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Innovative real-size tests for assessing the mechanical resistance of coppice stems against rockfall

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At lower altitudes ($\leq$ 1200 m a.s.l.) in many temperate mountainous regions like for example the French Alps, large parts of the forests are coppice stands. Still today, these forests are maintained for local fuelwood supply. Situated on slopes close to settlements and roads they often fulfil a protective function against falling rocks up to $1m^3$. This protective function can be estimated by using rockfall simulation models. However, current models that consider single impacts on trees are based on relatively few data on the mechanical resistance of trees against dynamic impacts obtained from experiments on mature conifers. In this study we developed two experiments that provide more reliable data on relatively small deciduous trees generally constituting coppice forests (Beech, Fagus sylvatica L., diameter at breast height (DBH) 3-10 cm).

First of all we constructed an open air pendulum impact device to determine the maximum mechanical resistance of green coppice stems to dynamic loads as they occur during rockfall impacts. The experiments consisted in impacting coppice stems that were vertically clamped into a fixed support, with a spherical bob of reinforced concrete (mass: 84 kg). It impacted the specimens horizontally at different heights with a maximum speed of 12 m/s. For qualitative observations and speed measurements we used two digital high-speed cameras. We quantified the resistance of the stems as the difference between the kinetic energy of the bob before and after impact. Up to now we tested 58 stems.

We observed very different breakage behaviours of the test specimens, including breakage at impact height, breakage at bearing height, longitudinal splitting, random detachment of small and large stem fragments, and strong elastic deformations. The occurrence of these phenomena was not correlated to stem diameter or impact height. We therefore conclude that the variability of breakage behaviour is due to the strong heterogeneity of the test material (i.e. knots, growth irregularities and stresses). The results of the video analysis showed an exponential relationship between DBH and dissipated energy. The run of the best-fit function corresponds to the findings of Dorren and Berger (2006) or Jonson (2007). However, our energy dissipation values are about half their order of magnitude.

In addition to the pendulum experiments we impacted 28 living beech coppice trees with spherical granite balls (mass: 60 kg). We accelerated the granite balls up to 16 m/s in a tube system placed on the slope just upwards of the target trees. In this way, we were able to control a short free flight trough the air before impact. The impact process was likewise analysed using 4 high-speed digital cameras.

Analogue to the pendulum tests we observed various breakage behaviours of the living coppice trees. The main differences were a stronger inertia of the upper part of the stems due to the still intact tree crowns and occasional breakage of superficial roots. For the obtained energy dissipation values we found an exponential relationship similar to the pendulum test results.

From this study, we conclude that the resistance of trees against rockfall impacts largely depends on the dimensions of the interacting trees and rocks. Therefore, results from dynamic real-size tests with relatively large rocks ($\geq$1 m^3) on mature trees ($\geq$ 25 cm DBH) should only carefully be used for quantifying the protective function of coppice forests. However, this study indicates that these forests have a substantial protective function given the generally high stand density. In addition, we showed that both test set-ups, forest and pendulum, are useful tools for determining the resistance of coppice trees against rockfall.