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Forests as sustainable mitigation measures against slope processes: the resistance of individual trees against dynamic impacts

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The role of trees and forests as mitigation measures is more and more taken into account in natural hazard engineering. This requires quantification of the capacity of individual trees to dissipate the energy released by dynamic impacts, which has previously only been based on data obtained from static tree-pulling tests or from dynamic impact tests on wood samples. We predicted that these data are not representative of the maximum amount of energy that can be dissipated by living trees during dynamic impacts. To test this prediction, we carried out rockfall experiments on a forested slope in the French Alps. To calculate the rock's energy before and after impact, rockfalls were filmed digitally. The recordings of nine impacts causing instantaneous breakage of *Abies alba* trees were analyzed in detail. An exponential relationship between stem diameter at breast height (DBH) and the maximum amount of energy a tree can dissipate was highly correlated for all of our experimental data. We applied this relationship to other tree species based on published fracture energies. The relationships obtained for *Cedrus spp.*, *Fagus sylvatica* and *Picea abies* were significantly correlated with data from other dynamic impact tests in the field and with maximum bending moments obtained from tree-pulling experiments. Multiple linear regressions showed that impact height influences the energy that will be dissipated by an Abies alba tree, particularly for trees with a DBH less than 15 cm. For trees with a DBH greater than 15 cm, the effect of impact height was minimal up to a height of 1 m. The results showed that data obtained from static tree-pulling tests or from dynamic impact tests on wood samples underestimates the maximum amount of energy that can be dissipated by living trees during dynamic impacts. In addition, the results provide in-

sight into the responses of single trees during dynamic impacts and will help improve quantification of the protective effects of trees and forests. More accurate comparisons of the protection afforded by forests with civil engineering works will facilitate the combined use of silvicultural interventions and technical protective structures in mitigating hazardous slope processes.