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Protection Roles of Tea-Citrus Garden on Slopes (N Iran)

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Abstract: This study investigates the effects of vegetation on the stability of slopes using the finite element method. Parametric studies were performed to assess the sensitivity of the stability of a slope to the variation in the key vegetation and soil parameters. Results show that vegetation plays an important role in stabilizing shallow-seated failure of slopes and significantly affects stability. As Iran has a long history of landslides, this research deals with the effect of scrubs on slope stability, in particular, the economic interest such as tea and Citrus. It is well understood that vegetation influences slope stability mechanical effects. The shear strength of the soil is increased through the mechanical effects of the plant root matrix system. The density of the roots within the soil mass and the root tensile strength contribute to the ability of the soils to resist shear stress. The effects of soil suction and root reinforcement has been quantified as an increase in apparent soil cohesion. The study was carried out in Roudsar Township in Gilan State of Iran. In this area of 20 ha were considered suitable for the purposes of this study. A large part of the area had slopes of steep gradients on which tea-citrus garden was present. Soil samples were taken from an area of approximately 25 ha large for testing in the laboratory. Direct shear tests were carried out on soil samples and the Factor Of Safety (FOS) calculated. Results showed that the FOS was increased in soils with tea and citrus roots present. The global slope FOS was then determined using Bishop's method. In this case study minimum FOS assumed 1.3, which corresponds to tea-citrus vegetation with 40-60% crown cover, a soil internal friction angle of 16° and a slope angle of 21 degree.

Key words: Root reinforcement, Gilan, landslide, factor of safety, soil internal friction angle

INTRODUCTION

The effects of vegetation on the stability of slopes are well recognized. Vegetation affects slope stability through modification of the internal fraction of soil, which in turn causes a variation in soil stability. Vegetation can enhance the stability of a slope by root reinforcement. Wu *et al.* (1979) investigated the stability of slopes before and after removal of forest cover and concluded that the shear strength contributed by tree roots is important to the stability of slopes. The study indicated that vegetation could contribute shear strength to the slopes through root reinforcement. Wu *et al.* (1979) showed that slope failure would have occurred if the effects of vegetation were not taken into account in slope stability analyses.

Slope instability is one of the major problems in geotechnical engineering where disasters, like loss of property, do occur. The majorities of these slope failures are of harvested vegetation or forested natural slopes. A natural slope is different from an embankment or a man-made slope in that the effects of vegetation and soil variability play an important role in their stability (Bibalani and Majnonian, 2007b).

Natural slopes are subjected to inherent variability both in the soil and the vegetation. It is unlikely that the underlying soil profiles of natural slopes are completely uniform or homogenous. Even within a homogenous soil layer, soil properties tend to vary from point to point. The growth of vegetation is sensitive to environmental conditions and changes. Typically different types of vegetation grow on a natural forest slope, such as a mixture of grasses, herbs, scrubs and trees. Their differences in size and physical properties will affect the slope stability in different ways. Therefore, the use of a single input value for the vegetation dependent parameters in analyses is best viewed as a first approximation of the field conditions.

This study investigates the effects of vegetation on the stability of slopes using the finite element method. The finite element method allows the extent of the vegetation effects to be defined by the user due to the

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nature of the method where slope geometry is dicretised into small elements. To limit the scope of this study, only the effects of root reinforcement are incorporated in the slope stability analysis. The variability in the vegetation and soil properties are not considered in this study. A homogenous slope with angle of inclination 15 degree (27% gradient) is used to investigate the effects of tea-citrus vegetation on slope stability. One key vegetation-dependent parameter is incorporated in the finite element slope stability analysis, namely, apparent root angle of internal friction with vegetation). Parametric studies were performed to assess the sensitivity of the stability of the slope to the variation in the key vegetation and soil parameters.

MATERIALS AND METHODS

The experimental site was situated in garden in the city of Rahomabad, N Iran [latitude 36°50'N, longitude 50°19'E, altitude 40 m on a North-facing slope. The site was characterized by deep silty-clay soil. Total annual rain in this aria is about 1600 mm. Recent climatic data (monthly means from 1995 through 2005) showed prevailing dry weather in summer months.

Model of root reinforcement: For the past three decades, research has focused on utilizing plant root reinforcement to stabilize slopes. The ability of plant roots to strengthen a soil mass is well known. The inclusion of plant roots with high tensile strength increases the confining stress in the soil mass by its closely spaced root matrix system. The soil mass is bound together by the plant roots and the shear strength is increased by this effect. The contribution of root reinforcement to shear strength is considered to have the characteristics of cohesion. Wu *et al*. (1979) proposed a simplified perpendicular root model to quantify the increased shear strength of soil due to root reinforcement. The increase in shear strength of the soil, S_r, was expressed by the following relationship:

$$S_r = t_r(\cos\theta\tan\theta' + \sin\theta) \tag{1a}$$

Where:

S_r = Shear strength increase from root reinforcement
t_r = Average tensile strength of root per unit area of soil
θ = Angle of shear rotation
θ' = Friction angle

Since the mechanical effect of plant roots is to increase the cohesiveness of the soil mass, S_r can be considered as equivalent to an apparent cohesion of the soil, known as apparent root cohesion (cR). These values were obtained from the studies of several investigators using different techniques including back analysis, direct shear tests, root density information combined with vertical root model equations and back analysis combined with root density information. The values of apparent root cohesion (cR) are dependent on the type of vegetation and in-situ soil conditions.

Previous slope stability analyses: Wu *et al*. (1979) incorporated the effects of vegetation in slope stability analysis by using conventional limit equilibrium method. In limit equilibrium methods, the shear strength of the soil along a potential slip surface is assumed to be fully mobilized at the point of failure. The Mohr-Coulomb equation is used to describe the shear strength of the soil:

$$\tau = c' + (\sigma - u)\tan\theta' \tag{1b}$$

By incorporating the effect of root reinforcement, Eq. 1c becomes:

$$\tau = (c' + cR) + (\sigma - u)\tan\theta' \tag{1c}$$

Wu *et al*. (1979) incorporated the apparent root cohesion (cR) in their infinite slope analysis and found an increase in the Factor Of Safety (FOS) for some slopes. The results indicated that tree roots improved the stability of forested slopes. There have been no published studies using numerical formulations to analyse root reinforcement effects. The present study employs numerical analysis which allows limiting the extent of the root zone. By assigning different values of apparent root cohesion (cR) to the root zone, its significance on the FOS is evaluated.

Trial pits with 90 cm diameter and about 150 cm depth was excavated on different slope (15, 18, 23, 27, 30 and 33 degrees) where no landslides had occurred. This area has been chosen in order to quantify the contribution of vegetation to soil reinforcement. The numbers of roots, with diameters of 10, 8 and 4 mm ranges were counted. Random soil samples with 20 cm diameter were taken from 15 ha outside of landslide area on which laboratory tests were carried out to determine certain mechanical characteristics. Triaxial tests were carried out soil samples without root in the laboratory. Shear tests were carried out without root in soil laboratory. The following equation is used to determine the increase in shear strength of soils (ΔSR) containing plant roots (Bibalani *et al*., 2007a):

$$\Delta SR = 1.15TR\frac{AR}{A} \tag{2}$$

Where:

TR = Tensile resistance (MPa) of the root was measured with root tensile test
AR = Total surface area (cm^2) of roots in A
A = Soil surface (m^2) and 1.15 in this equation is a coefficient

Slope stability was calculated using the Bishop method of analysis (Bibalani *et al*., 2005, 2006, 2007b; Bibalani and Majnonian, 2007a). Mean automatic procedure was developed for calculation purposes (Bibalani *et al*., 2005).The FS is calculated from:

$$FS = \frac{L}{\sum w.\sin\alpha}.\sum[\{c.b + (w - u.b)\tan\phi\}.\{\frac{\sec\alpha}{L + \frac{\tan\alpha.\tan\phi}{FS}}\}] \quad (3)$$

Where:

FS = Safety factor
α = Angle of slope (°)
w = Weight of soil on the slope (N)
c = Cohesion of soil (KN m^{-2})
L = Length of slope (m)
u = Pore pressure (KN m^{-2})
b = Width of area (m)
ϕ = Angle of internal friction (°)

The FS model was run to determine the influence of different species on slope stability and soil reinforcement with two ϕ (with and without roots).

On the basis of amount ΔSR, it is possible to calculate the angle of internal friction of soil (ϕ_2) and safety factor (FS) without (FS_1) or with (FS_2) plant roots.

From ΔSR (additional soil resistance with roots) can be calculating angle of internal friction with roots in soil (ϕ_2) with:

$$\tan\phi_2 = \frac{SR + \Delta SR - c}{h.b.l.dan} \quad (4)$$

Where:

SR = Soil resistance
ΔSR = Additional soil resistance with roots
h = Depth of soil (m)
b = Width of area (m)
l = Length of slope (m)
dan = Density of soil (kg m^{-3})
c = Soil cohesion

RESULTS AND DISCUSSION

FS_1 (safety factor without vegetation) was calculated with soil properties (u, ϕ_1, c and dan.) and area characteristic (b, α, l and h) and additional soil resistance with roots (ΔSR) was calculated with Eq. 2, then angle of internal friction without vegetation (ϕ_2) was calculated. FS_2 (safety factor with vegetation) was calculated with soil properties (u, ϕ_2, c and dan.) and area characteristic (b, α, l and h).

Finally, the least ground cover of different vegetation could stabilize soil on slope with different amount of angle of internal friction (ϕ) and different angle of surface with horizon, was shown in Table 1.

This study has revealed and quantified effect of tea-citrus in the N Iran, a phenomenon by means of which the vegetation stabilizes the slopes in the Roudsar and probably also in other areas where tea-citrus gardens are growing.

Although there are several factors which may affect slope stability and lead to small and shallow landslides in the study area, the main factor is the removal of the natural forest cover of the slopes to create tea-citrus garden. In order to increase the FS of slopes in this area with gradients more than 21% the least FS with attention to the angle of internal friction of soils (ϕ), the gradient of the slope (α) and for different vegetation cover is given for stabilizing slopes.

Table 1: Stability of slopes with attention to the angle of internal friction of the soil, angle of the slope and vegetation covers percentage

		α						
ϕ	Sp.	15	18	21	23	27	30	33
15	Tea-citrus	<20%	20-40%	U.st	U.st	U.st	U.st	U.st
16	Tea-citrus	St	<20%	40-60%	U.st	U.st	U.st	U.st
17	Tea-citrus	St	St	40-60%	U.st	U.st	U.st	U.st
18	Tea-citrus	St	St	20-40%	40-60%	U.st	U.st	U.st
19	Tea-citrus	St	St	20-40%	40-60%	U.st	U.st	U.st
20	Tea-citrus	St	St	20-40%	20-40%	>60%	U.st	U.st
21	Tea-citrus	St	St	<20%	20-40%	40-60%	U.st	U.st
22	Tea-citrus	St	St	St	<20%	40-60%	U.st	U.st

ϕ = Angle of internal friction of soil 15-26°, Sp. = Species of vegetation, α = Angle of slope (such as 15, 18, 21, 23, 27, 30 and 33°), St = Stable and U.st = Unstable with any vegetation

This study carried out to determine which crown cover of tea-citrus provided the best reinforcement to slopes in the Gilan Province. Soil shear tests were carried out on samples with and without roots of tea and citrus and the slope FS calculated. Results are discussed with regards to practical implications in this area.

In this case study minimum FS which corresponds to tea and citrus vegetation with 20-40% crown cover, a soil internal friction angle of 16° and a slope angle of 21°.

However, the contribution of plant roots to soil shear still needs much research and much work also needs to be carried out on the suitability of different species for stabilizing slopes.

It is important to appreciate that the significance of mechanical stabilizations of slopes by vegetation roots depends slip surfaces, the likely failure mode and the steepness of the slope. As a consequence, it is essential to identify the specific slope conditions and relate these to the properties of the particular plant species.

It is a pioneer study and the results have given estimations effect of the root of those vegetations for the first time in Iran. The findings and methodology of the study may be applied in other areas and to other plants.

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