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The Effect of Vegetation on Slope Instability as Predicted by the Finite Element Method

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ABSTRACT

The principal ways in which the removal of a forest cover influences the stability of sloping soils is briefly described. Potential destabilizing effects of surcharge are compensated by increased stability provided by root reinforcement. Root strength (reinforcement) data from previous studies was used. Increased soil strength measured from field tests on root permeated soil pedestals beneath different types of trees (conifers, alders, birch) in different types of soil (till and silt loam) ranged 1 to 10 kPa. The large range in strengthening effects is due mainly to very different tree-root network densities in terms of root weight per unit volume of soil. The using of Vegetation on slope was considered to simplify the problem to a plane strain two dimensional geometry. The program computes the factor of safety (FOS) of the slope by using the finite element method.

KEYWORDS: slope stability, finite element method, vegetation, factor of safety.

INTRODUCTION

Landslide frequency can increase after trees are removed from forested slopes (Croft and Adams, 1950; Kawaguchi and Namba, 1956; Bishop and Stevens, 1964**;** Swanson and Dyrness, 1975; Wu, 1976). Vegetation can modify slope stability by mechanically reinforcing slopes through plant roots, modifying soil moisture distribution and pore water pressures, adding slope surcharge from the weight of trees, and levering and wedging soil by roots (Gray, 1970). The first two factors increase stability of slopes; the third may increase, decrease, or have no influence on stability, and the fourth decreases stability.

Farshchi et al in 2012 were investigated on Soil-Root Interaction and Effects on Slope Stability Analysis. Their work combines the mechanical and hydrological effects of vegetation with a slope stability framework. The analysis provides further understanding of the effects of vegetation on slope stability analysis. From the results obtained, trees contribute to the stability of sloping ground both hydrologically as a result of increase in matric suction of the soil resulting in an increase in the shear strength while mechanically is due to root reinforcement, the shear strength of the rooted soil mass is enhanced due to the presence of a root matrix. It is found that the most significant benefit is likely to be achieved only when the tree is located at the toe of the slope. The results indicate that the Factor of Safety against failure can increase by more than 8% when including the influence of a mature tree located at toe of a slope. The results also indicate that the mechanical contribution to strength offered by vegetation is much greater than the influence of hydrological effects.

Cecconi et al in 2012 studied on Deep Roots Planting for Surface Slope Protection. The mechanical effects of vegetation result from the root/soil interaction processes, while the hydraulic effects derive from the significant reduction of water content enhanced by plant transpiration. The quantitative evaluation of the mechanical effect has been modelled and implemented in a computing algorithm.

Jia et al in 2015 were investigated on Rock Slope Vegetation Restoration Factors Analysis Based on Shandong Province Highways. In order to analyze the key factors affecting natural vegetation restoration of rock cut slopes, 126 quadrats of 3 provincial highways were investigated in the central mountainous area of Shandong Province, the effects of natural vegetation restoration for highway cut slope were evaluated at quadrat level using the vegetation restoration index (VRI) constructed in this paper. The key habitat factors affecting natural vegetation restorability were identified by correlation analysis, and a model was established to predict the effects of natural vegetation restoration. Results show that (1) the highest and lowest values of quadrat VRI are 100% and 0% respectively, those of coverage are 100% and 1%, and those of aboveground biomass are 900.00 g·m-2 and 6.50 g·m-2;indicating that the effects of natural vegetation restoration are obviously different under different habitat conditions; (2) among 7 habitat factors related to the variation of VRI, lithology, weathering degree, slope type, and slope gradient show obvious significance to restoration effects; (3) slope type based on micro-topography unit is an important parameter to indicate the natural vegetation restorability and predict the effects of natural vegetation restoration. Multi-bench and multi-crevice type slope, weathered layer type slope have higher VRI values than rock face type slope and rock crevice type slope.

Soil materials are transported from natural forested slopes to stream channels chiefly by mass erosion. From soil mechanics theory, mass erosion results if the shear stress acting on the material exceeds the available shear strength of that material (Swanston, 1974). Shear stress (τ) along a basal zone of sliding can be expressed as:

$$\tau = W \sin \alpha$$

where W is the effective weight of the soil and α is the slope of the failure surface. Shear strength (S) can be expressed as:

$$s = C + W \cos \alpha \tan \Phi$$

where C is the effective soil cohesion and Φ is the angle of internal friction. The increased shear stress produced by the weight of a mature forest on an unsaturated cohesionless soil is balanced by an equal increase in soil shear strength by the tree surcharge (Bishop and Stevens, 1964). For most mature forests, the weight of the soil overlying a potential failure plane far exceeds the weight of the trees and any additional surcharge contributed by the trees will have little effect on slope stability (Kawaguchi, et al., 1951; Gray, 1970; Swanston, 1970; O'Loughlin, 1974). If weight does become a problem, it is usually in cohesive soil during heavy rain when the weight of increased soil moisture increases shear stress.

The shear stress contributed by trees subjected to an 80 km/h wind is not likely to exert a strong influence on slope stability (Wu, 1976).

ROOT REINFORCEMENT

Plant roots can help stabilize slopes by anchoring a weak soil mass to fractures in bedrock, by crossing zones of weakness to more stable soil, and by providing long fibrous binders within a weak soil mass. In deep soil, anchoring to bedrock becomes negligible and the other two conditions predominate. The reinforcement effect of plant roots intermixed with soil resembles soil cohesion (Endo and Tsuruta, 1969). The role of plant roots in the calculation of soil strength can be expressed as:

$$S = (C + r) + \mathbf{W \cos \alpha} \tan \Phi$$

where r is the relative root reinforcement or apparent cohesion due to roots. The ability of roots to strengthen a soil mass is well known. The total force required to break a soil mass reinforced by linden (Tilia cordata) roots in a study in the U.S.S.R. was calculated to be about 137 tons. Of this force, 130 tons were required to break the roots and 7 tons to tear the sandy loam soil mass from a bank of the Moscow River. Breaking the linden roots took 95% 0f the total force, although the total cross-sectional area of all the roots comprised less than 0.5 percent of the wall area of the bank collapse (Turmanina, 1963).

The root network accounted for 71% of the shear strength at saturation Of glacial till soils on 35o slopes in British Columbia, Canada (O'Loughlin, 1972). An imposed load may be 70% greater before soil rupture in soils with a root network than in soils without roots (Bjorkhem, et al., 1975).

Also, Vegetation can affect the slope hydrology through the evapotranspiration, rootreinforcement is considered according to the simple model in [Waldron; 1977. Wu; 1976. Wu et al;1979]. The vegetation-slope interactions are shown in Fig. 1.

NUMERICAL MODELING

The finite element program Plaxis v8 was used to develop a numerical model of a reference problem to study effects of Vegetation on slope. The using of Vegetation on slope was considered to simplify the problem to a plane strain two dimensional geometry. This program has been used to analyse several slope stability problems including the influence of layering and free surface on slope and dam stability (Griffiths and Lane, 1999). The program computes the factor of safety (FOS) of the slope by using the nonconvergence solution, coupled with a sudden increase in nodal displacements as an indication of failure conditions (Griffiths and Lane, 1999). Properties of different materials are shown in Table 1. A plane strain analysis was carried out using Mohr-Coulomb criterion. A drained behavior was assumed for all materials.

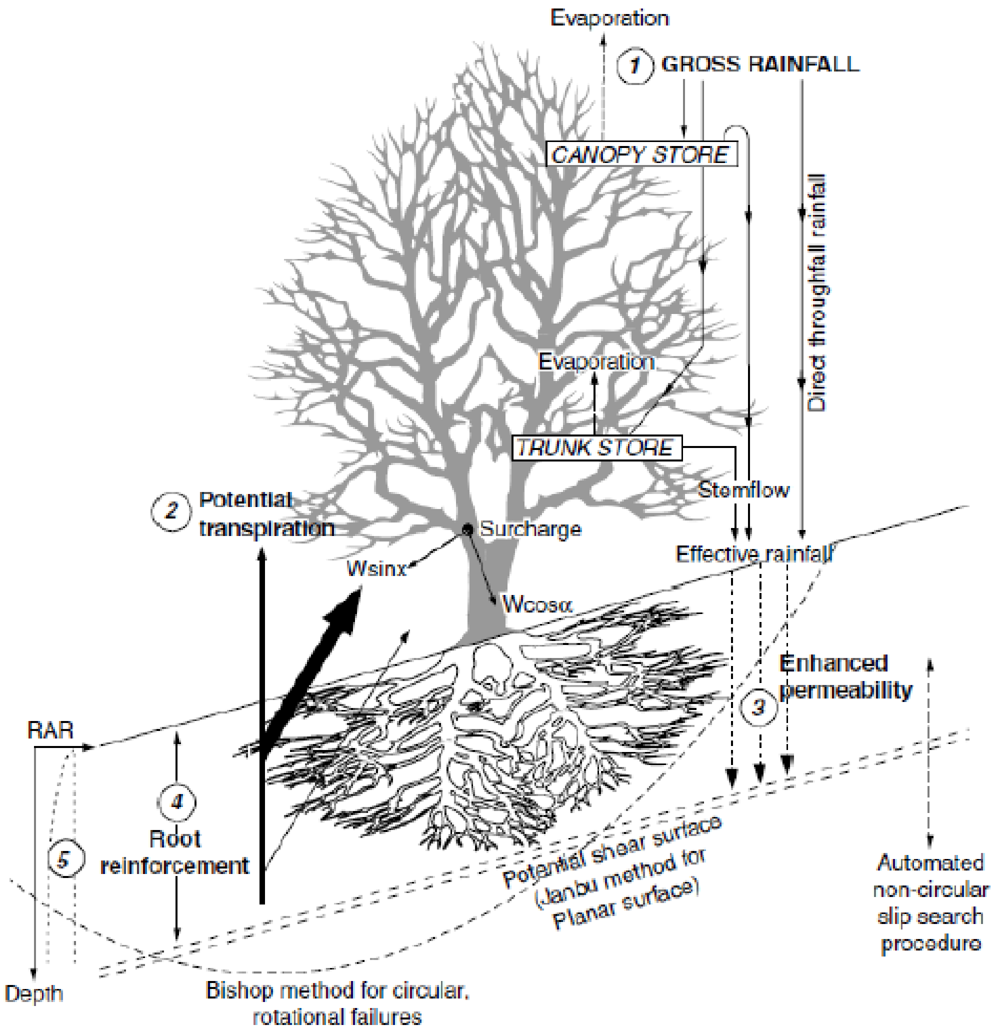

Figure 1: Vegetation-slope interactions [Wu et al; 2015]

Table 1: Properties of soil

	γ_{sat} (kN/m^3)	γ_{unsat} (kN/m^3)	υ	E (kN/m^2)	C (kN/m^2)	Φ (^{0})
Layer1	22	20.2	0.2	4000	11	25
Layer2	21	19	0.25	5000	12	30

Modeling the impact of plants on the slope

Vegetation Extending Over the Entire Ground Surface

In this part, the roots of plants up to a height 2 meter and cohesion of 5 kpa was modeled. Underground water level in the slope in this field, at a height of 6 meters below the Earth's surface.

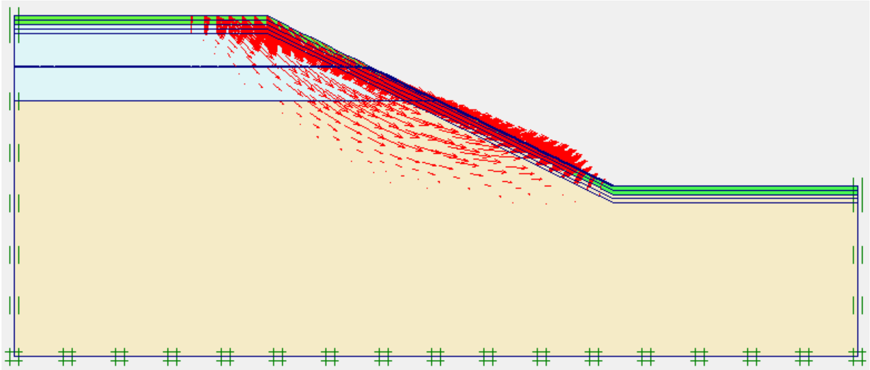

Figure 2: Total displacements occurred, in the case of Vegetation Extending Over the Entire Ground Surface to a height of 1 meter (Fs=0.995)

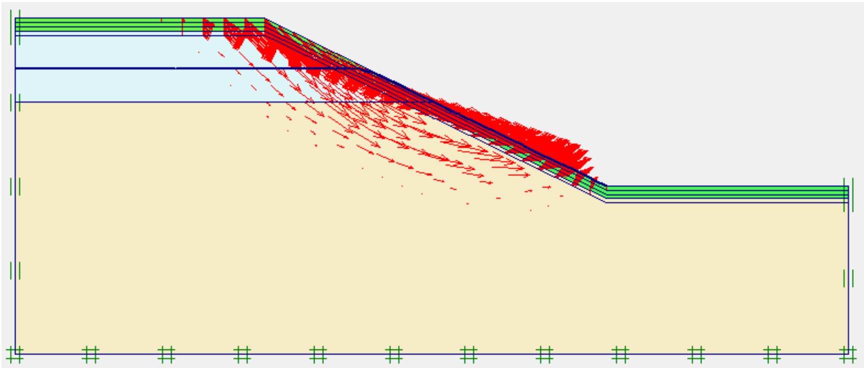

Figure 3: Total displacements occurred, in the case of Vegetation Extending Over the Entire Ground Surface to a height of 1.5 meter (Fs=1.007)

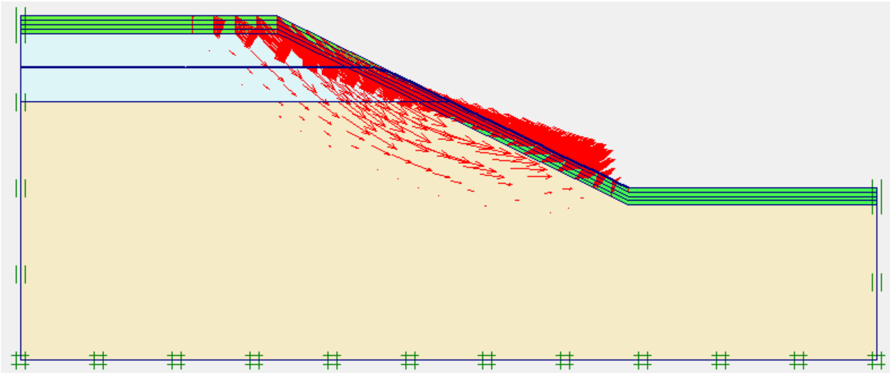

Figure 4: Total displacements occurred, in the case of Vegetation Extending Over the Entire Ground Surface to a height of 2 meter (Fs=1.01)

As was observed, with increasing and progression of plant roots in the depth of soil, safety factor of slope increased. That trend of this increasing shown in the following diagram.

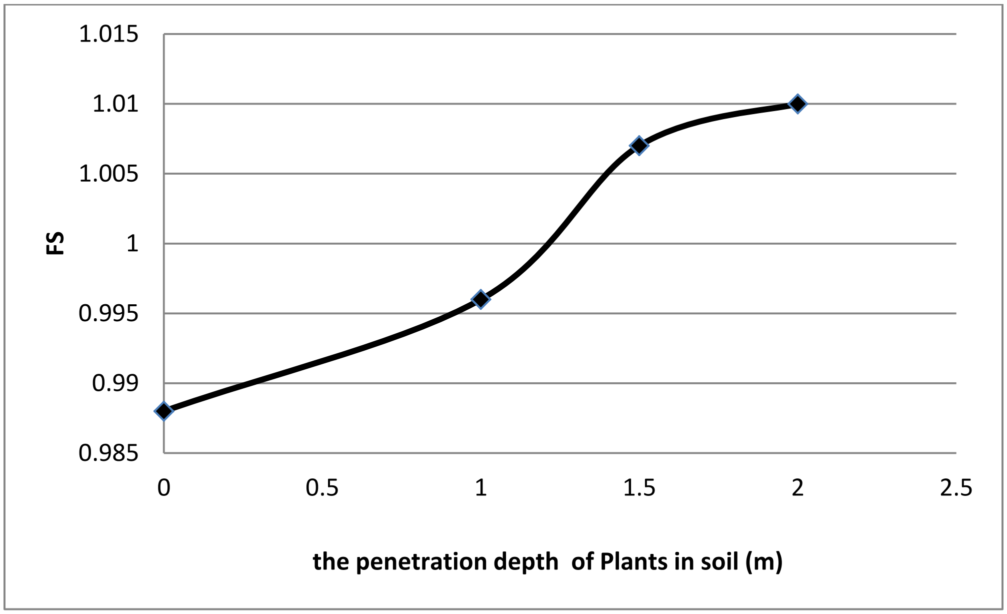

Figure 5: Change in safety factor of slope against the penetration depth of Plants in soil.

Vegetation Extending top of slope

In this part, the roots of plants up to a height 2 meter and cohesion of 5 kpa was modeled only at top of slope. Underground water level in the slope in this field, at a height of 6 meters below the Earth's surface.

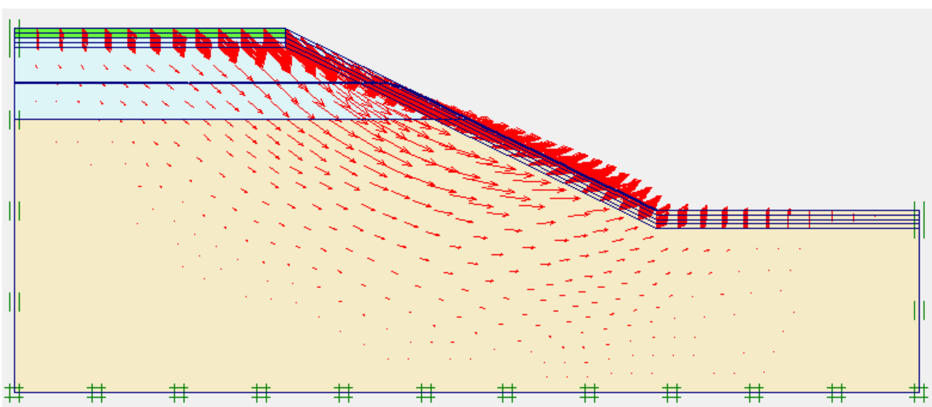

Figure 6: Total displacements occurred, in the case of Vegetation Extending At top of slope to a height of 1 meter (Fs=0.988)

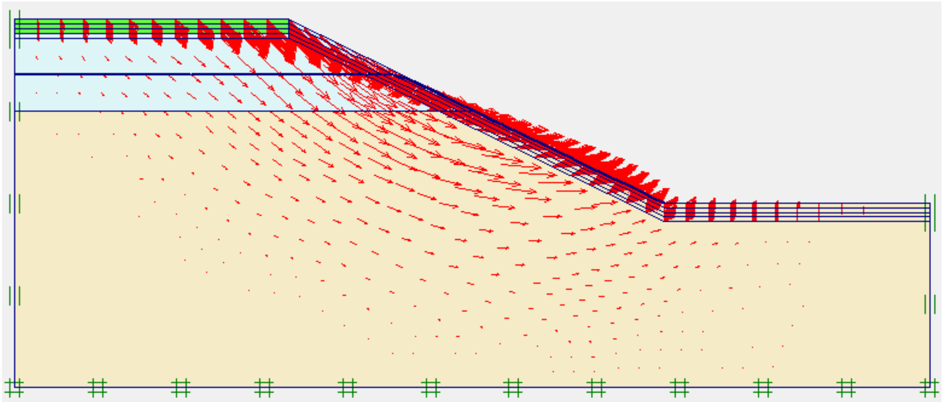

Figure 7: Total displacements occurred, in the case of Vegetation Extending At top of slope to a height of 1.5 meter (Fs=0.989)

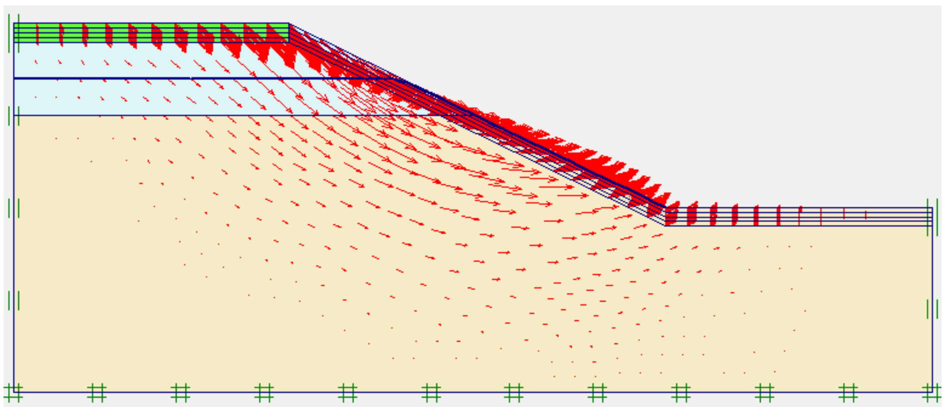

Figure 8: Total displacements occurred, in the case of Vegetation Extending to top of slope to a height of 2 meter (Fs=0.994)

Vegetation on Slope Surface Only

In this part, the roots of plants up to a height 2 meter and cohesion of 5 kpa was modeled only on Slope Surface. Underground water level in the slope in this field, at a height of 6 meters below the Earth's surface.

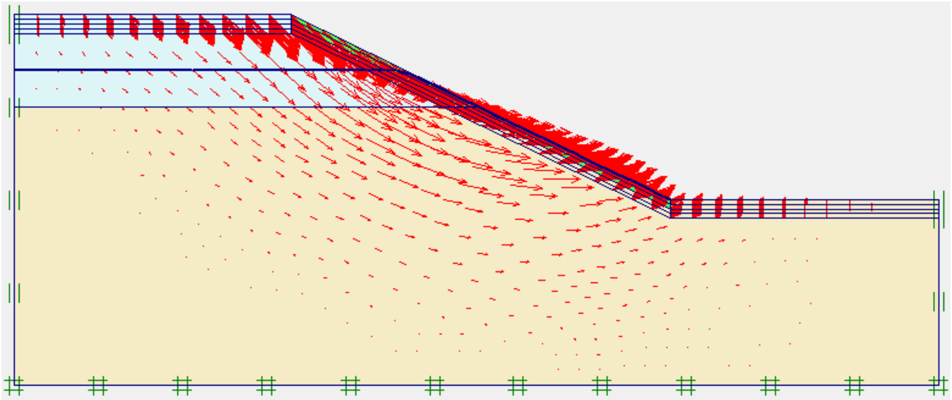

Figure 9: Total displacements occurred, in the case of Vegetation Extending only on Slope Surface to a height of 1 meter (Fs=0.987)

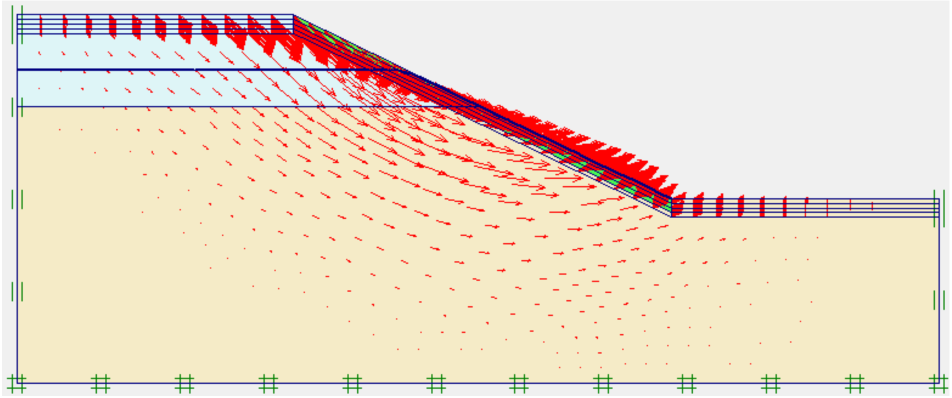

Figure 10: Total displacements occurred, in the case of Vegetation Extending only on Slope Surface to a height of 1.5 meter (Fs=0.993)

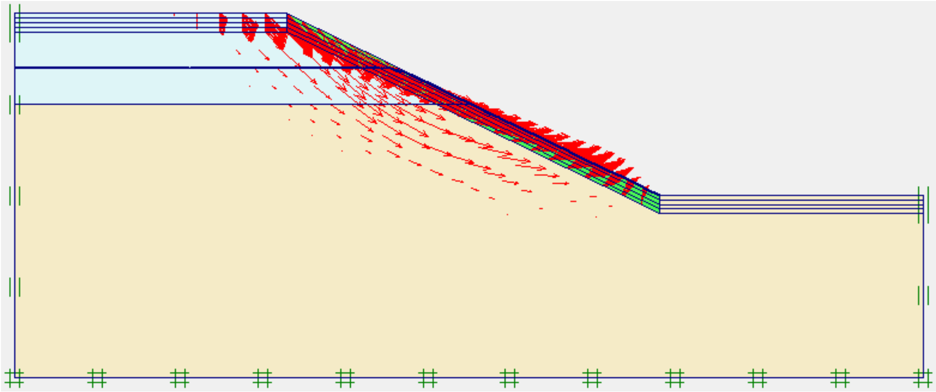

Figure 11: Total displacements occurred, in the case of Vegetation Extending only on Slope Surface to a height of 2 meter (Fs=1.004)

According to the above results, with increasing the height of the root on Slope Surface and over the entire ground surface, the safety factor increased. The process of this increasing, the changing in height of roots from 1 m to 2 m, the safety factor reach to the top of 1.

CONCLUSIONS

Vegetation helps stabilize steep forested slopes chiefly by reinforcing the soil through tree roots and by changing the soil water regime. Pore water pressures within the soil change seasonally in response to precipitation. Soil moisture in areas where the forest has been recently cut is usually greater than in uncut areas. Root reinforcement has been considered as an increase in apparent soil cohesion. The apparent root cohesion has been incorporated in the slope stability analysis using the finite element method. the results of this study have shown the beneficial effects of vegetation on slope. Therefore, On the basis of literature survey carried out following concluding remarks are made:

- With increasing the height of the root on Slope Surface and over the entire ground surface, the safety factor increased. The process of this increasing, the changing in height of roots from 1 m to 2 m, the safety factor reach to the top of 1.
- With increasing and progression of plant roots in the depth of soil, safety factor of slope increased.
- With increasing the height of the root from 1 m to 2 m on top of slope, the safety factor don’t reach to the top of 1.

REFERENCES

[1] Bishop, D.M. and Stevens, M.E.,, 1964:. Landslides on logged areas in southeast Alaska. U. S. Dep. Agric For. Serv. Res. Paper NOR-1.Juneau, AK, USA.

[2] Bjorkhem, U ., Lundeberg, G. and Scholander, J., 1975: Root distribution and compression strength in forest soils. Research Notes no. 22. Departments of Forest Ecology and Forest Soils, Royal College of Forestry, Stockholm, Sweden.

[3] Croft, A.R. and Adams, J.A., 1950: Landslides and sedimentation in the North Fork of Ogden River, May 1949. U.S. Dept. Agric. For. Serv. For. and Range Exp. Sta. Res. Paper 21. Ogden, UT, USA.

[4] Endo, T. and Tsuruta, T., 1969: The effect of the tree’s roots upon the shear strength of soil. 1968 Annual Report, Hokkaido Branch, Forest Experiment Station, pp. 167-182. English translation by Arata, J.M. and Ziemer, R.R., U.S. Dep. Agric. For. Serv. Arcata, CA, U S A.

[5] Gray, D.H., 1970: Effects of forest clear-cutting on the stability of natural slopes. Bull. of the Assoc. of Engineering Geologists, vol. VII, nos. 1 and 2, pp. 45-66.

[6] Griffiths, D.V. and Lane, P.A. (1999). “Slope stability analysis by finite elements,” *Géotechnique*, Vol. 49, No.3, pp. 387-403.

[7] Kawaguchi, T. and Namba, S., 1956: Landslides and erosion control. Rin-Go-Shiken-Hokoku, vol. 84, pp. 43-66.

[8] Kawaguchi, T., Watanabe, R. and Takiguchi, K., 1951: A study of landslides on Mt. Akagi. Bull. of the Government For. Exp. Sta., Rept. 4 9 . Meguru, Tokyo, Japan.

[9] M. Cecconi, V. Pane, P. Napoli, E. Cattoni.” Deep Roots Planting for Surface Slope Protection”. *Electronic Journal of Geotechnical Engineering, Vol. 17 [2012], Bund. U: pp* pp 2809-2820. Available at ejge.com.

[10] N. Ali, I. Farshchi, M.A. Mu'azu and S.W. Rees." Soil-Root Interaction and Effects on Slope Stability Analysis" ejge. Vol. 17 [2012], Bund. C.pp:319-328.

[11] O'Loughlin, C.L., 1972: An investigation of the stability of the steepland forest soils in the Coast Mountains, southwest British Columbia. Ph.D. dissertation, University of British Columbia. Vancouver, B.C., Canada.

[12] O'Loughlin, C.L., 1974: The effect of timber removal on the stability of forest soils. Jour. Hydrol. (N.Z.) , vol. 13, no. 2, pp. 121-134.

[13] Swanson, F.J. and Dyrness, C.T., 1975: Impact of clear-cutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. Geology, vol. 3, no. 7, pp. 393-396.

[14] Swanston, D.N., 1970: Mechanics of debris avalanching in shallow till soils of southeast Alaska. U.S. Dep. Agric. For. Serv. Res. Paper PNW-103. Juneau, AK, USA.

[15] Swanston, D.N., 1974: Slope stability problems associated with timber harvesting in mountainous regions of the western United States. U.S. Dep. Agric. Gen. Tech. Rept. PNW-21. Portland, OR, USA.

[16] Turmanina, V.I., 1963: The magnitude of the reinforcing role of tree roots. Moscow Univ. Herald, Scientific Jour., series V, no. 4, pp. 78-80.

[17] Waldron, L.J.: Shear resistance of root-permeated homogeneous and stratified soil. *Soil Science Society of America Journal* 41, 843–849 (1977).

[18] Wei Wu, Barbara Maria Switala, Madhu Sudan Acharya, Roberto Tamagnini, Michael Auer, Frank Graf, Lothar te Kamp, and Wei Xiang." Effect of Vegetation on Stability of Soil Slopes: Numerical Aspect". Springer International Publishing Switzerland, 2015. pp:163-177.

[19] Wu, T.H., 1976: Investigation of landslides on Prince of Wales Island, Alaska. Ohio State Univ. Geotech. Eng. Rept. 5. Columbus, OH, USA.

[20] Wu, T.H., McKinnell, W.P., Swanston, D.N.: Strength of tree roots and landslides on Prince of Wales Island, Alaska. *Canadian Geotechnical Journal* 114(12), 19–33 (1979).

[21] Wu, T.H.: Investigation of landslides on Prince of Wales Island, Alaska. Geotechnical Engineering Report 5, Ohio State University, Department of Civil Engineering (1976).

[22] [22] Zhirong Jia, Zhonghui Hu, Xuezhong Fan, Xuebo Liu, Zhifeng Liu." Rock Slope Vegetation Restoration Factors Analysis Based on *Shandong* Province Highways" *Electronic Journal of Geotechnical Engineering.* Available at ejge.com Vol. 20 [2015], Bund. 2. pp 723-730.

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