Research article

Erosion Control and Slope Stabilization for Loose Sandy Soil by Using Vetiver Grass

PIYANUCH JAIKAEW*
Faculty of Science and Engineering, Kasetsart University, Chalerm Prakiat Sakhon Nakhon Province Campus, Thailand
Email: piyanuch.jai@ku.th

KONGRAT NOKKAEW
Faculty of Engineering, Nakhonphanom University, Thailand

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Abstract The root of vetiver grass has been proven to be effective to decrease erosion and increase slope stability for soil slope. The important role of vetiver grass roots in preventing water erosion and mass movement has been well recognized. However, quantitative researches that present the contribution of vetiver grass to erosion control and slope stability are limited, especially in the field study. This article presents the use of vetiver grass to slope erosion control and the role of vetiver root strength on slope stabilization for loose sandy soil slope which is located at north eastern part of Thailand. The erosion was measured in the field and then compared with the prediction from the Universal Soil Loss Equation (USLE) proposed by the USDA Agricultural Research Service. The soil layer and properties were investigated by borehole drilling and Kunzelstab penetration test, which shown the slope was built with loose sandy soil. The root tensile strength of vetivers was tested in the laboratory by using direct tension test. As the diameter of root increase, the shear strength of roots decreases as a function of exponential. The slope stability of slope stabilized with vetiver and without vetiver was analyzed using Infinite slope method. Slope with vetiver has significantly higher factor of safety when compared to slope in bare soil.

Keywords slope stability, erosion control, vetiver, root stabilization

INTRODUCTION

Vegetation is usually used as an effectively protective layer for erosion control and slope stability reinforcement throughout both hydrological process and improving mechanical soil properties. The vegetation affects hydrological balance directly through evapotranspiration, water inception, infiltration, and surface crushing (Morgan and Rickson, 1995). Typically, vegetation roots can anchor the soft layer soil mass into stronger layer and cross zones of weakness to more stable soil. Roots system in the soil mass also provide tensile strength which contribute to improve the shear load resistance of soil.

Vetiver grass (*Chrysopogon zizanioides*) has been widely used in many tropical countries for erosion control and slope stabilization (Hengchaovanich, 1998). As vetiver grass is planted parallel to the slope contour with dense fine vertical deep root (3-4 m), it is effective for nailing soil mass within slope and reducing soil erosion from runoff. In addition, vetiver grass has high tensile strength of roots and high root distribution (Root Area Ratio), which contributes root reinforcement and increase slope stability. Other benefit of using vetiver grass in slope are there is its low-cost, tolerance, and self-repairing ability. As a result, it is popularly used for slope protection in tropical area for both natural slope or man-made slope.

OBJECTIVE

The studies described the engineering of combination root system and result from the field. In this study, the effect of root diameter on the tensile strength of roots was established.

METHODOLOGY

Erosion Control and Slope Stabilization with Soil-Bioengineering

1. Erosion Prediction using Universal Soil Loss Equation (USLE)

The Universal Soil Loss Equation (USLE) is a semiempirical equation developed by the USDA Agricultural Service in the early 1960s. The USE equation is formally used for predicting the erosion losses is crop land or agricultural activity, and then the equation was developed for construction activity such as slope highway, natural slope, and construction site. based on statistical results measured from the field. The USLE considers factors which cover climate, soil, topography, and vegetation cover (Gray and Sotir, 1996). The soil loss from a site is predicted according to the relationship:

$$A = R.K.LS.C.P \tag{1}$$

where A = is predicted soil loss (ton/ km^2 /year), R = is rainfall factor, K = is soil erodibility value, LS = is slope length factor, C = is vegetation factor, and P = is erosion control in practice factor.

The detail procedure and USLE parameter estimation can be seen in many researches e.g. Gray and Leiser (1982), Goldman and Bursztynsk (1986). However, on this paper the USLE Parameters will be applied according to Apiniti (2557).

As this paper focus mainly in the soil parameters, so the effect of soil type on measured erosion will be discuss extensively. The soil type is play important role on erodibility. The factors including gradation, plasticity indices, soil structure, and void ration can affect the soil erodibility value. A recommended hierarchy based on the Unified Soil classification system is presented as:

Most Erodible $\longrightarrow$ Least Erodible

ML > SM > SC > MH > OL >> CL > CH > GM > SW > GP > GW

when GW = is well graded gravel, GP = is poorly grade gravel, GM = is silty gravel, SW = is well graded sand, SC = is clayey sand, ML = is low plasticity silt, MH = is high plasticity silt, CL = is low plasticity clay, CH = is high plasticity clay, OL = is low plasticity organic soil.

2. Slope Stability with Vetiver Stabilization

The effect of vegetation on slope stability can be described as mechanical effects. Normally, soil has high compression but rather low tension. The roots of vetiver are strong tension with weak compression. Therefore, a combination of soil and vetiver roots can provide strength for the composite material (Thorne, 1990, Jotisankasa et al. 2015). Typically, the contribution of the Vetiver root on shear strength of soil can be described in term of soil cohesion due to root reinforcement, c_r . Many researchers proposed the equation to estimate the root cohesion. However, the root cohesion proposed by Wu et al. (1979) which describes the cohesion which considers the root tensile strength, area density and root distortion angle as:

$$c_r = T_r \left(\frac{A_r}{A}\right)(sin\theta + cos\theta tan\emptyset) \tag{2}$$

where c_r = is roots cohesion (kPa), T_r = is root tensile strength (kPa), Ar/A = is root-area ratio surface (consider at shear surface, θ is angle of distortion(degrees), and Ø is friction angle of soil (degrees).

Normally, slope or embankment in semi-tropical or tropical area may experience the unsaturated equation. The shear strength of soil which combined the effect of unsaturated soil and root reinforcement can be express as (3)

$$\tau = c_r + c' + \sigma_n tan\emptyset' - u_w tan\emptyset'' \tag{3}$$

where c' = effective cohesion, σ_n = normal stress, $\emptyset'$ = effective angle, u_w = pore water pressure, $\emptyset''$ = friction angle due to pore water pressure or matric suction which equal $\emptyset'$ when soil is saturated (u_w = 0).

The root cohesion and pore water pressure can be taken accounted in the slope stability equation for infinite slope proposed by Fredland and Raharjo (1993), which can be expressed as:

$$F = \frac{c_r + c' + (\gamma z cos^2\beta) tan\emptyset' - u_w tan\emptyset''}{\gamma z sin\beta cos\beta} \tag{4}$$

where F = factor of safety, β = slope angle, z = depth of failure plane, γ = soil unit weight. The mainly impacted of Vetiver root on factor of safety are to reinforce the soil mass and to reduce the pore water pressure u_w. The water table tend to decrease due to evaporation. If the pore water pressure decreases to negative, the tension in water will be generate. Then, shearing strength of soil will be increase significantly.

3. Site Investigation and Geotechnical Properties

To evaluate effect of Vetiver on erosion control and slope stability, the detention basin located in Kalasin Province the north eastern part of Thailand was be chosen as a study site. The detention basin is a large excavation project with total area 395 acres, and more than 10 km long for the boundary. The aerial photo of the detention basin was depicted as shown in the Fig. 1. The main objective of the project is to store the water from the flooding season and to store the water for the crops nearby the detention basin during the planting season 6.8 million cubic meter (At normal storage +132 Mean-sea average). A cross section for slope excavation is presented in Fig. 2. The total height of the slope is 8 m with slope 2:1 (horizontal: vertical, 26.6^o). The berm at 3 m was design for spawning fish, and counter weigh the toe slope.

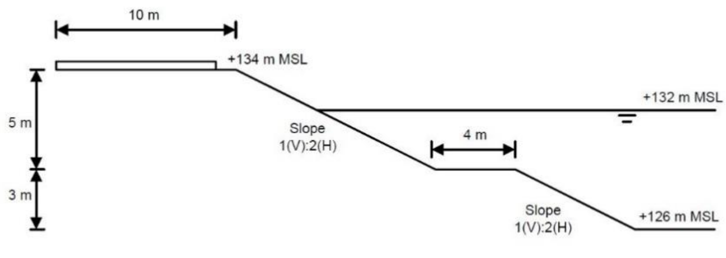

Fig. 1 Aerial photo of detention basin boundary **Fig. 2 Cross section for slope excavation**

3.1 Soil Profile and Geotechical Properties along the Detention Basin

The soil profile and geotechnical properties of soil was investigated by the borehole drilling with wash boring machine. The five boreholes including BH-1, BH-2 BH-3, BH-4, and BH-5 were drill along the slope of the detention basin and soil sample were collected for laboratory testing. The cross section of the soil profile is shown in Fig. 3. It is found that at the depth 0 m to10 m the soil layer for this area is non-uniform comprising with various fine soils such as low plasticity clay (CL), Low Plasticity Silt (ML), Low plasticity silt and low plasticity clay (CL). This maybe this area is located at the flooding plane. A highly weathered siltstone or mudstone which is a parent rock was found after 10 m at the BH-1 and BH-5. After 18 m, the dense to very dense sand (SM) was mostly found lay uniformly with depth. The relationship of standard penetration test (SPT) with depth for all boreholes were shown in the picture. At near surface (<5 m) the SPT is lower than 10, indicating of weak soil layer. The soil data from the borehole drilling will be used for slope stability analysis.

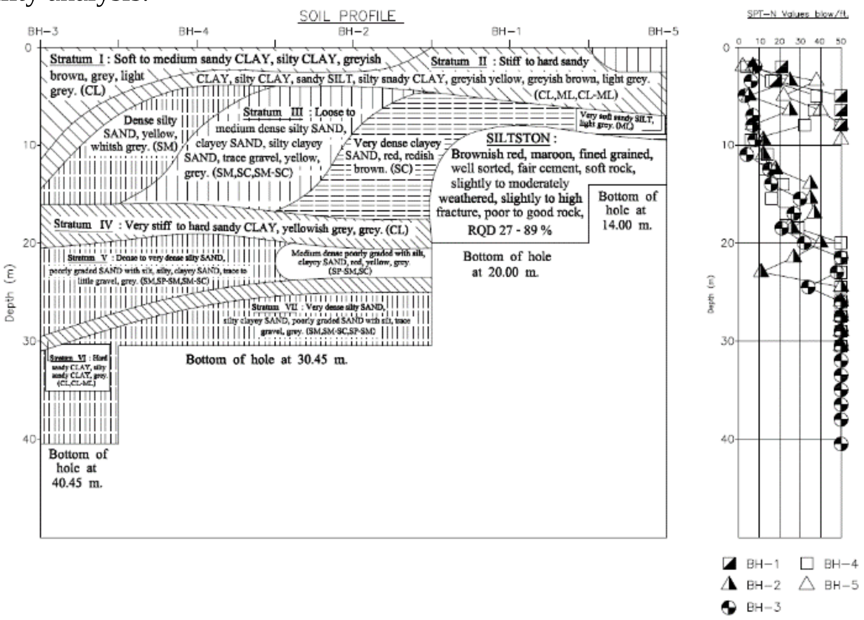

Fig. 3 Soil profile and the standard penetration value (SPT) from borehole BH-1, BH-2, BH-3 and BH-4

3.2 Soil Investigation and Sampling and at Near Surface along the Detention Basin

Since one of the objectives is to characterize the erosion of soil slope, the 15 soil samples which is used as representatives of soil along the detention basin were collected and test in the laboratory.

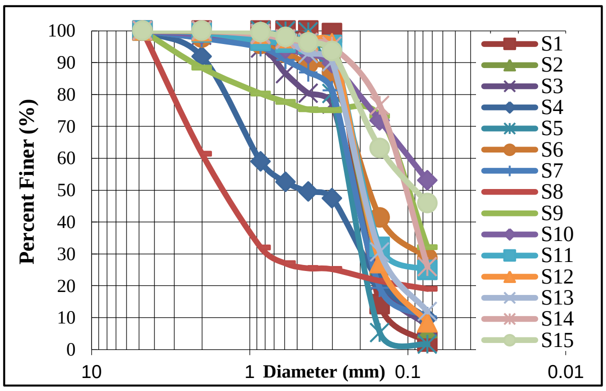

Fig. 4 Boundary of the detention basin and location for soil sampling

Fig. 5 Grain size distribution of tested specimens

Figure 4 presents the boundary of detention basin and location for soil sampling. The tests included grain size distribution, percent of and, percent of fines particle, plasticity indices, coefficient of uniformity (C_u), and coefficient of concavity (C_c) were determined for classifying soil type according to the Unified Soil Classification System (USCS). Fig. 5 present grain size distribution of all test samples. It is found that most samples comprising sand (particle between 0.075 mm to 4.75 mm) and tend to have uniform grade with size particles between 1mm to 3 mm. The percent of fines varies between 2.4% to 53.0%. For Atterbergs' limits, ten of fifteen samples are non-plasticity soil, and five samples present a low plasticity soil. Classified by soil the USCS most of soil are SP-SM while the rest are SM, SC, SP, and ML, respectively.

3.3 Soil Strength Investigation using Kunzelstab Penetration Test (KPT)

The Kunzelstab Penetration Test (KPT) is one of the in-situ strength test which popularly used because the test device is light weight, rapid to test, and economical to test when compare to other field test such as wash boring drilling or rotary drilling (Künzel, 1936; Krasaeteep and Thongchart, 2012). The Kunzelstab device comprises guild rod with diameter 25 mm, sounding rod with diameter 20 mm, hammer, anvil, base plate, penetration control, and cone with varying apex angle (60^o, 90^o, and 180^o) (Kererat, 2016). During the test, the 10 kgs hammer will be raised for 50 cm in height, and then drop freely, which equivalent 49 J (kg $m^2\,s^{-2}$)/blow. The test will continue until the advance distance of rod reach 20 cm. Then number of blows will be recorded (blows/20 cm). After that, the bow count will be converse to strength parameter such as cohesion or friction angle. Relationship between standard penetration test (SPT), Kunzelstab test (KPT), friction angle (Ø), and relative density for sand is shown in Table 1.

Table 1 Relationship between standard penetration test (SPT), Kunzelstab test (KPT), friction angle (Ø), and relative density for sand (EGAT 1980)

SPT (blows/30 cm)	KPT (blows/20 cm)	Ø (degree)	Relative density
0 – 4	0 – 6	25 – 30	very loose
4 – 10	6 – 18	27 – 32	loose
10 – 30	18 – 55	30 – 35	medium
30 – 50	55 – 92	35 – 40	dense
>50	> 92	38 - 45	very dense

RESULTS AND DISCUSSION

Erosion Prediction and Measurement

After the end of construction when the monsoon season pass, hundreds of erosions due to runoff water were observed along the slope. Many types of erosion including sheet erosion, rill erosion, gully erosion, until slope failure were observed along the slope of the project. The degree of severity for observed erosions can be ranked into four categories from level I low erosion, level II medium erosion, level III severe erosion, and level IV extremely severe erosion. The erosion level I represent non-erosion to rill erosion deep less than 5 cm. The level II erosion is rill erosion deep from 5cm to 10 cm. The level III erosion is the deep rill or gully deep more than 10 cm. The level IV erosion represents severe gully erosion with high volume soil mass. Fig. 6 presents erosion for each level observed from the detention basin project. As the slope is 10 km long with varying types of soil, the three zones were classified according by the soil type into zone A, zone B, and zone C as shown in Fig. 4. For Zone A, the typically soil is reddish silty sand which is highly decomposed from the weathered mudstone, a parent rock which lay underneath in this area. Zone B is the uniform loose sand (SM), and zone C is mainly low plasticity clay with sand (SC).

In this study, the erosion parameters required for the USLE were summarized based on Jotisankasa (2014). The Rainfall factor (R) was received from the rainfall station No 1110 Huasithon reservoir Kasasin Province (about 40 kms from the project). The soil erodibility (K) is depending on the soil types. As the slope geometry is similar along the slope distance (10 m in length and 26.6^o for slope angle), the slope length factor (LS) is the same value for zone A, Zone B, and Zone C. Vegetation factor (C) is equal 1.0 for uncovered soil, and equal 0.1 for slope covering with Vetiver. Erosion control in practice factor (P). As a result, the soil loss predicted from the USLE was 2,517.3 ton/hectare, 2,591.2 ton/hectare, and 1,258.7 ton/ hectare. The detail of parameters is shown in Table 2.

a) level I: low erosion

b) level II: medium erosion

c) level III: severe erosion

d) level IV: extremely severe erosion

Fig 6. Erosion level observed from the detention basin project

a) level I low erosion (erosion deep less than 5 cm) , b) level II medium erosion,
c) level III severe erosion (rill to gully erosion deep more than 10 cm, and
d) level IV extremely severe erosion deep gully

Table 2 Summary erosion parameters for soil loss prediction in case of without vetiver convers

Erosion Factor	Zone A	Zone B	Zone C
Rainfall Factor (R, mm/yr)	583.53	583.53	583.53
Soil erodibility value (K)	0.34	0.35	0.17
Slope Length Factor (LS,m)	9.76	9.76	9.76
Vegetation Factor (C)	1.0	1.0	1.0
Erosion control in practice factor (P)	1.3	1.3	1.3
Soil Loss (tons/hectare/year)	2,517.3	2591.2	1,258.7

Slope Stability Analysis with Rotation Failure

For deep slope failure, the slope stability for studied point were analyzed based on rotation method using Simplified Janbu (1973), Simplified Bishop (1955), and Spencer (1973) Method. The shear strength parameters used for analysis were obtained from Kunzelstab test. The possible worse scenario which water table at -1 m from the surface while the water level in the detention basin was set at 131 m mean-sea level. The KU Slope, a software developed by Kasetsart University, was used to calculate the factor of safety. The example of slope stability analysis at KPT-3 and compared to the slope failure which happen in the field the factor of safety for KPT-1, KPT-2, KPT-3, and KPT-4 calculated using various method were shown in Table 3. It is shown that the factor of safety ranges between 0.64 to1.60. The three analysis methods provide almost similar factor of safety. Typically, for permanent slope the Factor of safety should lower than 1.5, thus the four slopes at selected location have high risk to fail. The results from the analysis corresponds well with result in the field because after the end of rainy season all four selected locations failed with high soil mass movement.

Table 3 Factor of Safety calculated from Simplified Janbu, Simpliflied Bishop, and Spencer Method

Location	Factor of Safety		
	Simplified Janbu	Simplified Bishop	Spencer
KPT-1	1.23	1.24	1.25
KPT-2	0.64	0.69	0.72
KPT-3	1.56	1.53	1.60
KPT-4	0.81	0.88	0.94

Factor of Safety for Infinite Slope Reinforced with Vetiver Grass Root

In order to evaluate the effect of Vetiver grass root on infinite slope stability using equation (4), A scenario of soil slope and properties were set. In this analysis the root cohesion was calculated based on equation (2). The tensile strength is predicted from the pullout test with equation (5) when the root diameter equal was fixed at 1 mm. The unit weigh of soil is 1.8 t/m^2. The failure plane assumed to occur at 2 m. The pore water pressure (U_w) was assumed to be zero. Table 4 presents the factor of safety at varying percent of root area (A_r/A) which is calculated from equation (4). The factor of safety of bare soil (A_r/A = 0%) were 1.04, 1.02, 1.74, and 1.06 for Slope at KPT-1, KPT-2, KPT-3, and KPT-4, respectively, indicating high risk to fail (Factor of Safety <1.5). The factor of safety significantly increases with percent of root area ratio. With root area 0.2%, the factor of safety can increase more than 5 times due to root reinforcement. This result shows strong impact of Vetiver root on infinite slope, and it implies that slope will not fail in case of infinite slope if there is a Vetiver grass root ratio more than 0.2%.

Table 4 The factor of safety of infinite slope with varying percent root area (A_r/A)

Location	Factor of Safety at varying percent of root area (A_r/A)			
	0%	0.2%	0.4%	0.6%
KPT-1	1.04	5.20	9.36	13.51
KPT-2	1.02	5.18	9.33	13.49
KPT-3	1.74	5.90	10.05	14.21
KPT-4	1.06	5.21	9.37	13.53

CONCLUSION

This paper presents the ability of Vetiver grass for reducing erosions and stabilizing the soil slope with sandy soil. The detention basin project located at Kalasin Province, Thailand were selected because the project had plant Vetiver grass along the slope to relieve the erosions and slope failures in the project. The Vetiver roots were prepared and tested to obtain the tensile strength. It was found that the slope covering with Vetiver grass can reduce soil loss from erosion ten times than slope without Vetiver grass when computed with the Universal Soil Loss Equation (USLE).

The Kuzelstab is an effective tool for finding the strength parameters. The Factor of safety calculate from Simplified Janbu, Simplified Bishop, and Spencer were not significantly different. For pullout test, the vetiver roots provide high tensile strength ranging between 10 MPa to 50 Mpa. The tensile strength of Vetiver reduces with diameter as an exponential function. The Vetiver roots significantly contributes the soil slope stability for infinite slope. With roots area ratio 0.2% the factor of safety will increase five times.

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