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Interaction between trees and natural hazards in subalpine spruce forests

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Introduction

Forests protect men and infrastructure against natural hazards. The objectives of the tree stability project at the Swiss Federal Institute for Snow and Avalanche Research (SLF) is to understand the interaction between trees and natural hazards such as rockfall or wind as well as the single-tree and stand stability in protection forests, to comprehend the influence of forest management on this stability and to make a cost-benefit analysis of protection forest management.

One sub-project deals with the role of the root system in the anchorage mechanics of trees. Investigations on the interrelations between root architecture and mechanical parameters (e.g. root-soil stiffness and anchorage moment) are scarce (e.g. Neild and Wood, 1999). More information is needed about the anchorage failure of trees and how much trees are pre-stressed before it comes to failure. The forces acting on trees not only cause visible damage such as rockfall scars but may also lead to breaking of roots. After performing winching tests some trees maintained an inclination at the stem base of up to 0.5° (Jonsson *et al.*, submitted). Two reasons are suggested for this phenomenon, soil deformation or damages in the root system. To approach this fact, sap flow measurements were conducted as a non-destructive method to track a decrease in water conductivity due to injury of roots by measuring the water flow in the stem during winching tests. If roots break the water flow at the stem base decreases (Rust and Gustke, 2001).

Rockfall simulation tests were carried out to study the interaction between a rock and a tree. One objective was to predict the energy dissipation of single trees as a basis to improve rockfall models. When a rock hits a tree a transversal wave runs stem upwards and sometimes the tree top breaks off. Wind induced tree swaying leads to breaking of cell walls in the wood referred to as stress lines (Seubert Hunziker and Niemz, 2002). Whether these stress lines also occur after a rockfall impact is investigated in another sub-project.

Methods

Research site

The test site is located in a subalpine spruce forest near Davos, Switzerland, in an elevation of 1800 m a.s.l.. The site has an average slope of 30° in a south-western exposition. The stand density is about 500 trees per hectare, mainly Norway spruce (*Picea abies* (L.) Karst) with a small percentage of European larch (*Larix decidua* Mill.). The soil is a podzolic brown soil with a varying soil depth of 0.2 to 0.7 m and a high percentage of stones.

Mechanical tests

For the winching tests a steel cable was fixed to the stem in 5 m height (Fig. 1) and the tree was equipped with inclinometers at 2 %, 5 % and 20 % of the tree height, respectively. The trees were pulled sideways along the prevailing wind direction during subsequent tests in 0.5° steps from 1.5° up to 3.0°. From the recorded data (pulling force, inclination, and sap flow) and the mass distribution in the tree various information on the performance of the tree and its anchorage in interaction with natural hazards is gained. For further details of the tests and the evaluation see Jonsson *et al.* (submitted).

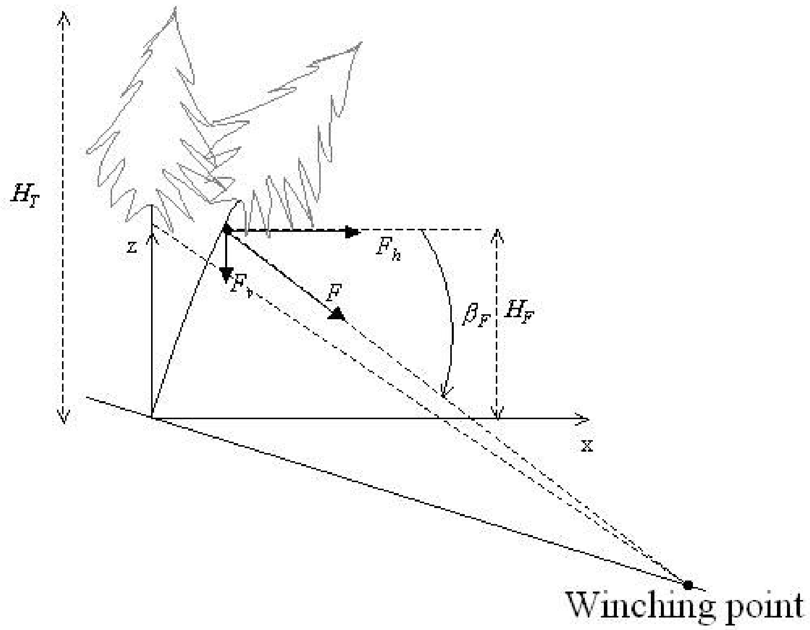

Figure 1: Test set-up of winching test.

For the impact tests, trees were selected that represented the diameter distribution in the plots. With a trolley of a variable impact mass (517 to 917 kg) guided downslope on steel cables a rockfall event was simulated. The velocity of the impact mass was measured on the trolley and the acceleration of the stem at 2 %, 5 %, 20 % and 75 % of the tree height were recorded. The tree's reaction was also recorded using video and high speed cameras for further analysis of the deformation of the tree.

Sap flow measurements

In the vegetation period of 2004 sap flow measurements (Granier system, UP, Ibbenbüren, Germany) were conducted on trees exposed to winching tests. On each tree, three sensors were inserted into the stem at 0.60 to 0.80 m height above ground. One sensor pointed in the direction from where the tree was pulled, the other two were on the opposite side of the

stem, so that each third of the stem was equipped with a sensor. The sensors were sealed against water and sunlight and the power was supplied by solar panels.
The sampling interval was 10 seconds and the logging interval was set to 2 minutes.

Wood anatomy

Stem disks were taken from trees exposed to impact tests (rockfall simulation) in intervals of 0.5 to 2 m along the stem. The last tree rings (2003 and 2004 respectively) were followed through the stem. Microtom slices of 24 μm thickness were cut from different sides of the disk and investigated microscopically with a magnification of 200 to 400. Stress lines caused by the impact were located and their distribution and frequency in the early and late wood were determined.

Results

Mechanical tests

From the winching tests the root-soil stiffness can be calculated (Jonsson *et al.*, submitted). The tests from the trees with the sap flow system will be evaluated later in the year, this is because the evaluation routine needs information about mass distribution which is obtained when the trees are felled after the field tests are completed.
For details on the impact tests and the energy dissipation in the tree see Lundström *et al.* (in preparation) and Foetzki *et al.* (2004).

Sap flow measurements

The sap flow showed a typical variation over the daytime with a maximum during midday and a minimum at dawn. On warm days with a high irradiance a midday depression could be observed.
During the tests the sap flow pattern was monitored. Although the trees had a remaining inclination at the stem base of about 0.5° after being pulled to an inclination of up to 2° at the stem base, no signal in the sap flow was recorded. At an inclination of 2.5° at the stem base, one of the test trees showed a reaction, supposably first roots broke. This resulted in a reduction of sap flow in one part of the tree, and a compensation in the other part. The other trees have not shown an effect so far although they were pulled to an inclination of 3° at the stem base.

Wood anatomy

Stress lines were found in different heights of the stem. The breaks in the cell wall did not occur evenly distributed but clustered and not in the same frequency on all sides of the stem. The frequency of stress lines was higher in late wood than in early wood.

Discussion

Sap flow measurements

With the test results a critical angle for root breakage can be found. Whether it is dependent on the stem diameter, root architecture, slope or direction of pulling have to be further investigated. First results of winching tests on different sites showed a dependance of the maximal bending moment on the stem diameter (unpublished data). Whether roots already break before the maximal bending moment is reached will be shown in additional tests. If the roots are also damaged during storms and how to quantifiy the stress for the tree due to these damages are the next questions to answer.

Wood anatomy

The frequency and distribution of the stress lines can be compared with the compression wave that runs stem upwards. The stem deflection and bending stresses during the impact were analysed at the SLF (Lundström and Simon, submitted). Can stress lines in the wood be found at the same heights of the stem where the amplitudes of deflection are predicted by this calculation? Stress lines reduce the tension strength of wood (Sonderegger and Niemz, 2002); this may have an influence on the tree stability.

Further studies could include the deflection propagation in the wood structure and address the differences between early and late wood.

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