum \text{dry mass of roots in the range}}{m_R} \times 100\% \quad \text{.......................................}(4)$$

3 RESULTS AND DISCUSSION

Figure 6 presents the relationship between the root area ratio and the maximum shear strength test for different normal stresses, 50 kPa; 100 kPa, and 150 kPa. The result of this research shows that the root reinforced soil increases the shear strength of

ISBN 978-979-99327-7-8

Table 1 Correlation analysis of the *RAR*, D_R and S_f

S_f	*RAR*	Finer root (< 1 mm)	Medium root (1 – 2 mm)	Thick root (> 2 mm)
σ = 50 kPa	0.47	-0.16	0.09	0.22
σ = 100 kPa	0.45	-0.47	0.46	0.32
σ = 150 kPa	-0.36	-0.39	0.27	0.39

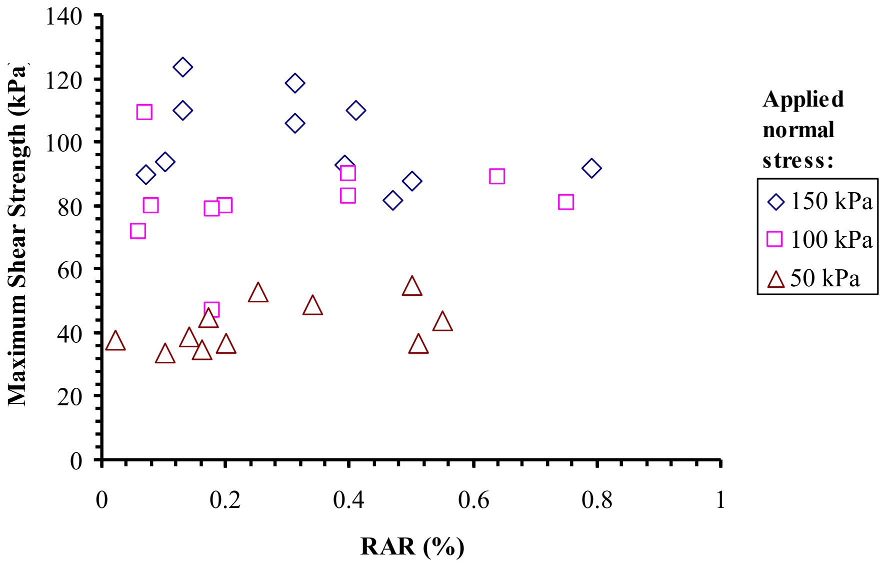

Figure 6 The variation of the maximum shear stress with *RAR*

soil significantly. It is also observed that the soil reinforced by roots tend to affect the soil cohesion more than the friction angle. The results are similar as the results proposed by Zhang et al. (2009). According to Loades et al. (2009), the shear strength of soil increases with the density of roots increases. Thus the outcome of this research has identical results to the results proposed by Loades et al. (2009) where the report shows that increasing planting density increases the shear strength of soil planted with barley under both natural and ideal glasshouse conditions.

It was shown in Figure 5 that the root diameter of the cogon grass is mainly lesser than 1 mm diameter. A correlation analysis was performed to determine the contribution of root size distribution on the shear strength. Table 1 presents the correlation coefficient among the parameter *RAR*, D_R and shear strength (S_f). According to the correlation analysis in Table 1, the correlation between S_f and finer root diameter (D < 1 mm) is negatively correlated. It means that the S_f decreases with increases in number of finer root diameter. In contrast, medium and sticky root is positively correlated with the shear strength. The results indicates that the amount of medium and sticky root contribute more than the finer root to increase the shear strength. However, previous research shown that the presence of finer roots increased significantly the tensile strength (e.g. Operstein & Frydman 2000; Gray & Barker 2004). It can therefore be hypothesized that a large number of small roots will contribute more to soil reinforcement as compared to a small number of thick roots.

ISBN 978-979-99327-7-8

4 CONCLUSION

The laboratory investigation has been performed successfully to study the effect of root density on the shear strength of root-reinforced soil. It can be concluded that the vegetation roots improved significantly the soil shear strength. The maximum shear strength of the soil increased linearly with the increases in fiber content of the roots. medium and sticky root is positively correlated with the shear strength. The maximum shear strength was depending on the applied normal stress. A higher normal stress, a higher maximum shear strength was obtained.

5 REFERENCES

Abernethy B and Rutherfurd I D (2001) The distribution and strength of riparian tree roots in relation to riverbank reinforcement. Hydrological Processes, 15(1), 63-79.

ASTM Standard D1997 (2011) Standard Test Method for Laboratory Determination of the Fiber Content of Peat Samples by Dry Mass, ASTM International, West Conshohocken, PA

ASTM Standard D3080 (2011) Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions, ASTM International, West Conshohocken, PA

Burroughs E R and Thomas B R (1977) Declining root strengths in Douglas-fir after falling as a factor in slope stability. Research Paper INT-190. 27 pp. Forest Service. U.S. Dept. of Agriculture, Ogden, Utah.

Coppin N.J. and Richards, I.G. 1990. Use of vegetation in Civil Engineering. Butterworths. London. 292 pp.

Endo T and Tsurata T (1969) Effect of tree's roots upon the shearing strength of soils. Annual Report No. 18 of the Hokkaido Branch Government Forest Experiment Station, Tokyo, 1968. pp. 167-182.

Gray D H and Barker D (2004) Root-soil mechanics and interactions. In: Bennett JJ, Simon A (eds) Riparian vegetation and fluvial geomorphology. Water Science and Application 8. American Geophyisical Union, New York, pp 113–123.

Gray D H and Leiser A T (1982) Biotechnical slope protection and erosion control. Van Nostrand Reinhold Co., New York.

Gray D H and Megahan W F (1981) Forest vegetation removal and slope stability in the Idaho Batholith. Research Paper, INT-271, 23 pp. Forest Service. U.S. Dept. of Agriculture, Ogden, Utah.

Gray D H and Ohashi H (1983) Mechanics of fiber reinforcement in sand. Journal of Geotechnical Engineering ASCE 109 (3), 335-353.

Gray D H and Sotir R B (1996.) Biotechnical and Soil Bioengineering Slope Stabilisation: A Practical Guide for Erosion Control. John Wiley & Sons, New York, 378 pp.

Greenway D R (1987) Vegetation and slope stability. In: Slope Stability. M.G. Anderson and K.S. Richards (Eds.). John Wiley & Sons Ltd, Chichester. pp: 187-230.

Hausmann M R (1976) Strength of reinforced soil. Proceedings of the 8th Australian Road Research Conference Volume 8(13), 1-8.

Loades KW, Bengough AG, Bransby M F, and Hallett P D (2009) Planting density influence on fibrous root reinforcement of soils. Ecological Engineering 36(1), 276-284

O'Loughlin C L (1974a) The effects of timber removal on stability of forest soils. Journal of Hydrology, New Zealand 13, 121-134.

O'Loughlin C L (1974b) A study of tree root strength deterioration following clear-felling. Canadian Journal of Forest Research 4 (1), 107-113.

O'Loughlin C L, Rowe L K, and Pearce A J (1982). Exceptional storm influences on slope erosion and sediment yields in small forest catchments, North Westland, New Zealand. National Conference Publication 82/6. Institute of Engineering, Barton, ACT, Australia, pp. 84-91

Operstein V and Frydman S (2000) The influence of vegetation on soil strength. Ground Improvement 4, 81–89

Riestenberg M M and Sovonick D S (1983) The role of woody vegetation in stabilizing slopes in the Cincinnati area, Ohio. Geological Society of America Bulletin 94, 506-518.

Styczen M E, and Morgan R P C (1995) Engineering properties of vegetation. In: Slope Stabilization and Erosion Control: A Bioengineering Approach. In R.P.C. Morgan and R.J. Rickson (Eds.). E & FN Spon, London. pp: 5-58.

Waldron L J (1977). The shear resistance of root-permeated homogenous and stratified soil. Journal of the Soil Science Society of America 41, 843-849.

Waldron L J and Dakessian S (1981) Soil reinforcement by roots: Calculation of increased soil shear resistance from root properties. Soil Science 132 (6), 427-435.

Wu T H (1995) Slope Stabilization. In: Slope stabilization and erosion control: a bioengineering approach. Eds: R.P.C. Morgan and R.J. Rickson (Eds.). E & FN Spon. London.

Zhang C B., Chen L H, Liu Y P, Ji X D, and Liu X P (2009) Triaxial compression test of soil–root composites to evaluate influence of roots on soil shear strength. Ecological Engineering 36(1), 19–26.

ISBN 978-979-99327-7-8