Plant root biomechanics and slope stabilisation

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Plants root systems have evolved into complex engineered structures capable of mechanically supporting a large shoot mass above ground by forming a biological anchor in the surrounding soil. Roots also have a huge capacity to reinforce soil, increasing slope stability and the resistance to physical degradation. Although it is well accepted that roots are extremely important to these processes, surprisingly little is understood about the mechanical interaction between soil and roots. This presents challenges to crop production, the safety of slopes (particularly along transport corridors) and the ecological restoration of degraded soils.

One example of the economic significance of this problem is crop lodging, which cost British farmers £120 million during a particularly bad season in 1992. New cereal varieties have been bred with shorter stem lengths to reduce lodging, but it may still occur through the rupture of the root system. Tree blow-down is also affected by the capacity of roots to act as an anchor. Landslides following forest clearcutting have highlighted the importance of vegetation to slope stability. A new industry, often referred to as 'Soil Bioengineering', advocates the planting or maintenance of specific vegetation on potentially unstable slopes, to reinforce soil. This may help reduce the £40-50 million annual expenditure incurred by Network Rail maintaining earthworks along the UK railway network. Ongoing maintenance to clear trees beside railway lines may decrease problems with 'leaves on the line', but the implications for slope stability are not certain. Slope failure caused 30 train accidents in the UK in 2000. These problems are predicted to worsen with climate change, due to the increasing variability of rainfall and greater frequency of more intense rainfall.

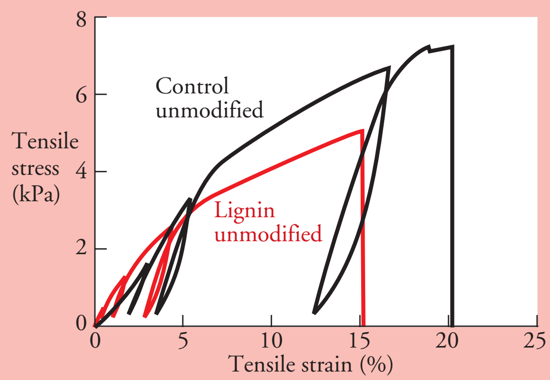

Figure 1 Mechanical behaviour of tobacco roots under tensile strain.

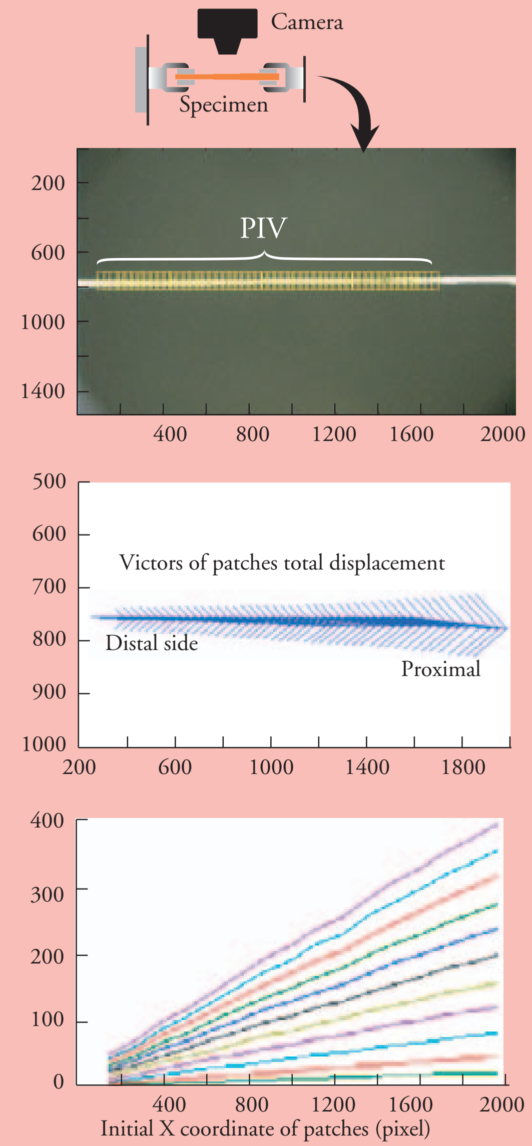

Figure 2 Particle image velocimetry (PIV) allows us to detect localised strain fields that are common in biological material. High quality digital photographs are taken as the root is stretched under tension. Patches placed over the image are analysed to detect any movement, which relates to the deformation of the root as it is stressed.

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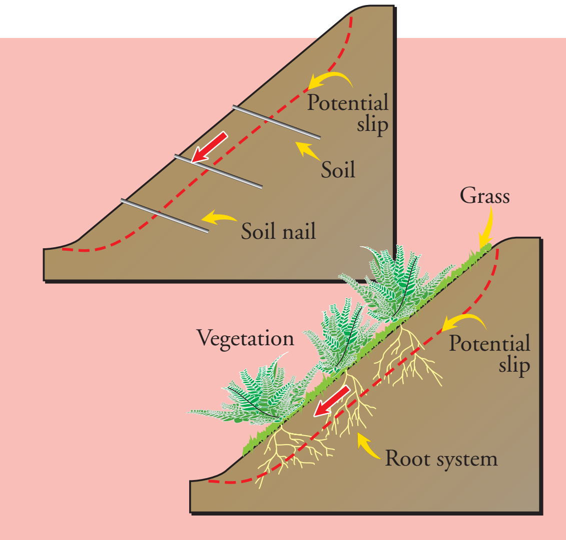

Figure 3 Roots can reinforce soil in a similar way to soil nails by bridging potential slip surfaces.

Through research collaboration with the University of Dundee, we are investigating plant root biomechanics and the use of roots to improve slope stability. Recent advances in geotechnical engineering, developed primarily for understanding the reinforcing effect of soil nails and micropiles, are being used to understand the mechanical interaction between roots and soil. We believe that by using complex constitutive equations of soil mechanical behaviour, combined with numerical approaches, accurate predictions of root-soil mechanical interactions are possible. This is a technological leap from the previous research that relied heavily on engineering approaches based on simple assumptions that were developed almost 40 years ago.

The research ranges from a genetic level understanding of root biomechanics to predictions of large scale slope instability. Model plant systems are being used to understand the biomechanics of individual roots. By suppressing 1 or 2 specific genes in tobacco, Dr Halpin has produced plants that differ only in the composition and abundance of lignin. Reduced lignin density alters the mechanical behaviour of roots (Figure 1), thereby providing an ideal model system to quantify the influence of genetics and cellular structure on root biomechanical behaviour.

Funding from the Discipline Hopper scheme (MRC/EPSRC/BBSRC) has allowed a University of Dundee geotechnical engineer, Omar Hamza, to work exclusively on applying geotechnical engineering to plant root biomechanical behaviour. Particle image velocimetry (PIV) has shown the localised strain fields that develop in mechanically stressed roots under tension (Figure 2). Both cellular rupture that controls root strength and slip planes that affect root pull-out from soil will be affected by localised strain. We believe that this is the first time that PIV has been applied to the tensile testing of materials. The technique may prove useful to a wide range of other applications, including medical biophysics and materials science and will be used to study root-soil interaction later in the research programme.

A new project funded by the EPSRC will examine the stabilisation of slopes with plant roots. Figure 3 illustrates the similarity between plant roots and the use of soil nails for slope mechanical reinforcement. This part of the project seeks to investigate the link between root systems, root mechanical properties and soil slope stability. By testing slopes at small scale on 1 m^3 models (but at the correct stress levels, using a geotechnical centrifuge), slopes will be brought to ultimate limit (i.e. "failure") and serviceability limit conditions so that the exact reinforcing effect of the vegetation can be quantified. In addition to testing real root systems, the creation of reduced-scale root analogues will allow different root architectures to be investigated sequentially. Ultimately the work will provide a quantitative basis for making recommendations for the design of root stabilised slopes. It will also provide an experimental basis for future modelling studies and the selection of plant varieties for improved slope stabilisation.

Our unique collaboration aims to provide both agronomic and engineering solutions from a strong base of fundamental science. An industrial steering committee has been formed to help direct us towards practical applications and facilitate the rapid dissemination of new knowledge. We have already received considerable interest from industries concerned with the management of vegetation on steep slopes.