SURFACE PROTECTION OF SLOPES BY GRASS COVERING TECHNIQUES

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The role of vegetation in protecting slopes from erosion has long been studied and documented by experiments. Over the years several techniques have been developed for soil protection and renaturalization. Among them, an innovative technology uses only natural perennial grass plants with deep roots and allows operating in areas where climatic conditions were until a few years ago considered prohibitive for the development of vegetation. The application field of this technology is quite broad in many regions in Italy: embankments and ridges of roads and railways, quarries, mines, landfills and facing sea areas, banks protection of rivers, torrents, and artificial canals. The installation of deep rooting grassy plants to contrast water erosion on sloping ground looks promising for the following reasons:

- vegetation dissipates most of the kinetic energy of raindrops, weakening the erosion action;
- during heavy rainfalls, a major fraction of rainwater flows above the aerial portion of plants, even when the vegetation is dried up, thus reducing water infiltration;
- vegetation reduces the speed of runoff water on the ground.

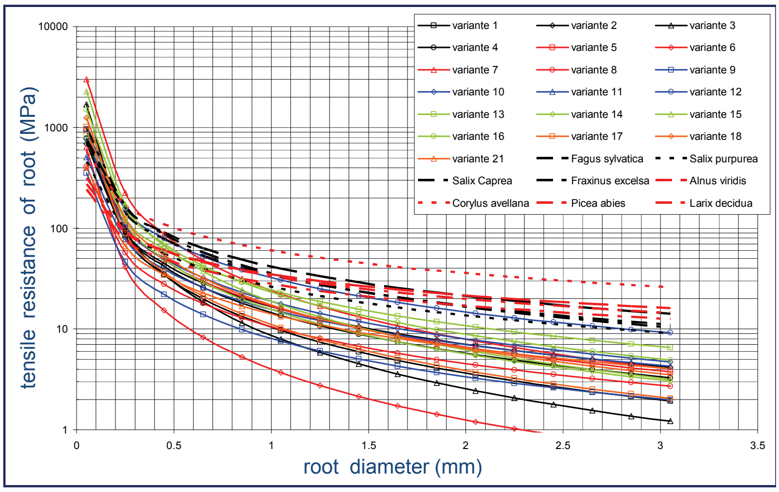

Fig 1 Tensile resistance of roots as a function of root diameter from experimental tensile tests (Prati Armati s.r.l).

The grass covering technique looks promising also with respect to shallow instability of slopes: the deep roots, in fact, induce mechanical and hydraulic effects on slope equilibrium that typically increase the shear strength of soil. The mechanical effects of plant roots result from the root/soil interaction processes, while the effects of hydraulic nature derive from the reduction of water content and degree of saturation of soil caused by the presence of grass. The problem of mechanical/hydraulic interaction between root and soil becomes crucial when the deep roots system bears the dual purpose of fulfilling the primary function of erosion protection and, additionally, to contrast possible surface instability events (thickness of unstable layers not greater than 1÷1.5 m). From a purely mechanical point of view, the roots provide an increase in shear strength of soil, $\Delta\tau_{rad}$, that, based on experimental tests, is directly proportional to the average tensile strength of roots T_R and to the rooting ratio A_R /A. Fig. 1 shows the tensile resistance of roots T_R as a function of root size, measured from experimental tests on different herbaceous species.

With reference to the scheme of infinite slope, it is possible to solve the equation that expresses the safety factor (FS) and to quantify the stabilizing contribution given by roots to the upper layers of soil, namely:

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$$FS = \frac{\tau_f(z) + \Delta\tau_{rad}(z)}{\gamma \cdot z \cos\alpha \sin\alpha} = \frac{c' + \left(\gamma - \dfrac{D_w}{z}\gamma_w\right) z \cos^2\alpha \tan\phi' + \Delta\tau_{rad}(z)}{\gamma\, z \cos\alpha \sin\alpha} \qquad (1)$$

with: *c'* and ϕ': soil strength parameters; γ and γ_w: respectively, unit weight of soil and water; α : slope angle; *z*: depth of the potential sliding surface measured from ground surface; $\tau_f(z)$: soil shear strength along the potential sliding surface; D_w: sliding surface depth with respect to ground-water level. Plant roots will also help to increase the soil shear strength as they may induce a significant reduction in content water, absorbed by the roots themselves. The distributions curves of water content and suction vs. depth - linked by the hydraulic retention curve - can be evaluated by numerical integration of the well-known Richards differential equation (1931).

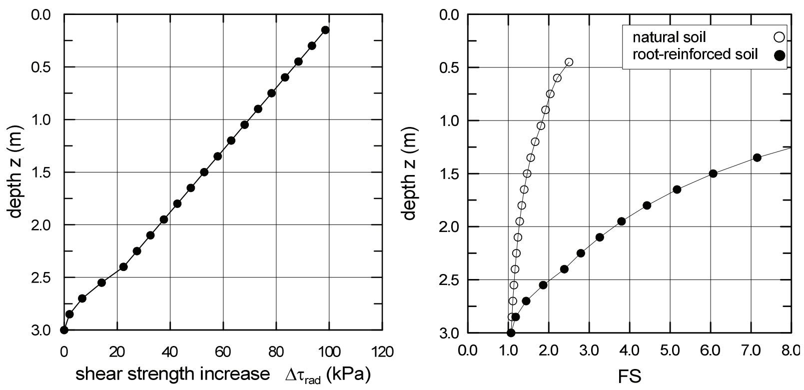

Fig. 2 Numerical example showing the mechanical effect of root reinforcement on the slope stability: shear strength increase *vs* depth (left); safety coefficient FS *vs.* depth (right).

Fig. 3 Example of intervention: Orvieto (Terni, Italy) – 'SP111 della Badia'. a) front situation in December 2004, before intervention; b) after renaturalization intervention (May 2006).

Once the suction profile is known, it is possible to calculate the shear resistance τ_f of soil in partially saturated conditions, using one of the failure criteria proposed in the literature; finally, with reference to the scheme of infinite slope, the safety factor may be calculated from equation (1). The Authors recently launched a study aimed at numerical modelling of both mechanic and hydraulic interactions between roots and soil. The results of the study, still to be refined, allow a quantitative estimation of the increase in soil shear strength induced by the roots system, and an evaluation of equilibrium and safety conditions for events of shallow instability. A numerical example showing the increase of the safety coefficient FS (Eq. 1) is plotted in Fig. 2 as a function of depth z from the ground table.

The results shown in Fig. 2 have been calculated for the following set of data (*roots:* d_{min} = 0.8 mm, z_{rad} = 3 m from the ground table; *slope (infinite slope):* α = 25°, D_w = 1 m; *soil shear strength parameters:* ϕ' = 32°, c' = 4 kPa).

A typical installation example of herbaceous plants with deep roots, aimed to erosion prevention and surface stabilization of slopes, was carried out in a site in central Italy, as shown in Fig 3. In December 2004, a remarkably high and steep slope (70-80°) consisting of pyroclastites and strongly altered basaltic outcrops developed a surface slide that blocked the underlying province road (Fig .3a). A few months after the intervention, the grass plants completely re-naturalized the slope despite the unfavourable lithological and morphological conditions. Moreover, the deep root system was able to definitely stabilize the upper layer of the slope, blocking at the same time the erosion (see Fig. 3b).

Keywords: soil erosion, mechanics of root reinforcement, role of vegetation on slopes