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Quantifying the additional cohesion of the soil due to root systems and its space variability

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Vegetation is commonly recognised as a significant stabilising factor of mountainous hillslopes, because of its effects on hydrological processes and its mechanical reinforcement of soil. Although the stabilising effect is well known from ages (e.g. restrictions on logging can be found in documents of the Republic of Venice, Italy, dating back to the 13th century), only in the last decades it has been established by technical studies (mainly related to the increase of landslide's occurrence in timbered areas) and only in the last years it has been quantified by back analysis procedures or direct shear tests.

Due to the burden of direct shear tests on one hand, and the need for a generalisation of the results (e.g. for hillslope stability evaluation) on the other hand, the problem of quantifying the contribution of vegetation to slope stability has been successfully approached by modelling. In such a perspective it is common to distinguish the action of the huge number of small roots, which is accounted altogether as an additional cohesion, and the action of bigger roots, which contribute separately as anchors or piles. Because the difficulty to estimate the action of single roots, in the stability evaluation of vegetated hillslopes, only the additional root cohesion is generally accounted for.

The most common root cohesion model is the Wu and Waldron model, which is based on the concepts of the earth reinforced with fibers. According to such a model the root cohesion (c_R) can be simply estimated as summation of the products between the average tensile strength of roots of a specific diameter class (T_{r_i}) and the fraction of the soil cross section actually occupied by roots of such a diameter class (a_{r_i}), all multiplied by a factor accounting for the different orientation of roots (for common values of root orientation and soil friction angle, such a factor - k'- varies between 1.0

and 1.3):

$$c_R = k' \sum_{i=1}^{N} T_{r\,i} a_{r_i} \tag{1}$$

To be properly applied the original model of equation (1) should be modified to account for the spatial variability of root distribution (especially with depth), and to account for the probability that not all the roots in the soil actually mobilise their whole tensile strength (there's no guarantee that all roots break at the same time due to different tortuosity and elasticity). Moreover, in the initiation process of shallow instability phenomena the root cohesion actually mobilised can be estimated as the sum of the basal root cohesion ($c^Z_{R_{bas}}$) due to the roots crossing the basal shear plane at depth z and the lateral root cohesion ($c^Z_{R_{lat}}$) due to the roots crossing the lateral shear surface.

In the present work a general model of such a behaviour is presented and the model is applied to different sites in order to evaluate, for different plant species, the magnitude of their root cohesion and its variability with depth and with sampling point at the same site.