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SLIDEFOR^NET: a web tool for assessing the effect of root reinforcement on shallow landslides

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Introduction:
Protection forests are an important element in the integrated management of natural hazard risks, usually mentioned as “biological measures”. In fact, protection forests are recognised to play an important role in the mitigation of natural hazard risks in many mountainous regions. However, the integration of the protective effect of forests in regional/national management plans and political strategies is often hindered by difficulties with the quantification of those effects. One of the main reason is the lack of data and methods that allow accounting for the protective effect of forest in hazard analysis. In addition, the definition of forest target profiles in silvicultural guidelines are mostly based on scientifically founded forest ecological know-how, but not on quantitative knowledge of the interaction between forests and gravitational processes.

In the case of rockfall, the recent scientific contribution in term of new experimental data and development of numerical tools has allowed a considerable improvement in the quantification of protection forest effects, and it can be considered as good example for the quantification of protection forests function. In the case of erosion and shallow landslides, the lack of knowledge is due to : 1) the difficulty in synthesise the global effects of vegetation on the complex interaction of processes related to slope instabilities (hydrological & mechanical), 2) the lack of scientifically based information (e.g. data on root distribution of different tree species, studies on root reinforcement under compression). Nevertheless, ongoing research is contributing to better approach the quantification of some stabilisation mechanisms due to vegetation such as root reinforcement or evapo-transpiration (Stokes et al., 2014). In this paper we discuss in particular the possibility to quantify the effect of root reinforcement on slope stability.

The objective of this paper is to introduce new concepts on root reinforcement mechanisms emerged due to recent studies and to present a new tool, SLIDEFOT^NET, for the quantification of the stabilisation effect of root reinforcement on steep slopes.

The contribution of roots to slope stabilisation are usually considered as additional shearing strength on a potential shearing plane. Tsukamoto and Kusakabe (1984) well illustrate some types of scenarios where vertical roots may reach or not stable or not stable substrates (such as fragmented bedrock or over-consolidated soil material). Giadorssich et al. (2013) have introduced e new conceptual framework that considers two additional types of root reinforcement mechanisms: the lateral effect of root reinforcement and the stiffening effects of soil under compression due to roots. The three type of reinforcement mechanisms (basal, lateral, stiffening) are illustrated in figure 1, listed in order of efficiency. In the case where vertical roots reach underlaying stable strata, their stabilising effect may be really efficient and extended over large areas (infinite slope approach for stability calculations would in this case give plausible results). In the case where roots form a homogeneous networks parallel to slope, their contribution to slope stability is considerably reduced and is related to the dimension of the potential shallow landslides (Schwarz et al., 2010); in this case, the stabilisation is achieved through a combined effect of: 1) the additional lateral root tensioning and 2) the stiffening of soil material due to roots within the sliding mass. In the case where the root network is not homogeneous and roots are present only at the margins of a shallow landslides, only the additional tensioning effects of roots on the tensions cracks may be considered. In view of this possible scenarios, the last one may be considered the most pessimistic and conservative.

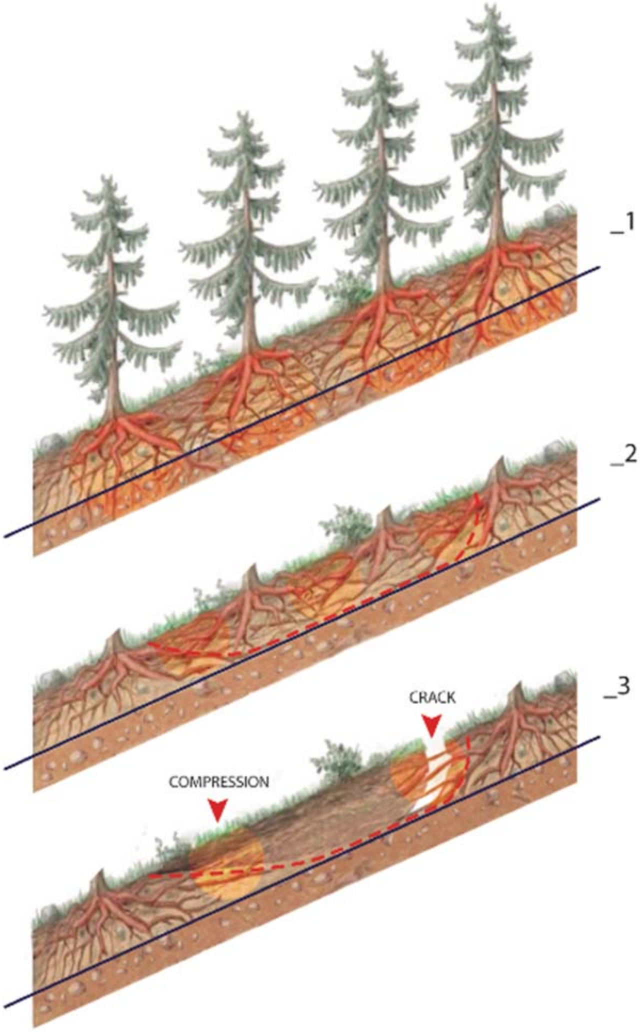

Fig. 1: Illustration of three different mechanisms of root reinforcement (Giadrossich et al., 2013): 1) basal root reinforcement along a potential slip surface (black line), 2) lateral root reinforcement combined with stiffening of soil mass, 3) lateral root reinforcement at the margins of the landslide

Recent studies on the spatial and temporal distribution of root reinforcement in the alpine region allow a quantitative comparison of the effect of different type of forests on slope stability (Schwarz et al., 2013). In particular, data and modelling of root distribution of the main alpine tree species (spruce - Picea abies, fir - Abies alba, and beech - Fagus silvatica) allow the calculation of the potential lateral and vertical distribution of root reinforcement at the hill-slope scale. This type of information are fundamental for the implementation of root reinforcement in slope stability calculations.

SLIDEFOR^{NET}:

SLIDEFOR^{NET} is a web tool developed for the estimation of root reinforcement effects on slope stability and for the comparison of the protection effects of forest in different conditions. The stability calculation is based on a 3D force balance approach that assumes an elliptical shape of shallow landslides. Analog to other approaches, the landslide mass is considered perfectly rigid allowing all the lateral forces to act simultaneously. Root reinforcement is implemented in the calculation considering the roots on the upper margin of the landslide only (along the potential tension crack) (no stiffening effects of roots are considered). The stabilisation effects due to roots crossing the shearing plane is not considered. However, if considerable values of minimum basal root reinforcement are present at stand scale (>5 kPa), a full stabilisation of potential shallow landslides could be aspected for shallow soils (< 0.5 m depth). For detailed description of the equations we refer to Schwarz et al. (2010).

In order to consider the effects of lateral root reinforcement on different dimensions of shallow landslides, a gamma probability function is used to describe the frequency-magnitude distribution of potential shallow landslides volumes during an event (Malamut et al, 2004).

The input parameters such as depth of shearing plane and soil effective cohesion for the stability calculations are implemented using a stochastic approach; for both these parameters a defined standard deviation is considered and a random generating function is used to create a normal distribution array of values. In order to have a representative number of calculations using combination of random generated values, a total number of 10’000 potential shallow landslides is used. The number of resulting unstable landslides (red/green colons in figure 2) is not related to a specified event magnitude or return period, instead it represents the partial probability that landslides of a certain area may occur (Landslide Frequency/10000) under full saturated condition (pore water pressure = soil depth*9.81). Figure 2 shows the interface of the SLIDEFOR^{NET} tool with the list of input parameters (left) and the results of the calculations (right). On the top right of figure 2, the calculated “degree of protection” is shown classified in 6 cathegories. The “degree of protection”is calculated on the base of the reduced number of landslides due to the presence of lateral roots (total number of landslides without forest - total number of landslides with forest, in percent on the total number of landslides without forest). Considering the information of the forest stand (mean stem density per hectar, mean stem diameter, and species composition), the model classify the calculated minimum root reinforcement in three classes (5, 10, and 15 kPa) rounding the values per defect (bottom right of figure 2). Finally, the model calculates the weight of the trees in order to discuss the role of this force component on slope stability.

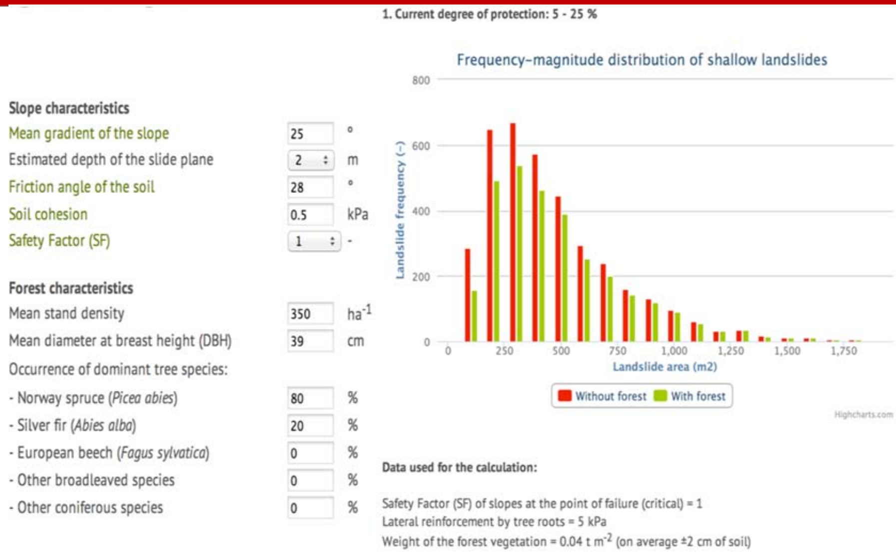

Fig. 2: User interface of the tool SLIDEFOR^{NET}.

Case studies :
In order to show the possible application of the tool SLIDEFOR^{NET} we consider three areas of the swiss pre-alps documented in Schwarz et al. (2013). Table 1 summarised the main characteristics of the stand. The soil depth indicate the depth of potential sliping surface, which can be estimated observing previous event or literature information. The most difficult parameter to be estimated are the geo-technical values (effective friction angle and cohesion). However, soil classification tables (e.g. USGS) may be used to get plausible estimation of these values and their standard deviation. Species compositions of the forest stand are characterised in term of percentage of coverage, considering the “present” conditions or “optimal” profile in accord to NaiS (Frehner et al., 2005).

Tab. 1: Main characteristics of the study areas. Sp=Spruce (Picea abies), Fi=fir (Abies alba), Be=Beech (Fagus silvatica)

Area	slope inclination [°]	Soil depth [m]	Effective friction angle [°]	Effective cohesion [kPa]	Species composition, present [%]	Species composition, optimal* [%]	Mean DBH [m]	Stems Density [N°/ha]
“Schangnau”	25	1.5	25	0.5	Sp:80,Fi:20, Be:0	Sp:0,Fi:40,Be:60	0.39	350
“Spisibach”	35	2	29	0.5	Sp:40,Fi:50, Be:10	Sp:0,Fi:40,Be:60	0.4	250
“Gantrisch”	20	1	27	1	Sp:80,Fi:20, Be:0	Sp:30,Fi:70,Be:0	0.41	300

*”optimal profile” defined in accord to the NaiS guide lines (Frehner et al., 2005).

Using the information of table 1 it is possible to visualise the results with SLIDEFOR^{NET} on the web. The results have shown that the degree of protection of forest decrease with increasing slope inclination (this is related also to a general increment of soil mechanical parameters) and may considerably change from stand to stand. Changes in species composition, mean DBH, and stems density have a major impact on the changes of minimum lateral root reinforcement at the stand scale, which may range between 0 and 15 kPa. The histograms shows that lateral root reinforcement is effective especially for landslides with areas up to 500 m^2, depending on the slope inclination. The role of the vegetation weight at stand scale result to be neglectable in comparison to the total balance of forces considered in stability calculations.

Final remarks:
The overall objective of developing SLIDEFOR^{NET} is to allow practitioners to perform a quick quantitative evaluation of the protection effect of forests in regions susceptible to shallow landslides. The tool may be used to discuss the protection function of present forest conditions, or to compare the effects of future possible scenarios in view of management measures. The tool serves as complementary instrument for the definition of "optimal" stand profile looking at the physical effects of forest structure and composition, nearby the ecological aspect defined in selvicultural guidelines such as NaiS (Frehner et al., 2005). The tool may be applied directly in the field (on smart-phone or tablets), or used to plan field survey.

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