

Influence of forest structure on the mitigation of shallow landslides: a case study in St. Antönien (Switzerland)

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INTRODUCTION

Root reinforcement is recognized as an important factor for the stabilization of shallow landslides. Field studies revealed that root distribution has a high temporal and spatial variability influenced by numerous factors, of which local ecological conditions and tree species composition are of highest importance (Schwarz et al., 2010). Additionally, forest structure, mainly the diameter and position of trees, determines the spatial distribution of roots. Consequently, quantitative methods adapted for an assessment at hillslope scale are required to better understand the effects of forest structure and corresponding distribution of root reinforcement on slope stability.

The objective of this work is to apply state of the art methods for the quantification of root reinforcement at hillslope scale and to analyse the influence of forest structure on slope stability combining statistical and physical models.

METHODS

The study area is located on a south-east exposed hillslope in the alpine region, in St. Antönien (Eastern part of Switzerland). In 2005 a heavy rainfall event triggered numerous shallow landslides in the area. Shortly afterwards a detailed landslide inventory was compiled by Rickli et al. (2008). In addition to the 2005 landslides sites under forest, a set of control sites without landslide activity served as reference data. The random determination of the control sites was based on two variables dictated by the landslide sites: slope angle and tree coverage. The values of these explanatory variables were extrapolated from digital elevation models or collected in the field. Both landslide and control plots were characterised by a relatively open forest structure (15-70 % degree of forest cover) including clustered patches of spruce trees and gaps of different size.

The root distribution was recorded in soil pits at regular distances from 7 tree stems. In a first step the results served to calibrate the root distribution model of Schwarz et al. (2010) which, in a second step, described the root distribution for a large set of tree diameters (DBH) and distances from tree stems. The physically based numerical Root Bundle Model (RBMw; Schwarz et al., 2013) finally calculated root reinforcement as function of tree dimension and distance from tree stem.

The resulting root reinforcement served as input parameter to assess the influence of forest structure on slope stability following two different approaches: 1) statistical analysis and 2) a physically based model.

The statistical analysis of the relations between landslide occurrence and potentially relevant explanatory variables (such as lateral root reinforcement, slope inclination, water logging, slope curvature, etc.) were analysed using logistic regression as well as recursive partitioning based on the R package „Random Forest“.

The physically based model SlideforNET (www.slidefor.net) is based on a 3D force balance assuming an elliptical shape of the shallow landslide body. Root reinforcement is implemented in the calculation by considering 1) the roots crossing at the upper margin of the landslide (lateral root reinforcement along the potential tension crack) and 2) the roots crossing at the basal shearing plane (basal root reinforcement). In order to account for 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 landslide volumes following Malamud et al (2008). The resulting number of unstable landslides both with and without root reinforcement is used to quantify the stabilising effect of forest structure on shallow landslides.

RESULTS AND DISCUSSION

The results of the statistical analysis show that the explanatory variables related to forest structure significantly explain landslide susceptibility along with topographic and hydrological factors. Significant effects were found for gap length and the distance to the nearest trees. The random forest analysis shows that a gap length of 20 m can be considered as a critical threshold for increased susceptibility to shallow landslides. The calculated maxima of lateral root reinforcement of the five nearest trees to landslide and to control points are significantly different (Figure 1) and indicate that root reinforcement of about 2 kN/m may be considered a significant contribution to slope stability. The results of the physically based model agree with the results of the statistical analysis and show that the efficiency of lateral root reinforcement depends on the dimension of the shallow landslides and on the slope angle.

The results of this study support requirements (e.g. maximum gap length) of the general indications for an ideal forest structure in the Swiss guidelines for protection forest management (NaiS, Frehner et al., 2005) and offer the possibility

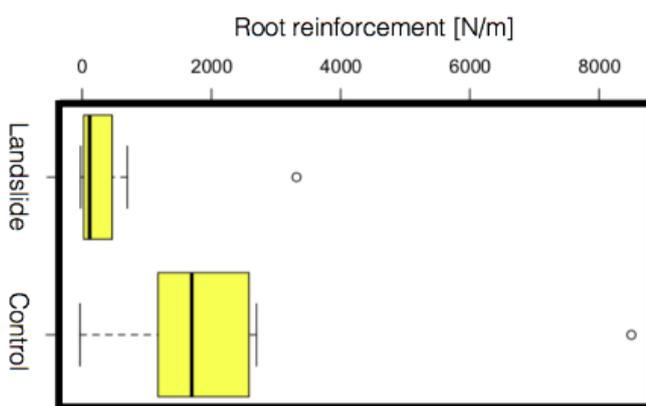


Figure 1. Boxplots of the calculated maximum root reinforcement (considering roots up to 15 mm diameter) at the distance between the (potential) release point to the five nearest trees in landslide and control plots.

KEYWORDS

shallow landslides; protection forests, forest structure; slideforNET

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to elaborate a framework for more detailed indication based on specific local conditions (different tree species, morphological conditions, climatic conditions, geotechnical conditions, etc.).

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