Modelling the effects of vegetation in bio engineered sloped soils

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Abstract. Due to industrialization, with the passing days, people are encroaching weak soils as there is scarcity of land. Improving the quality of soil with the help of synthetic reinforcement like cementious cover, metal piling and the use of geosynthetic material have been a common practice. However, the long term impact of these synthetic materials on soil health is a significant issue. Moreover, with the decline in resources and inconsistent global climate changes, people are seeking for greener solutions to solve the problem. In this context, an attempt has been made in this paper to investigate the effect of vegetation numerically using finite element method. Plant roots are modelled using the root cohesion approach and pile approach. Vegetation was distributed along different locations to show the effect on shear strength of soil. Water table, slope angle and root depths were altered to understand the effect of plant roots. The results showed that vegetation, if planted on slope and toe as a combination showed better results.

Keywords: Vegetation, Finite Element Analysis, Root Cohesion, Plantation Strategy.

1 Introduction

The effects of global climate change with extreme precipitation and drought bring upon adverse impact on both natural and manmade slopes [6]. Due to the growth of industrialization, people are nowadays forced to utilize weak soil as there is scarcity of land. The soil available there is not of good quality to suit engineering purposes. Synthetic reinforcement such as metal piling, geosynthetic and cementious cover were earlier used to improve the quality of soil [12]. But in addition to the improving the soil, we also need to consider the environment. Soil Bioengineering provides us witha certain answer to protect the environment while still achieving our goal to improv- ing the soil. It is economical, environmentally beneficial and attractive. Vascular plants such as trees, shrubs and grasses are generally used as they have vascular tis- sues which promote both the transport and water holding mechanism [11].

Vegetation improves the root-soil composition with the help of plant roots, thus binding the soil together and enhancing the cohesiveness of the surrounding soil [4]. The mechanism of improving the shear strength of soil includes the transmission of shear stresses built across the soil to the root fibers through tensile energy mobilized in roots (Fig. 1) [1]. Stability of soil using vegetation depends on mainly mechanical and hydrological reinforcement [2]. Mechanical reinforcement shows us the stress strain response of soil whereas the hydrological reinforcement considers the plant traits and the exposed conditions of atmosphere [5] [7]. The complex interaction of plant-soil-atmosphere-water makes this topic quite versatile [10]. Since the scope of work is limited, so only the effect of mechanical reinforcement is considered.

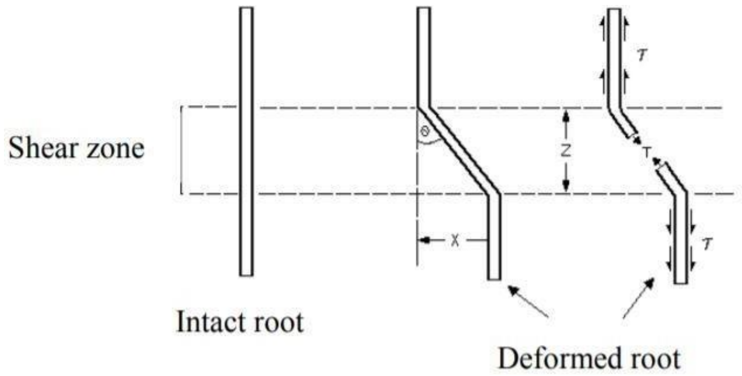

Fig. 1. Schematization of root reinforcement (from Tsige et al.).

Over the years, analytical, experimental, statistical and numerical modelling has been done to come at some definite conclusions. However, it is still not widely used be- cause of their variations in results. Chok et al. [8] suggested that slope toe appears to be the most critical region where vegetation needs to be considered in slope stabilisa- tion. However, Danjon et al. [3] showed that staggered distribution of trees provided better FOS results as compared to uniform rows as they can overall arrest the down- ward movement of soil during landslide. An attempt has been thus made to study the effect of vegetation through numerical analysis using PLAXIS 2D software. Two different methods [9] were used to model the soil root zone and their effect with dif- ferent parameters is analysed.

2 Methodology and Numerical Analysis

Different researchers have used different techniques to model the root soil zone. However in our present study, the effect of vegetation has been quantified using two methods namely effective cohesion method and root as a pile approach. The geometryand properties of the Model 1 is adopted according to Tsige et al [1]. It is divided into two subsections 1a and 1b which signify the different root parameters of the same geometric model. The geometry and properties of the Model 2 is adopted according toRao et al [9].The summary of the root parameters used are given in Table 1. Medium mesh discretization is used for this study. For the same type of soil and plant, the additional root cohesion values are adopted from Tsige et al [1] and Rao et al [9].

Table 1. Summary of the root parameters for different models

	Root Depth	Additional Root Cohesion
Model 1a	2.2m	9.9 Kpa
Model 1b	1.8m	7.44 Kpa
Model 2	2.0m	15 Kpa

2.1 Equivalent Cohesion Approach

The shear strength of root-permeated soil has traditionally been investigated by calculating the so-called extra root cohesion and factoring it into slope stability projects. One of the most important shear strength models for root penetrated soil was devel- oped by Wu et al. (1979) [4]. It follows the basic Mohr's Columb Model.

$$S= C + \sigma_N \tan(\phi) \quad (1)$$

$$S= C + \sigma_N \tan(\phi) + (\Delta S) \quad (2)$$

Where S is the shear strength of soil, σ_N is the normal stress acting on the soil, C is the cohesion due to soil matrix, ϕ is the soil friction angle and ΔS is the additional root cohesion. This additional root cohesion is the summation of the mobilized tensile stress due to root fibres per unit area of soil.

As per as this approach the increase in shear strength is mainly due to the increased cohesion values. Cohesion is varied at the upper layers to represent the different densities due to vegetation (Fig 2). Model 1a and Model 1b have same dimensions but the root depths are different whereas Model 2 has different geometric and soil parameters.

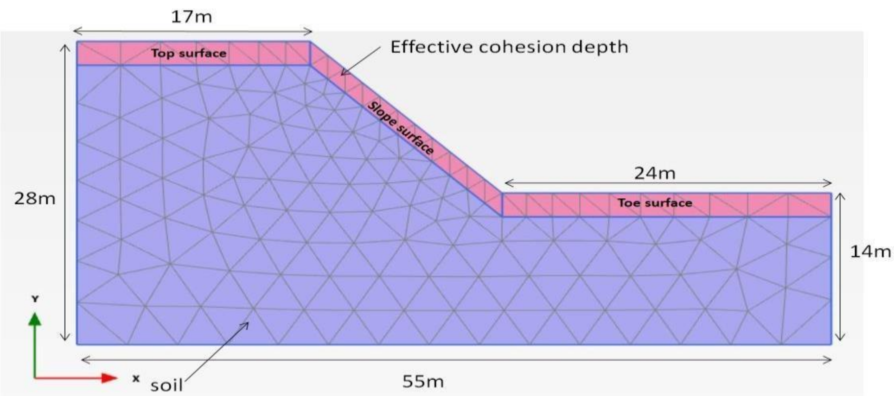

Fig. 2. Schematic diagram of root permeated soil using effective cohesion approach.

2.2 Root as a Pile Approach

Many researchers [9] have conducted their study based on the fact that the entire root zone is considered as a single pile. However in our study, the total roots of an individual plant are considered as an embedded beam (Fig 3).

The slope is analysed as a plain strain model. Fifteen noded triangular elements are selected to model the soil layers accurately.

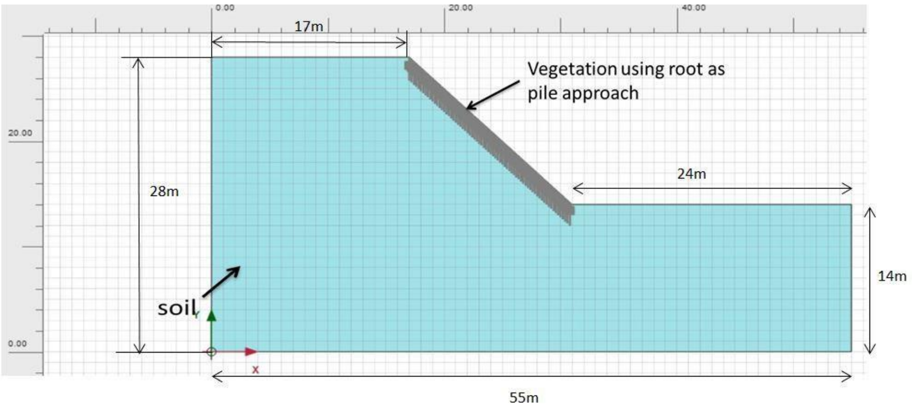

Fig. 3. Schematic diagram of the root as a pile approach

3 Results and Discussions

3.1 Effects of Vegetation

Vegetation was planted across different regions. At first, it was placed in the entire region, followed by slope surface, toe surface and top surface. Table 2 shows the variation of factor of safety when effective cohesion approach is used for modelling.

Table 2. Variation of FOS with the regions of vegetation for different soil model using effective cohesion approach

	FOS				
	No vegetation	Entire region	Slope surface	Toe surface	Top surface
Model 1a	1.312	1.443	1.343	1.325	1.314
Model 1b	1.312	1.412	1.337	1.326	1.313
Model 2	1.223	1.531	1.449	1.232	1.219

Table 3 shows the variation of FOS with different region of vegetation when root as a pile approach is used.

Table 3. Variation of FOS with the regions of vegetation for different soil model using pile approach

	FOS				
	No vegetation	Entire Region	Slope surface	Toe surface	Top surface
Model 1a	1.312	1.407	1.333	1.321	1.313

It is seen that whenever vegetation is planted, be it any region, there is an increase in the factor of safety. This holds true for all models using both the approaches. It is also observed that the factor of safety is highest when vegetation is planted in the entire region, followed by sloped surface, toe surface and top surface.

It can be also noted that even though both the approaches are similar, effective cohesion approach gives slightly higher values (around 3%) as compared to root as a pile approach.

3.2 Best Combination (Region Based)

After knowing the effects of vegetation when they are placed in individual regions, vegetation is planted as a combination of different regions. Since the FOS is found to be highest in sloped region, that region is taken as constant. Two different combinations with that region is considered and their effects are observed (Table 4).

Table 4. Variation of FOS with the combination of regions of vegetation for Model 1a

	FOS		
	Vegetation only in sloped region	Vegetation in sloped region and top surface	Vegetation in sloped region and toe surface
Effective cohesion approach	1.343	1.344	1.442
Root as a pile approach	1.333	1.335	1.406

It is seen that the combination of sloped region and toe surface is the most effective as it gives largest safety value. Vegetation in sloped and top surface gives values similar to that sloped region, thus indicating that it is not beneficial to plant vegetation in top surface when shear strength characteristics are considered.

3.3 Effect of Water Table

Water table is an important parameter that affects the slope stability analysis. Here, the water table is varied across different depths and its effects are observed (Table 5). The toe surface is taken as a reference point and from that the water table is varied across 2, 4, 6 and 8m respectively. NA suggests no effect of water table. 0 signifies water table at the reference point (Fig 5).

Table 5. Variation of FOS with the water table for Model 1a

	FOS				
Water Table	Entire slope	Slope surface	Top surface	Toe Surface	Slope and Toe surface
NA	1.443	1.343	1.314	1.325	1.442
0m	1.393	1.321	1.306	1.322	1.393
2m	1.421	1.336	1.313	1.325	1.421
4m	1.431	1.342	1.314	1.325	1.431
6m	1.439	1.342	1.314	1.325	1.438
8m	1.442	1.342	1.314	1.325	1.441

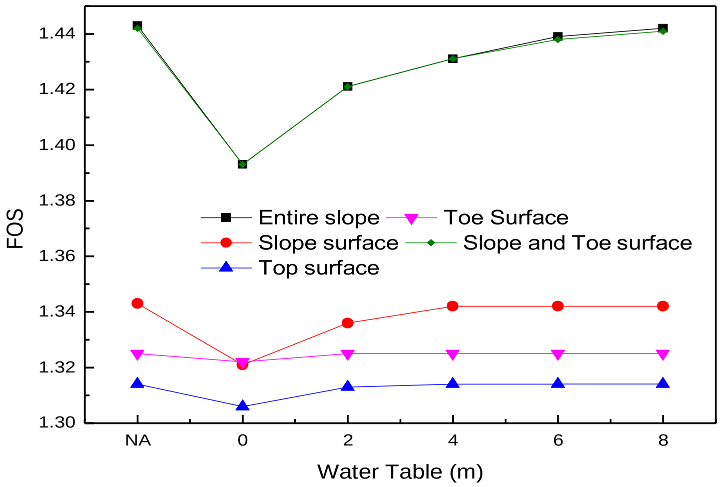

Fig. 5. Variation of FOS with the change in water table depth

It is seen as with the introduction of water table, there is a reduction in the factor of safety values. This same phenomenon is observed in all the regions.

It can be also noted that the effect of water table nullifies after a certain depth. Up to that depth, there is an effect of water table but after that depth, the FOS value be- comes constant thus justifying the statement.

3.4 Effect of Slope Angle

The slope angle was altered and their effect on stability analysis was observed on both vegetated as well as bare sloped soils (Fig 6).

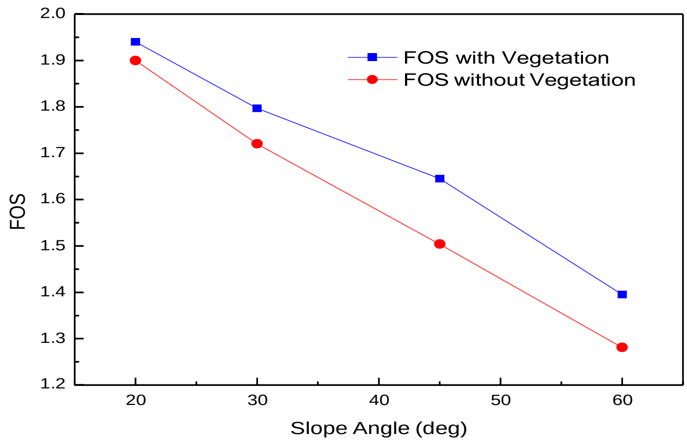

Fig. 6. Variation of FOS with slope angle

It is seen that as the slope angle is increased from 20° to 60°, FOS values are de- creased. It was thus concluded that flatter slopes showed higher strength characteris- tics as compared to higher inclination slopes.

3.5 Effect of Root Depth

Root depth is also an important parameter when vegetation is used as a mean to im- prove the stability of soil. Two plants of different root depth of 2.2m and 1.8m are considered and their effects are seen (Fig 7).

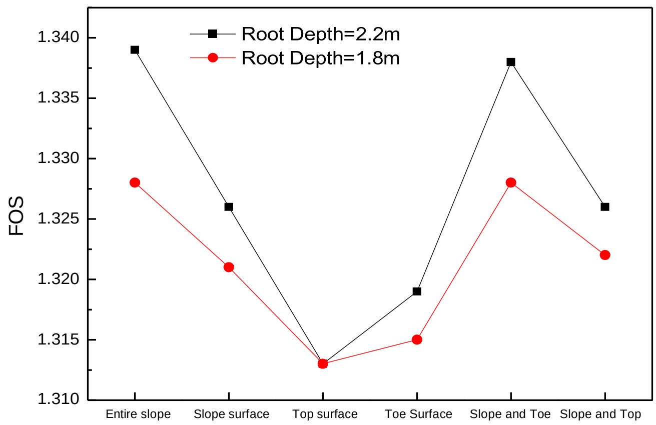

Fig. 7. Variation of FOS with root depth

It is observed that plants with larger root depth show better FOS results as compared to smaller root depth.

4 Conclusions

Based on the following variations, the results were evaluated and discussed and the following conclusions were observed.

- Strength characteristics of soil improved by 25% due to the effect of vegetation.
- Effective cohesion approach gave slightly higher values as compared to root as a pile approach even though both methods can be considered.
- FOS was seen to be highest in entire region, followed by slope, toe and top surface.
- Slope and toe surface was considered to be the best region for planting vegetation due to the maximum FOS values.
- Wet condition showed reduced FOS values as compared to dry condition.
- Water table effect is seen only up to a certain depth, after that depth the effect is negligible.
- FOS values decreased with higher slope angle and it increased with flatter slope angle.
- It is seen that as the root depth is increased, better shear strength characteristics is observed in soil.

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