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Tensile forces and failure characteristics of individual and bundles of roots embedded in soil – experiments and modeling

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The quantification of soil root reinforcement is relevant for many aspects of hillslope stability and forest management. The abundance and distribution of roots in upper soil layers determines slope stability and is considered a mitigating factor reducing shallow landslide hazard. Motivated by advances in modeling approaches that account for soil-root mechanical interactions at single root and bundle of roots of different geometries (the root bundle model – RBM), we set up a series of root pull out experiments in the laboratory and in the field to study the mechanical behavior of pulled roots. We focused on the role of displacement and root failure mechanisms in determining global tensile strength and failure dynamics in a root bundle.
Strain controlled pull out tests of up to 13 roots in parallel each with its own force measurements provided insights into the detailed soil-root and bundle interactions . The results enabled systematic evaluation of factors such as root tortuosity and branching patterns for the prediction of single root pull out behavior, and demonstrated the importance of root diameter distribution for realistic prediction of global pullout behavior of a root bundle. Analyses of root-soil interface friction shows that force-displacement behavior varies for different combinations of soil types and water content. The maximal pull out interfacial friction ranges between 1 for wet sand (under 2 kPa confining pressure) and 17 kPa for dry sand (under 4.5 kPa confining pressure). These experiments were instrumental for calibration of the RBM which was later validated with six field experiments on natural root bundles of spruce (Picea abies L.). The tests demonstrated the progressive nature of failure of a bundle of roots under strain controlled conditions (such as formation of tension crack on a vegetated hillslope), and provide important insights regarding stress-strain behavior of natural root reinforcement.