FULL SCALE FIELD TESTS ON ROCKFALL IMPACTING TREES FELLED ACROSS THE SLOPE

Franck Bourrier[1], Luuk Dorrren[2] and Frédéric Berger[3]

INTRODUCTION

Although recognised since centuries, the protective function of forests against rockfall continuously gains importance in densely populated areas and along traffic ways throughout the Alps. Maintenance of these forests, in order to optimise or sustain this protective function, which accounts for all types of protective measures, has become an important task for those responsible for managing those forests. Common practices in the European Alps show that a considerable part of the trees felled in rockfall (and also avalanche) protection forests are left in place, in oblique position to the steepest slope direction. This is being done to compensate for the temporary loss of protection due to the reduced forest in the felling area. These fellings are, however, necessary to promote natural regeneration of the, in many cases, over-aged protection forests. Although being a widely used technique, there is little objective information on the efficacy of these trees felled across the slope (in German: *Querfällung*). Therefore, the research work presented in this paper aims at providing practical information to stakeholders, foresters, and natural hazard managers to quantify the protective function of such structures and at defining optimal design schemes (trunk anchorage, optimal oblique stem angle regarding the steepest slope direction, dealing with wood decay). For that purpose, full scale (or real-size) rockfall impact tests on mature trees felled across the slope were carried out and filmed at the study site of Vaujany. This site has been used for full scale rockfall experiments since 2002 by the researchers from Cemagref.

EXPERIMENTS

The experimental site (Dorren et al, 2006; Bourrier et al., 2009) is located in the 'Forêt Communale de Vaujany' in France (lat. 45°12', long. 6°3'). The study area covers an Alpine slope ranging from 1200 m to 1400 m above sea level with a mean gradient of 38°. The experimental site covers an avalanche couloir and is therefore denuded of trees. However, the trees standing along the border of the avalanche couloir allowed selecting four trees (2 white fir, 1 beech and 1 spruce tree) for the installation of a protective structure using felled trees. They were located around 40m down slope from the release point of the rocks. The four trees were felled by experienced lumberjack from Vorarlberg (Austria) and placed in an oblique way regarding the direction of the couloirs (Fig. 1). Finally, the felled stems were attached to their stumps by wire cables.

Before each single rockfall experiment, the rock to be thrown was weighted by an excavator using a load cell. Its dimensions were estimated by measuring the height, width and depth along the three most dominant rock axes. A total of 50 rocks were released individually, one after the other. The mean volume of the rocks was $1m^3$. High-speed cameras (211fps) were used to measure the translational and rotational velocities of the rocks before and after impacting the trees felled across the slope. These measures allowed us evaluating the local efficacy of the protective structure in terms of energy dissipation and changes in fall directions. The velocities and passing heights of the rocks were also measured at two "Evaluation Lines" located 185 and 235m from the release point using two video cameras. These measurements were done to be compared with similar values without protection structures measured at the same evaluation screens during the experiments described in Dorren et al. (2006). This comparison allowed evaluating the global efficacy of the installed protective structure.

[1] Franck Bourrier. Cemagref Grenoble - UR EMGR, France (email: franck.bourrier@cemagref.fr)
[2] Luuk Dorren. Federal Office for the Environment FOEN - Hazard Prevention Division, Switzerland
[3] Frédéric Berger. Cemagref Grenoble - UR EMGR, France

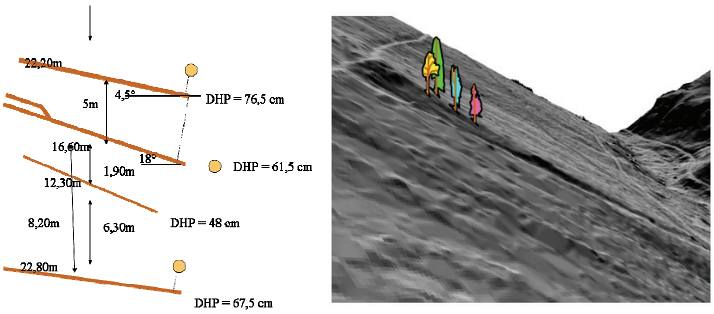

Fig. 1 (left) Scheme of the protection structure made of cut trees (DHP = diameter at breast height); right) 3D view of the study site and the original location of the four selected trees.

RESULTS - DISCUSSION

The experiments firstly show that 85.7 % of the released rocks impacted the structure and only 8.5% were directly stopped.

The velocities of the rocks before and after rebound were decomposed into a normal and tangential (with respect to the surface) components. Based on the analysis of 25 rebounds, the results show that the tangential components of the velocity were significantly reduced (-30%) whereas both normal and rotational components were hardly modified. The impact on the structure therefore induces kinetic energy loss. Changes in the fall direction towards the direction of the felled stem were also observed.

Finally, no significant differences with and without the protective structure were observed for the velocities and passing heights at the two evaluation screens located more than 100m further down slope. Consequently, despite significant energy losses when impacting the structure, the rock energy significantly increases again after the structure. Consequently, a larger number of felled trees is required to stop all rocks. In addition, the structure height seems to be not sufficient: in this site and for 1m^3 rocks, structures made of stacked trees could be significantly more efficient. However, the comparison also shows that the mean energies are higher and the associated standard deviations are smaller if a structure is in place which indicated that low speed rocks are preferentially stopped by the structure. As rocks velocities are generally smaller in forested areas, one can presume that such structures are more efficient on forested slopes.

CONCLUSIONS & PERSPECTIVES

The experiments allowed testing the efficacy of a protective structure made with trees felled across the slope. The results confirm the empirical knowledge regarding the design of these structures: trees felled in an oblique way have a high probability to be impacted by falling rocks and such trees induce rockfall energy dissipation and a change in the fall direction. On the basis of the field observations, several preliminary design schemes, including the optimal distance between two stems, the structure height in relation to the mean diameter of the falling rocks, as well as the optimal felling angle, have been developed. These preliminary schemes will be presented in the final paper. The improvement of our knowledge on these structures however requires further laboratory studies to explore several design schemes as well as additional field experiments to evaluate the efficacy of such structures.

REFERENCES

Bourrier F., Dorren L., Nicot F., Berger F., Darve F. 2009. Towards objective rockfall trajectory simulation using a stochastic impact model. *Geomorphology* 110: 68-79.

Dorren L. K. A., Berger F., Putters U. S. 2006. Real-size experiments and 3-D simulation of rockfall on forested and non-forested slopes. *Natural Hazards and Earth System Sciences* 6: 145–153.

Keywords: Rockfall, forest, field experiments