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An assessment of models that predict soil reinforcement by plant roots

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Predicting soil reinforcement by plant roots is fraught with uncertainty because of spatio-temporal variability, the mechanical complexity of roots and soil, and the limitations of existing models. In this study, the validity of root-reinforcement models was tested with data from numerous controlled laboratory tests of both fibrous and woody root systems. By using pot experiments packed with homogeneous soil, each planted with one plant species and grown in glasshouses with controlled water and temperature regimes, spatio-temporal variability was reduced. After direct shear testing to compare the mechanical behaviour of planted versus unplanted samples, the size distribution of roots crossing the failure surface was measured accurately. Separate tensile tests on a wide range of root sizes for each test series provided information on the scaling of root strength and stiffness, which was fitted using power-law relationships. These data were used to assess four root-reinforcement models: (1) Wu et al.'s (1979) root-reinforcement model, (2) Rip-Root fibre bundle model (FBM) proposed by Pollen & Simon (2005), (3) a stress-based FBM and (4) a strain-based FBM.

For both fibrous (barley) and woody (willow) root systems, all of the FBMs provided a better prediction of reinforcement than Wu's root-reinforcement model. As FBMs simulate progressive failure of roots, they reflect reality better than the Wu model which assumes all roots break (and contribute to increased shear strength) simultaneously. However, all of the FBMs contain assumptions about the distribution of the applied load within the bundle of roots and the failure criterion. The stress-based FBM assumes the same stiffness for different sized roots, resulting in progressive failure from the largest to smallest roots. This is not observed in testing where the smallest roots fail first. The Rip-Root FBM predicts failure from smallest to largest roots, but the distribution of load between different sized roots is based on unverified scaling rules (stiffness is inversely proportional to diameter). In the strain-based FBM, both stiffness and strength data are used to evaluate root breakage. As roots stretch across the shear surface, the stress mobilised in individual roots depends on both their individual stiffness and strain. Small roots being stiffer, mobilise more stress for the same strain (or shear displacement) and therefore fail first. The strain based FBM offers promise as a starting point to predict the reinforcement of soil by plant roots using sound mechanical principles. Compared to other models, it provided the best prediction of root reinforcement. Further developments are required to account particularly for the stochastic variability of the mechanical behaviour and spatial distribution of roots and this will be achieved by adapting advanced fibre bundle methods.

Pollen, N., and A. Simon. 2005. Estimating the mechanical effects of riparian vegetation on stream bank stability using a fiber bundle model. Water Resour. Res. 41: W07025.

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