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The Role of *Vetiveria zizanioides* Nash Root on Shear Strength Characteristic of Eolian Soil Slope

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Summary: Highly eroded eolian soil is widely distributed in the Northeastern, Thailand. Cut slopes and embankments of this soil are prone to scouring and sliding. The role of *Vetiveria zizanioides* Nash root for stabilizing these soils was investigated and included analyzing the root characteristics and soil strength properties. Shear strength tests of the soil specimens with and without root were conducted by triaxial, large and small scale direct shear methods. The average strength of natural free root determined from triaxial method was $c=1.2$ kPa, $\phi=19^\circ$ and from large and small direct shear was $c=17$ kPa, $\phi=30^\circ$. The study revealed that a year old root penetration terminated at 2.5 m depth. The average root density found densest about 5.5 kg/m³ at 0.5 meter and linearly reduced down to 1.2 kg/m³. The cohesion ratio (CR) from direct shear and triaxial test showed descending variation from 2.7 to 1.3 and 9 to 2, conforming to the root density. The effect of the root to internal friction was negligible. Slope model consisting of a three-layered root was proposed. Four potential failure surfaces were analyzed. The safety factor ratios (FR) between rooted and bare slopes for failure less than 2 m deep conditions, were 1.3 - 2.5. The reinforcement role of *Vetiveria zizanioides* Nash root for slope stabilization was concluded to have moderate effectiveness.

INTRODUCTION

Eolian soil formation is commonly found as surficial deposits in the town of Khon Kaen, Northeast, Thailand. It is reddish to yellowish, loose silty sand about 2-8 m thick. Wannakao L. and Sinchai CH. (1999) stated that this eolian deposit has a collapsing behavior. It is hard when dry, but easily loses strength when wet. Cut slopes and embankments are easily eroded causing shallow surface sliding. Vetiver grass has long been used as erosion control. The effectiveness of the root has been discussed. Most of the research paid attention to individual root tensile strength. However, there are many factors limiting the root strength determination such as the root branching, diameter and freshness. Though, the nature of root reinforcement on a slope is tensile action, it also produces a normal force acting along the potential shearing plane (Hengchoavanich & Nilaweela, 1999). Therefore, the shear strength parameters of the root reinforcement soil are of interest. Direct shear and triaxial testing methods were selected for determining strength parameters of the soils with and without root. *Vetiveria zizanioides* Nash is considered due to its root characteristics and availability. It is a very coarse, tough bunch grass that grows up to 1-1.5 m. It forms a clustered mass of dense stems with a deep penetrating root system ranging from 3 - 5 m. It can survive in any kind of soils even in low fertility like an eolian soil. Thus, the effect of vetiver grass root to the strength of this soil was investigated. A year old *Vetiveria zizanioides* Nash grass farm was available in Land Development Department area 5, Khon Kaen Province Thailand (Figure 1).

METHODOLOGY

Natural eolian soil specimens were collected from BH-1WR, BH-2WR, and BH-3WR, while the root permeated soil specimens were taken from BH-1R, BH-2R, and BH-3R (Figure 2). According to root penetrating depth, the specimens were consecutively selected at 0.5, 1.0, 1.5 and 2.0 m. The in situ soils were cut into blocks of 60x60x30 cm size and fitted into plastic lined wooden boxes. Then, four specimens of 60 mm diameter and 20 mm thick and 150 mm diameter and 35 mm thick were prepared for a set of small and large scale direct shear tests. A 60 mm soil specimen collected with a thin wall sampler was cut into four specimens of length to diameter ratio (L/D) = 2 for a set of triaxial tests. A summary of the tested specimens are listed in Table 1. Direct shear and triaxial laboratory tests followed ASTM D3080 and D 2850 standards. The variation of normal stress on each direct shear plane and the confining stress applied on each cylindrical specimen are listed in Table 2. Tests to determine physical properties such as grain size, Atterberg limits, density and void ratio of each free root soil specimen were also conducted. After testing, the root from each rooted soil were cleaned, dried at low heat, then weighed. The dry weight of root to total volume of soil, called root density was evaluated.

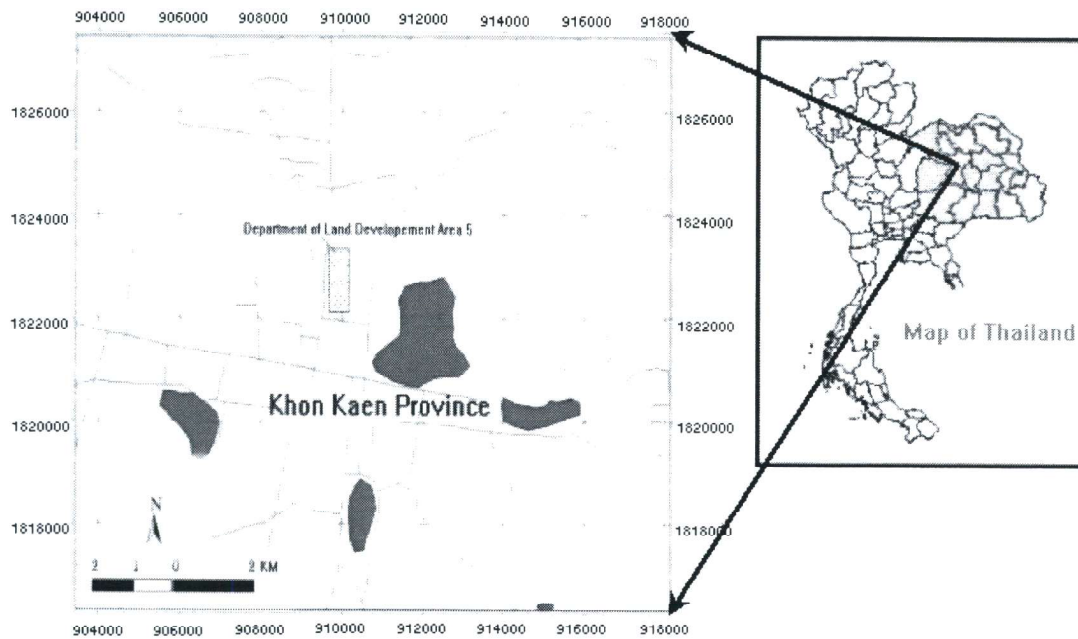


Figure 1 Location of the Study Area, Khon Kaen, Thailand

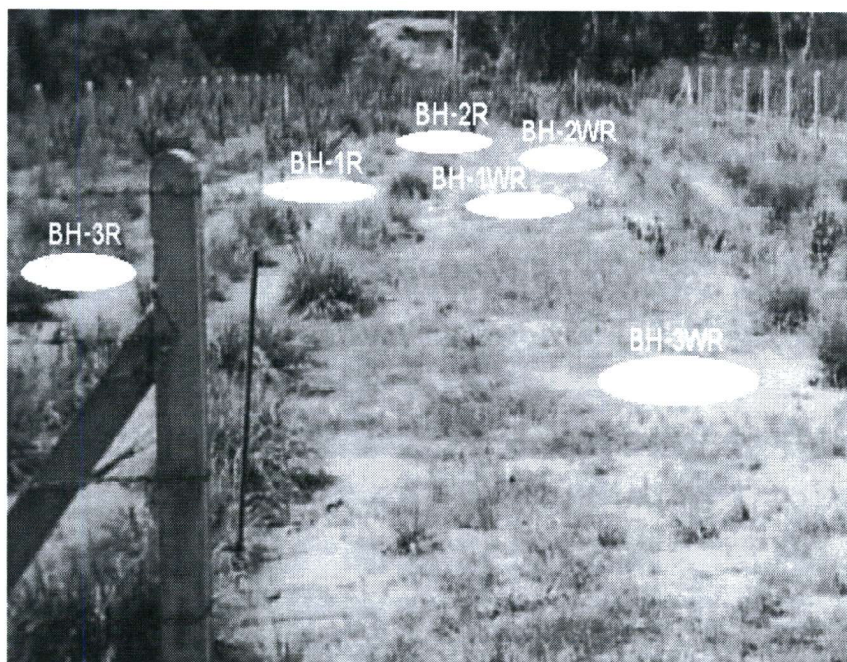


Figure 2. The sampling points in vetiver grass farm at Land Development Department area 5, Khon Kaen Province, “R” denotes for rooted samples and “WR” denotes for without root sample.

Table 1. Number of Tested Specimens

Depth (m)	Number of specimens					
	Rooted			Bared		
	Direct shear test		Triaxial test	Direct shear test		Triaxial test
	small	large		small	large	
0.5	12	8	8	12	8	8
1.0	12	8	8	12	8	8
1.5	12	8	8	12	8	8
2.0	12	8	8	12	8	8

Table 2. Normal and Confining Stresses Used in a series of Direct Shear and Triaxial Testing.

Depth (m)	Normal stresses (kPa)								Confining (kPa) Triaxial test			
	Small scale				Large scale				1	2	3	4
	1	2	3	4	1	2	3	4				
0.5	36.3	72.3	108.9	145.2	33.9	67.9	113.2	147.4	25	50	100	150
1.0	72.6	145.2	217.8	290.3	67.9	147.2	215.2	283.1	50	100	200	300
1.5	108.9	217.8	326.7	435.6	113.2	215.2	328.4	430.3	100	200	300	400
2.0	145.2	290.3	435.6	580.8	147.2	283.1	430.3	577.1	150	300	400	600

RESULTS AND DISCUSSION

Characteristics of the eolian soil

Tests of natural eolian soil at the study site revealed non plastic to very low plasticity index (approximately 2%) and liquid limits of 14.3-14.9%. It typically comprises more than 60 % sand, 20-30% silt and less than 10% clay, and could be classified as silty sand (SM) as summarized in Table 3. Average void ratio and dry unit weight of the soil were 0.74 and 14.0 kN/m³, indicating loosely packed soil. The effective grain size varied from 0.005-0.018 mm. The soil permeability as calculated from Hazen's equation was 3.2×10^{-6} - 2×10^{-7} cm/s.

Table 3. Grain Size Distribution of the Eolian Soil

BH	Depth (m)	Sand (%)	Silt (%)	Clay (%)	D ₁₀ mm	D ₆₀ mm	D ₃₀ mm	C _u	C _z	USCS
1WR	0.5	59.0	34.0	7.0	0.005	0.25	0.055	50.0	2.4	SM
	1.0	69.6	25.4	6.0	0.012	0.16	0.071	13.3	2.6	SM
	1.5	70.0	24.0	6.0	0.016	0.25	0.065	15.6	1.1	SM
	2.0	72.8	22.2	6.0	0.016	0.35	0.08	21.9	1.1	SM
2WR	0.5	63.4	32.6	4.0	0.005	0.26	0.07	52.0	2.8	SM
	1.0	66.4	25.6	7.0	0.009	0.16	0.07	17.8	2.4	SM
	1.5	69.2	23.8	7.0	0.018	0.24	0.07	13.3	1.1	SM
	2.0	71.8	23.2	5.0	0.018	0.37	0.08	20.6	1.0	SM
3WR	0.5	69.3	24.7	6.0	0.013	0.31	0.07	23.8	1.2	SM
	1.0	66.8	25.4	6.0	0.013	0.18	0.07	13.8	2.1	SM
	1.5	70.7	23.3	6.0	0.018	0.26	0.075	14.4	1.2	SM
	2.0	70.6	22.4	7.0	0.013	0.35	0.075	26.9	1.2	SM

Characteristics of the *vetiveria zizanioides* Nash root

The *Vetiveria zizanioides* Nash, a year old from the test site has a bundle root system with root diameter of 0.1-3.0 mm diameter. The root shows a narrow vertical growth with root bundle at the base (Figure 3a). The variation of root density for different types of tested specimens and depth is depicted in Figure 3b. The highest root density occurred at a depth of 0.5 meter and linearly decreased with depth. At 0.5 meter, the cylindrical triaxial specimens gave the highest root density up, to 6.8 kg/m³, while large scale direct shear samples show the lowest at 4.2 kg/m³. All specimens pertaining vetiver root gave similar density dropped and merged to 0.6-1.7 kg/m³ at 2 meter. The sampling techniques, fibrous root branching and the size of the specimens may cause lateral root density variation. The influence of the root was terminated at 2.5 meter. Thus, the variation of root density will be considered in modelling a rooted slope.

Strength properties of eolian soil with and without vetiver root

The shear strength parameters c, ϕ of the eolian soil with and without root were compared at each depth and each testing method (Table 4). Soil strength from triaxial test showed almost no cohesion conforming to theoretical silty sand behavior. Some cohesion (about 5.6 – 28.6 kPa) was obtained from both large and small scale direct shear tests. This phenomena may be due to fine particle attractive forces due to a thin film of water and some clay minerals. Triaxial tests gave lower internal friction angle (18°-20°) than the direct shear tests (28°-32°). The internal friction angle of rooted soil was slightly higher in direct shear tests (about 1-2°). But, cohesion of rooted soils dramatically increased especially at 0.5 m, then declined with increasing depth. As to emphasize the influence of vetiver root to strength of root permeated soil, the cohesion ratio (CR) between soil with root (c_R)

and without root (c) was introduced. The relationship between root density (RD) to cohesion was found as in Figure 4.

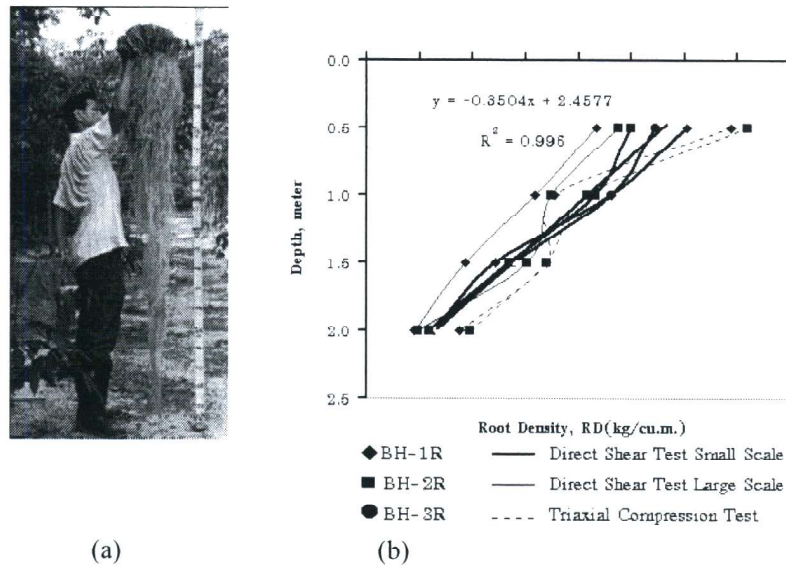


Figure 3 (a) *Vetiveria zizanioides* Nash root (b) Distribution of root Density Versus Depth and Sample Size.

Table 4 Summary of Shear Strength Parameters from Triaxial, large and small scale direct shear tests

BH	Depth (m)	Triaxial Test				Large direct shear test				Small direct Shear test			
		c (kPa)		ϕ (Degree)		c (kPa)		ϕ (Degree)		c (kPa)		ϕ (Degree)	
		R	WR	R	WR	R	WR	R	WR	R	WR	R	WR
1	0.5	11.3	1.2	19.2	19.4	41.4	25.6	30.5	29.2	52.4	28.6	30.5	28.6
	1.0	4.3	0.6	19.8	19.9	34.0	21.4	32.1	31.1	43.5	25.8	30.7	30.0
	1.5	4.5	0.9	20.6	20.2	23.1	15.5	32.8	32.5	37.8	24.5	31.2	30.6
	2.0	1.9	1.1	18.5	18.3	9.5	7.6	31.1	31.2	23.1	17.6	30.8	29.8
2	0.5	13.2	1.4	19.6	19.9	35.6	13.1	31.0	29.1	49.4	25.3	30.1	28.9
	1.0	7.3	1.1	20.1	20.3	26.5	10.0	31.9	30.3	44.7	24.0	30.6	29.7
	1.5	6.6	1.8	20.0	20.1	19.4	9.5	33.1	32.4	39.2	23.1	31.0	30.3
	2.0	2.9	1.4	19.4	19.3	9.7	5.6	32.9	31.7	28.3	19.6	29.5	30.2
3	0.5	-	-	-	-	39.4	8.0	31.5	30.0	-	-	-	-
	1.0	-	-	-	-	30.2	15.3	31.6	30.8	-	-	-	-
	1.5	-	-	-	-	18.5	9.9	31.8	32.0	-	-	-	-
	2.0	-	-	-	-	12.1	7.1	32.1	32.0	-	-	-	-

The cohesion ratios could be predicted from their linear curve fit as following equations, $CR = 1.2 \cdot RD + 1$ for triaxial and $CR = 0.2 \cdot RD + 1$ for direct shear strength parameters. The results indicate that the root has more role in strengthening the soil in the triaxial mode of testing. This is believed to be a consequence of the oblique failure plane and longer root in the tested specimen causing more surface area and dragging force effect along the plane. Though, the root density significantly had affected the cohesion parameters, the density of the soil did not increase. The shear stress - horizontal displacement and deviator stress - axial strain in Figure 5 verified loose soil behaviour in both root and no root specimens.

Simplified *Vetiveria zizanioides* Nash root slope model

A one year *Vetiveria zizanioides* Nash planted slope was assumed with a 2:1 slope. The root zone within the slope was modelled as three different layers with characteristics mentioned in the above section. Each layer was 0.5 m thick and the root zone was terminated at 2 m. Material properties (total unit weight and strength) were averaged from the rooted soil test results at a specific depth. Beyond the root zone, average bare root soil properties were used. A circular failure surface on a slope face was proposed in the analysis. Four limiting failure boundaries were assumed as illustrated in Figure 6. The models were analyzed by slope/w version 3.1, using the ordinary method of solving. In order to quantify the effectiveness of vetiver root in stabilizing the slope, safety ratio (FR) was calculated for slopes with and without root. The results of each model is tabulated in Table 5. The root gave the highest improvement to stability for shallow failure surfaces (model 1) and the triaxial strength parameters were used. With deeper failure surfaces, declining FR values are obtained. In all cases, the root increased the

stability with FR ranging from 1.2-2.6 depending on the depth of the failure surface. Though, the typical failure model falls within the triaxial mode (figure 7) and cohesion ratios from triaxial were approximately 5 times greater than from direct shear ones, the strength parameters determined from 3 testing methods showed no significant influence on the FR value.

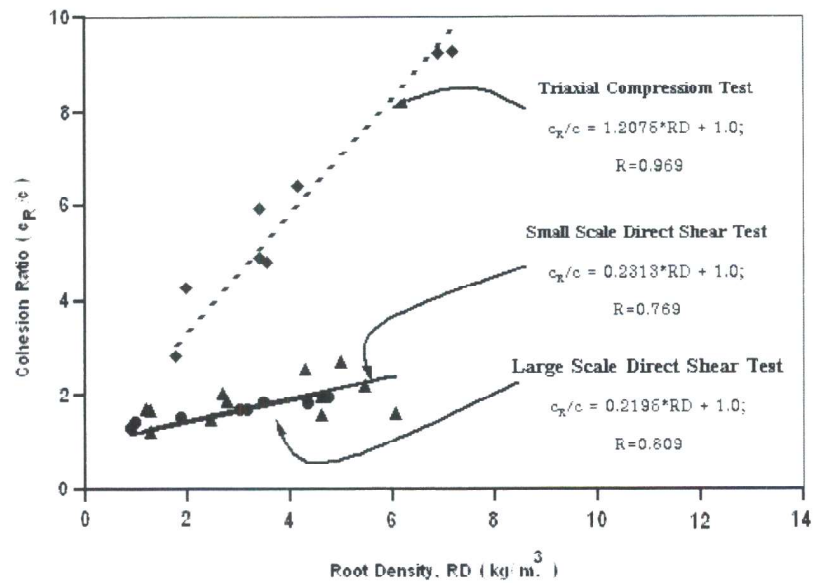


Figure 4 The Relationship Between Cohesion Ratio (CR) and Root Density from Different Testing Methods.

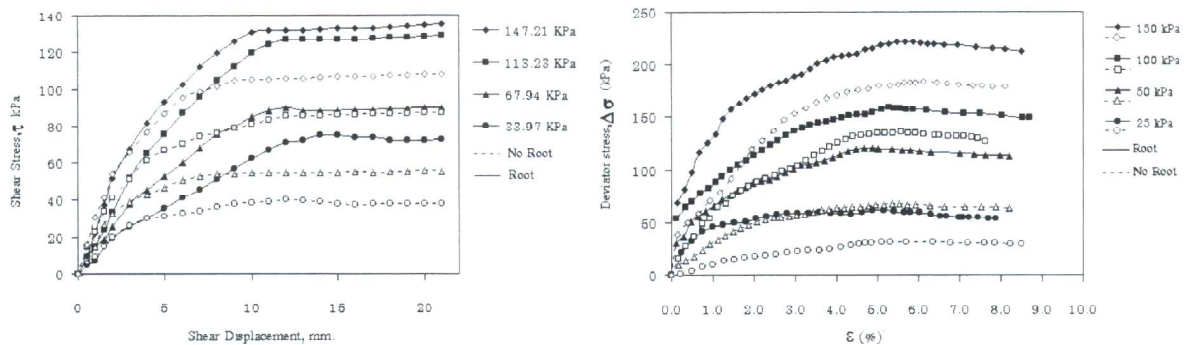


Figure 5 Behaviour of the Soils With and Without Root from Large Direct Shear and Triaxial Tests.

Table 5 Factor of Safety Ratio of the Assumed Slope Models Analyzing According to Strength Parameters from Three Types of Testing.

Strength parameters	Failure Boundary model	Factor of Safety (FS)		Safety Ratio, FR ($\frac{FS_R}{FS}$)
		Rooted	Bare	
Small Direct shear	1	6.54	3.88	1.69
	2	4.30	2.79	1.54
	3	3.17	2.31	1.37
	4	2.72	2.16	1.26
Large Direct shear	1	8.17	4.93	1.66
	2	5.35	3.44	1.55
	3	3.92	2.67	1.47
	4	3.29	2.64	1.24
Triaxial	1	2.41	0.94	2.57
	2	1.54	0.92	1.71
	3	1.29	0.91	1.44
	4	1.19	0.90	1.30

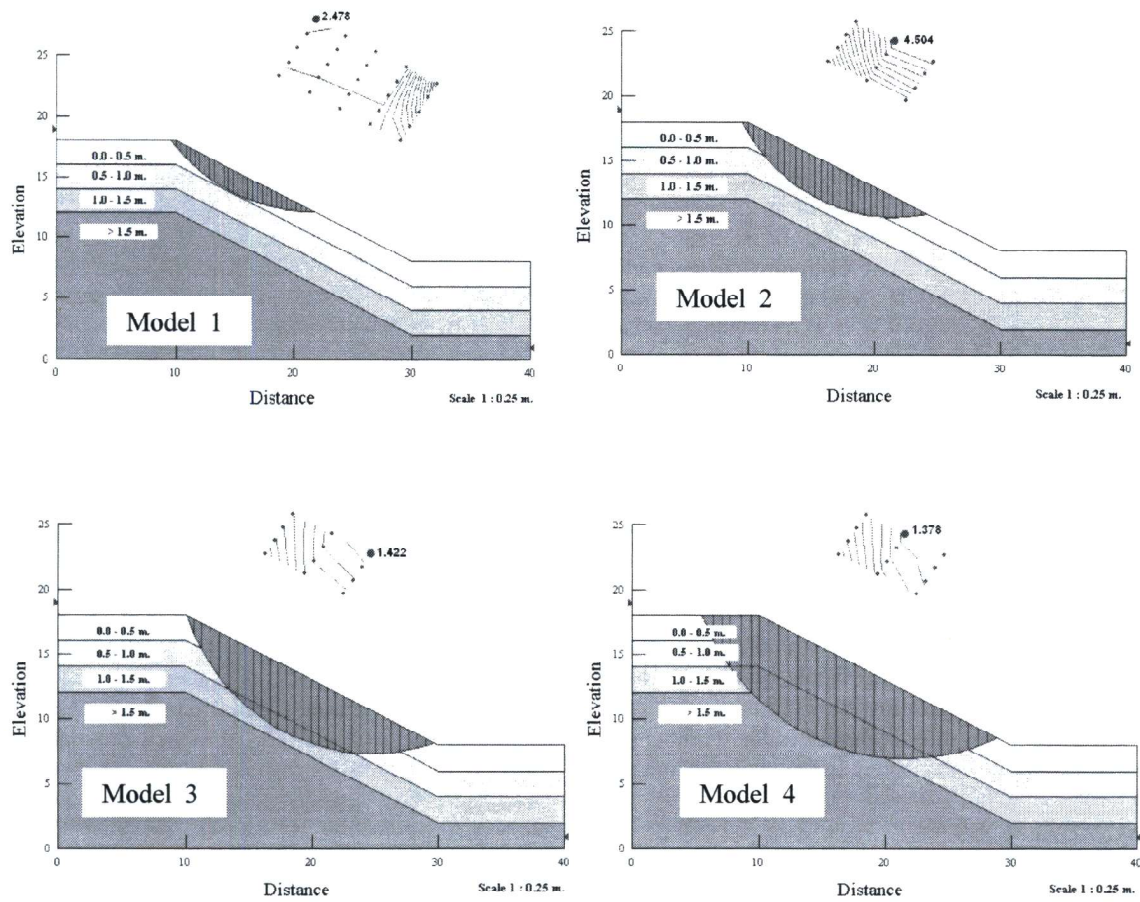


Figure 6 Tentative Materials and Failure Limited Boundaries According to Variation of Root Properties .

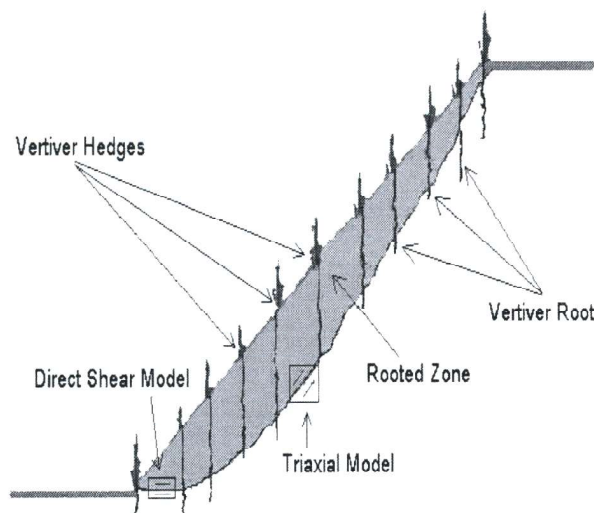


Figure 7 Root Zone, Failure Plane and Practical Strength Parameters Model.

CONCLUSIONS & RECOMMENDATIONS

The one year old *Vetiveria zizanioides* Nash root grown in eolian, silty sand can penetrate as deep as 2.5 m. The highest root density was found at 0.5 m depth. Average root density at this depth was 5.5 kg/m^3 and linearly decreased to 1.2 kg/m^3 at 2.0 m. The root has a great influence on the cohesion parameter no matter which method of testing is used. Triaxial tests showed significant increase in (CR) value from 2-9 with increasing root density. The CR value from both large and small direct shear tests also increased with root density, with the increase in the range of 1.4 – 2.7. The relationship between CR and root density (RD) was found to be $CR = 1.2*RD + 1$ for triaxial and $CR = 0.2*RD + 1$ for direct shear tests. The root had no significant effect on the internal friction angle. The effectiveness of the root could be analyzed from the safety ratio (FR), on 4 proposed root slope models. The model had a fixed geometry at 2:1, slope, three layered root zone at 0.5 m each, four limiting failure boundaries. In the case of shallow instability less than 0.5 m, the FR was about 1.7-2.5 indicating a moderate improvement. The deeper failure outer the root zone, the worst case, the root still gave a slight improvement with the FR of 1.2-1.3. Roles of *Vetiveria zizanioides* Nash as a slope protection must be limited to shallow instability case.

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