MODELLING OF SLOPE STABILITY ANALYSIS WITH VEGETATION

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ABSTRACT: Soil erosion and landslides are the two great concerns in the hilly terrains of the world. The presence of root system in the soil plays good role in increasing the stability of the slope .The hydrological and geo mechanical effects due to the vegetation increases the stability of the slope. The hydrological effect due to the vegetation is related to the soil suction regime and the geo mechanical effect is related to the reinforcement provided by the root network in soil. In this paper, the mechanical effect of vegetation on the slope stability is calculated. The effect of vegetation on the stability of slope is calculated using (i) equivalent cohesion approach and root (ii) root as a pile approach. The analysis was done as per finite element package PLAXIS 3D is used for stability analysis of the slope. The effects of the layers of the vegetation on the stability of slopes are considered. The effect of diameter and spacing of the trees are also considered. The present study will help in modelling the effect of vegetation on the stability of slope and further study is required to validate the present study with that of field trials.

INTRODUCTION

Soil Erosion and loss of soil mass from the land (landslides) are the two great concerns to the Land managers in the world. The root system in the soil plays a good role in increasing the stability of the slopes which may be artificial or natural slopes. The following are the two main effects responsible for the increase in stability of slopes which are covered with vegetation. Those are hydrological and mechanical effects. The geo-mechanical effect is related to the reinforcement that is provided by the root system and the soil hydrological effect is related to the soil suction (capillary) regime which is effected by the root water uptake. The mentioned two effects are very much interrelated. The root distribution in the soil is effected by the climatic regions and the soil-hydrological properties, particularly in the regions where the plant-growth occurs in water-limited condition sand the mechanical strength parameters of the root-soil network is effected by the strength of the single root, strength of the soil, root distribution in the soil and the strength at the interface of the soil and the root. In this project, the methodology is developed for quantifying the effect of vegetation on the slope stability and also the reliability analysis is performed for the slope which is covered with the vegetation.

Available study on slope stability analysis with vegetation

Soil erosion and Landslides are the two natural phenomena which lead to cause the economical and human loss. Many of the researchers developed different methods to quantify the effect of the vegetation on the slope stability.

Zhou et.al (1998) studied on the effect of lateral roots of ***pine forest*** on shallow soil .This study reveals that the lateral roots of the ***pine forest*** produce excellent tractive resistance in the upper region of the soil i.e. 60cm below the surface of the soil. From this study it is also observed that the tensile strength of the upper soil is increased by minimum of 5.7kPa.

Comino et.al (2001) conducted the laboratory experiments in order to know the root reinforcement effect on the shear strength of the soil. From this study, it is observed that shear strength of soil is increased very effectively at 10 cm depth from the surface of the soil due to the presence of the root network.

Pollen et.al (2004) studied on the hydrological effects of the riparian root system on stream bank stability. From this study it is observed that the hydrological reinforcement to the soil is due to the increased in matric suction which is not constant throughout the year. The increased in shear strength is due to the increased in the apparent cohesion in the root zone. It is observed that due to the hydrological effects of riparian roots the apparent cohesion in the vegetated columns varied from 0.95-3.2 kPa at 30 cm and 0.54-5.2 kPa at 70 cm.

Pollen et.al (2005) studied on 'The geo- mechanical effects of riparian roots on stream bank stability'. Fiber bundle approach is used in this study to model the tensile strength of riparian vegetation. From this study, it is observed that the tensile strength of the root is decreased non- linearly with the increase in diameter of the root species tested and force required for breaking the root linearly increases with diameter of the root.

P. Lac et.al (2006) developed the finite element model to analyze the effect of 3-dimensional spatial distribution of trees on the hill slope. By using geometric patterns (cylindrical, cone and sphere), different types of root zones are modelled according to their root system structure. The finite element software ABAQUS is used to analyze the effect of forest structure on the hill slopes.

Schwarza et.al (2009) used WU model and FBM for determining the role of the grass species on the slope stability. Results of the experiments show that lateral roots influence the stability of the slope up to certain area and the stabilizing effect magnitude depends on the distribution of the root in the soil, soil mechanical properties and inclination of the root.

Naghdi Ramin et.al (2012) studied the biotechnical characteristics of root system of the ***Alder***. The biotechnical characteristics considered for this study are root area ratio and the tensile strength of the root. The results of this investigation shows that the root area ratio decreases with depth and its maximum value is observed at depth of 10 cm below the top of the soil surface and they also reported that the mean tensile strength of root is equal to the 16.29 MPa and this value decreases with increase in the diameter of the root.

Objective and Scope

The main objective of this study is numerical analysis of the slope with vegetation and the scope of this study includes the deterministic and reliability analysis of the slope with and without vegetation by using the finite element package PLAXIS 3D

METHODOLOGY

Present Methodology for quantifying the effect of vetiver root on the stability of the slope

Many different solutions techniques are developed over the years to determine the effect of vegetation on the stability of the slope. In this project, the effect of the vetiver root on the slope stability is quantified by using the following two approaches.

1. Equivalent cohesion approach
2. Root as pile approach

Equivalent cohesion criteria

As per this criteria the entire root zone is considered as single block and to this block the increased shear strength parameters are assigned. Many of the investigation results show that the increase in shear strength in the root zone area is mainly due to the increase in the cohesion value of the soil in the root zone. Mathematically, the increase in the cohesion in the root zone is expressed as follows.

$$C_r = t_r(\cos\theta \tan\emptyset + \sin\theta)$$

Where

C_r = increase in cohesion value in the root zone

t_r= average tensile strength of the considered roots per unit area of the soil.

Φ = angle of internal friction of the soil.

The incremental cohesion in the root zone mainly depends on the root and soil properties. Generally for the Vetiver roots the additional cohesion in the root zone varies from 15- 20 Kilo Pascal. Finally, the whole slope is assumed to be consisting of two parts; surrounding soil whose soil properties are not disturbed by the vegetation columns and the root reinforced soil Zone.

Root as pile criteria

In this approach, the entire root zone is considered as a single pile and to this pile the root properties such as modulus of elasticity and tensile strength of the roots are assigned. Generally the modulus of elasticity of Vetiver root is about 2.6 Giga Pascal and the tensile strength of this root is varying from 45-145 Mega Pascal (average 75 MPa). The diameter of the Vetiver is generally varying from the 0.2-2mm.

PLAXIS

PLAXIS is a finite element software which is used to model and analyze the complex problems that are commonly encountered in Geotechnical Engineering. As per Burd (1999), this finite element package was initially launched by the Pieter Vermeer in 1974 for solving the Cone penetration problem. The name PLAXIS is derived from the Plasticity and Axis symmetry. This software also allows the modelling of soil structure interaction problems which are very difficult analyze mathematically. By using this software total displacement, displacement in different direction, pore water pressure, total and effective stresses can be calculated. In this project PLAXIS 3D is used for quantifying the effect of the Vetiver grass on stability of slope.

Model simulation

In the present work PLAXIS 3D version 2013 is used to simulate the effect of the vetiver grass on the stability of slope.

Strength reduction technique

In slope stability analysis , the initial stresses are generated by using the gravity loading method. The initial stresses are developed due to the self-weight of the soil/strucure and generated pore water pressure.The K_0 procedure is used for the models if their ground surface is horizontal in position. The earth pressure coefficient at rest can be calculated by using the Jaky's formula .

$$K_0 = 1 - \sin\emptyset' \qquad (1)$$

Where ø' = Effective angle of internal friction of soil.

In PLAXIS 3D, the safety factor of the slope is calculated by using the phi-c reduction method. The parameters cohesion (c) and the angle of internal friction (ø) of the soil are reduced until the slope becomes unstable. The parameters Poisson's ratio (v) and the Modulus of Elasticity (E) have no influence on the safety factor (M_{sf}).

$$safety\ factor = \frac{Resisting\ force}{Driving\ force}$$

Equivalent Cohesion approach

Many researchers developed different methods to quantify the effect of vegetation on the slope stability. In this present work, the effect of vegetation on the stability of slope is calculated by using the equivalent cohesion and root as pile approaches. The finite element package PLAXIS 3D version 2013 is used to model the slope with vegetation.

Deterministic analysis of slope (without vegetation)

For this study a homogenous slope of 8 meters height, 8 meters width and 10 meters length is considered. Table 1 shows the parameters used in the analysis of slope.

Table 1 Parameters used in the analysis of slope

	Description	Unit	Value
Soil (Mohr - Coulomb model)	Unit Weight	kN/m^3	16
	Modulus of Elasticity	kPa	7500
	Effective Poisson's ratio	-	0.35
	Effective Cohesion	kPa	5
	Effective friction angle	$(^0)$	30

Figure 1 shows the PLAXIS 3D modelling of the considered slope. Figure 2 shows the deformed mesh of the considered slope.

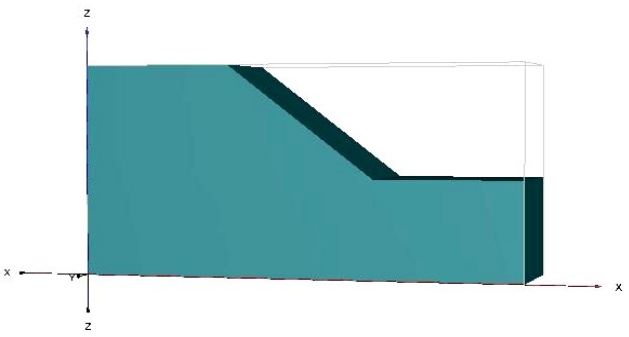

Fig. 1 Geometric modelling of slope

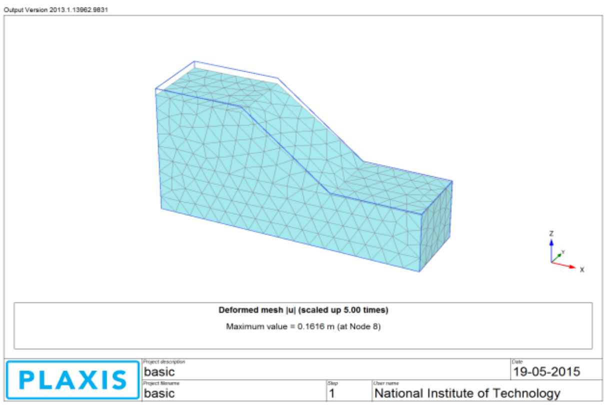

Fig. 2 Deformed mesh

Figure 3 shows the incremental deviator strain which representing the critical failure surface of the considered slope. Figure 4 shows the graph between total displacement and incremental multipliers. From this graph safety factor of slope is measured as 1.36

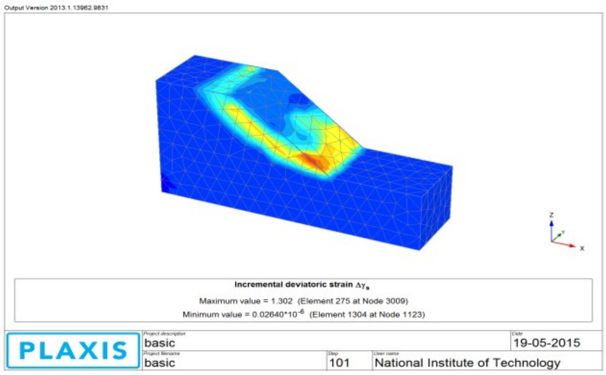

Fig. 3 Failure surface of slope

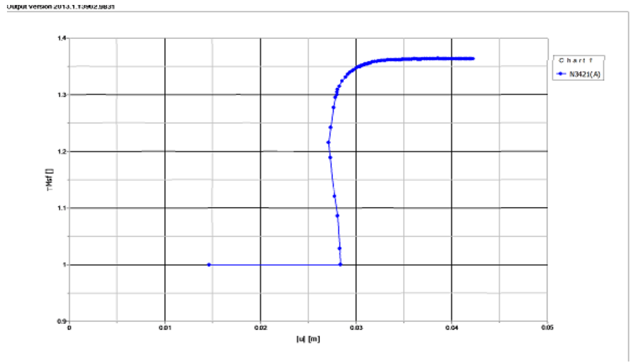

Fig. 4 Total displacement (U) Vs Incremental multipliers (M_{sf})

DETERMINISTIC ANALYSIS OF SLOPE (WITH VEGETATION)

The effect of vegetation on the slope stability is calculated by using the following two approaches.

1. Equivalent cohesion approach
2. Root as pile approach

EQUIVALENT COHESION APPROACH

As per this approach, the entire root zone is considered as single block and to this increased shear strength properties are assigned .the increased in shear strength is mainly due to the increase in the cohesion value of the soil in the root zone. the modelling of the slope with vegetation is done by using the Plaxis 3D software. Table 2 shows the parameters used in the analysis of the vegetated slope.

Table 2 Parameters used in the analysis slope by using Equivalent Cohesion approach

	Description	Unit	Value
Soil (Mohr - Coulomb model)	Unit weight (γ)	kN/m^3	16
	Modulus of Elasticity (E)	kPa	7500
	Poisson's ratio (ν)	-	0.35
	Effective Cohesion (C)	kPa	5

	Effective Friction angle (Φ)	(^{0})	30
	Incremental Cohesion (C')	kPa	15

Figure 5 shows the PLAXIS 3D modelling of slope with vetiver grass by using the Equivalent cohesion approach. The size of the square block considered in this problem is 0.8m .Figure 6 shows the deformed mesh of the slope.

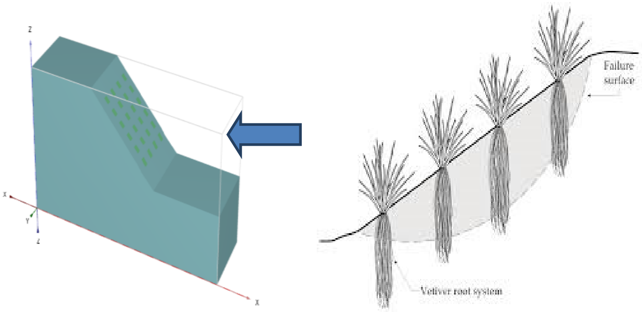

Fig. 5 Geometric modelling of slope with vetiver grass

Figure 6 shows the deformed mesh of the slope. Figure 7 shows the critical failure surface of the slope. Figure 8 shows the graph between the total displacement and the incremental multipliers. From the graph it is observed that the safety factor of the slope is equal to 1.43

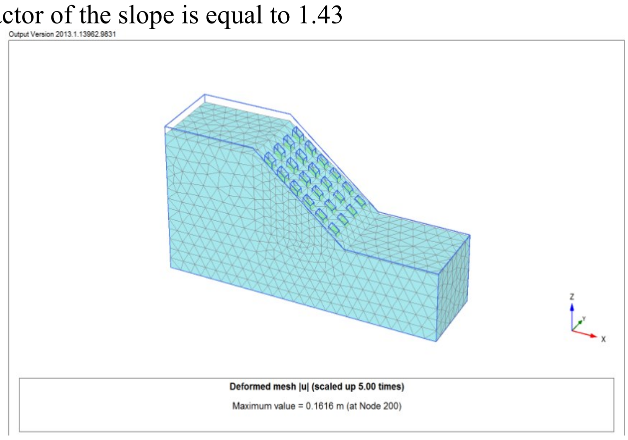

Fig. 6 Deformed mesh of the slope

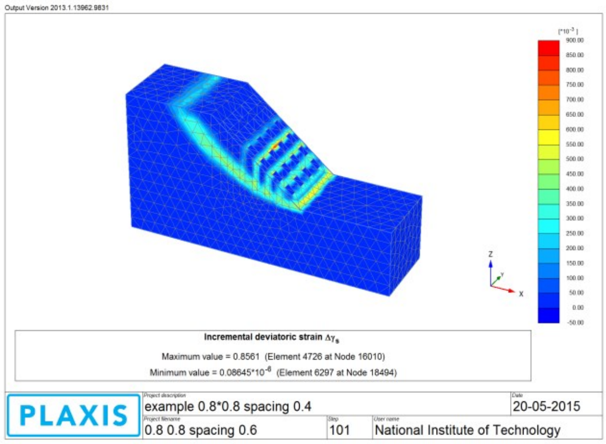

Fig. 7 Critical failure surface of slope

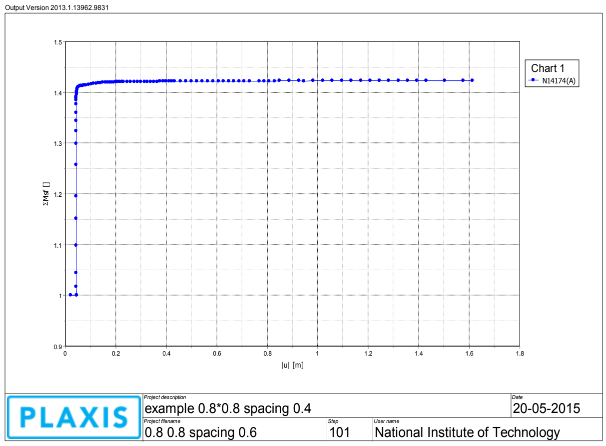

Fig. 8 Total displacement (U) Vs Incremental multipliers (M_{sf})

Table 3 shows the percentage increase in the safety factor due to the vegetation for the different block sizes by using the Equivalent cohesion approach.

Table 3 Percentage increase in the safety factor due to the vegetation

Size of the block (m x m)	spacing (m)	FOS	% increase
0.6 x 0.6	0.6	1.396	2.6470588
	0.4	1.43	5.1470588
0.8x0.8	0.6	1.46	7.3529412
	0.8	1.43	5.2941176
1x1	0.6	1.523	11.985294
	0.8	1.482	8.9705882
	1	1.46	7.3529412

ROOT AS PILE APPROACH

Deterministic analysis of slope with vegetation by using root as pile approach

As per this approach, entire root zone is considered as single pile and to this pile root properties are assigned. The modulus of elasticity of vetiver root is about 2.6 gpa and its tensile strength of the root is varying in between 45 – 145 mpa (average 75mpa). The diameter of the vetiver root is generally varying form 0.2-2.2mm. Table 4 shows the parameters used in the analysis of slope.

Table 4 Parameters used in the analysis slope by using Root as Pile approach

	Description	Unit	Value
Soil (Mohr – Coulomb model)	Unit weight(γ)	kN/m^3	16
	Modulus of Elasticity (E)	MPa	7500
	Effective cohesion(C)	MPa	5
	Effective Friction angle(φ)	$(^0)$	30
	Poisson's ratio(ν)	-	0.35
	R_{inter}	-	0.8
Pile	Modulus of Elasticity (E_{pile})	GPa	2.5

Figure 9 shows the geometric modelling of slope in PLAXIS 3D. The diameter of the pile considered in this problem is 0.8meter. Figure 10 shows incremental deviator strain of the slope which representing the critical failure surface of the slope.

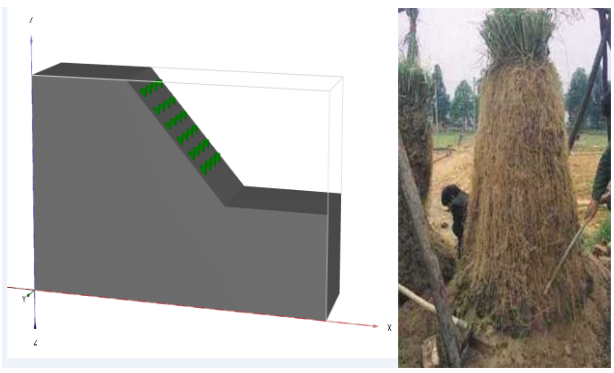

Fig. 9 Geometric modelling of slope

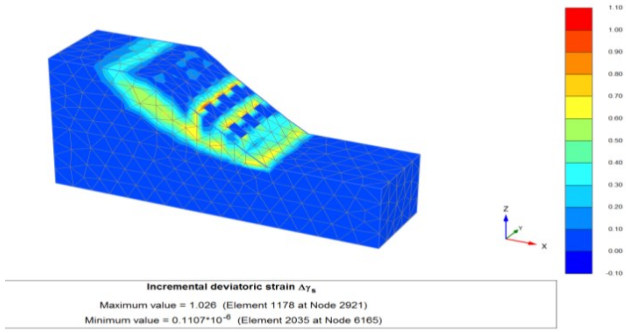

Fig. 10 Critical failure surface of slope

Figure 11(a) shows the graph between the total displacements and incremental multipliers. From this graph it is observed that the safety factor of the slope without interface is 1.56 and from the Figure 11(b) safety factor of the slope is 1.412

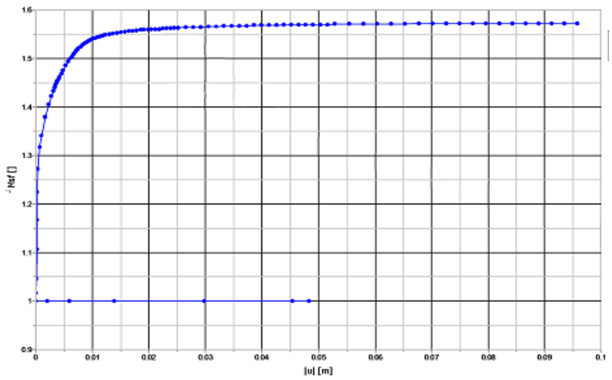

Fig. 11 (a) without interface

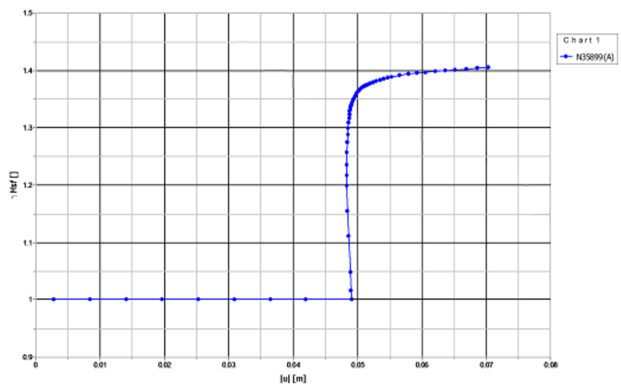

Fig. 11 (b) with interface

Fig. 11 Total displacement Vs Incremental multipliers

Table 5 shows the percentage increase in the safety factor due to vegetation for the different diameter of the piles.

Table 5 Percentage increase in the safety factor due to vegetation by using the Root as the pile approach

Diameter of the Pile (m)	Spacing (m)		FOS	% increase
0.6	0.6	Without interface	1.50	10.29
		With interface	1.41	3.67
0.8	0.8	Without interface	1.50	10.29
		With interface	1.41	3.72
1	0.8	Without interface	1.54	13.23
		With interface	1.48	8.67

CONCLUSIONS

In the present study, the mechanical effect of effect of vegetation on the slope stability is calculated. The reliability analysis is also performed on the slope with and without vegetation by using the first order reliability method (FORM).

From the present study the following conclusions are made:

1. Safety factor of the considered slope without vegetation as per deterministic analysis is found to be1.36.
2. As per deterministic analysis, safety factor of the slope with vegetation by using the equivalent cohesion approach is found as 1.43.
3. Based on the deterministic analysis, the factor of safety of slope with vegetation by using root as pile approach is found as 1.412.
4. From the results, it is observed that the Equivalent cohesion approach gives slightly higher value of safety factor compared to the Root as Pile approach.
5. The percentage increase in the safety factor due to inclination effect of piles ($\theta = 30^0$) is found as 1.28%.

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