

ROCKFALL PROTECTION 2008: FLEXIBLE ROCKFALL BARRIERS SUBJECTED TO EXTREME LOADS AS HIGH-SPEED ROCKFALLS OR FALLING TREES

Aron Vogel¹, Axel Volkwein², Werner Gerber², Andrea Roth¹

Flexible rockfall barriers are proven protection systems to mitigate the hazard of rocks hitting people or infrastructure. In order to assure that such systems are able to dynamically stop falling rocks in reality, several guidelines requesting full-scale tests were introduced worldwide. These guidelines consider very standardized and repeatable load cases but do not take into account extreme loads. This paper deals with such loads acting on flexible barriers and the consequences for the designers. Two examples of such extreme loads are chosen. The first one is the impact of high-speed rockfalls with impact velocities of well above 25 m/s as described in the testing guidelines. The second extreme load is the impact of a tree trunk with the same weight as a falling rock but with a much smaller impact area.

Keywords: Rockfall barriers, extreme loads, tree fall, high-speed rockfall, full-scale tests, numerical modelling

INTRODUCTION

The current guidelines for the testing of rockfall barriers take into account the full-scale test of the kits with a standardized test body made of concrete and an impact velocity of 25 m/s (e.g. Swiss guideline [2]). This velocity was gained by the back-calculation of rockfalls but is exceeded in areas with very high slopes or cliffs. In such cases, the validity of the executed rockfall tests is not given anymore since such high-speed rockfalls can create puncturing effects on the net structure which is not observed with slower and bigger rocks, even when the energy level is the same.

The same effect can be seen with falling trees where the logs can be quite heavy (comparable to falling rocks) but the impact area is much smaller since the trees tend to slide down the slope and hit the bottom of the barriers with their tip. Another extreme load for rockfall barriers is the impact of snow slides in winter time. This was investigated by Margreth et al. [3] and led to the conclusion that it is possible to design flexible barriers in such a way that they can cope with falling rocks in spring/autumn and snow slides in winter.

As done with the snow slides, the extreme loads high-speed rockfalls and tree falls were tested in full-scale tests without extrapolation and then back-calculated by numerical modelling. It was investigated how to improve flexible rockfall protection systems in such a way that they are able to withstand these extreme loads.

¹ Geobrugg AG Protection Systems, Hofstr. 55, CH-8590 Romanshorn, Switzerland

² WSL Swiss Federal Institute for Forest, Snow and Landscape Research, Zuercherstr. 111, CH-8903 Birmensdorf, Switzerland

FLEXIBLE ROCKFALL BARRIERS SUBJECTED TO HIGH-SPEED ROCKFALLS

In certain cases rockfall protection is required below vertical rock faces [4] (Fig. 1). If these rock faces are high, the possible maximum velocities of falling rocks can become high as well. The problem of the so called bullet-effect becomes evident. The performance of barriers with velocities higher than 25 m/s was not investigated so far. To achieve a similar safety level for barriers impacted with high velocities, full-scale field tests were executed in 1999/2000 in Varen, Switzerland with velocities of more than 40 m/s (Fig. 1).

The following observations were made. High-tensile chain-link mesh stopped 50 kJ at $v=43$ m/s (52 kg at 96 m free fall) without damage. Standard chain-link or hexagonal mesh on top of ring nets got perforated from rocks of 20-30 kg at $v=43$ m/s (96 m free fall). Ring nets need to be covered with high-tensile chain-link in case of $v > \text{approx. } 30\text{-}35$ m/s. The energy absorption capacity of ring nets at $v=43$ m/s is approx. 25% less than with $v=25$ m/s. With this knowledge it is possible to determine under what conditions the ring net has to be reinforced and the secondary netting has to be replaced by high-tensile mesh.

FLEXIBLE ROCKFALL BARRIERS SUBJECTED TO TREE FALL

In steep, afforested terrain, being hit by a sliding tree is a frequently encountered hazard for people and infrastructure (Fig. 2). The tree impact can result from either forest operations, old or instable trees or storms. If trees start sliding and lose their limbs, their trunks can reach relatively high velocities. Very often flexible rockfall protection systems are installed between protective forest and infrastructure in order to protect it from rockfalls or are specifically installed before forest operations. In both cases impacts of trees can occur into flexible protection nets that were originally developed and designed for catching rocks.

For the systematic analysis of the interaction between flexible protection systems and impacting trunks a test series with a 1'000 kJ system was carried out in 2005 (Fig. 2). The tests were made at the WSL-test site in Walenstadt, Switzerland. The trunks were accelerated vertically by free falling into the installed protection system. Three tests were executed with 160 kJ (1'600 kg tree with 14 m/s impact velocity), 320 kJ (1'600 kg with 20 m/s) and 610 kJ (2'000 kg with 24 m/s) resp. There was no maintenance on the system in between the tests (Fig. 2).

At all the tests the tree trunk got caught and stopped by the protection system. The forces in the superstructure are comparable with a rockfall of the same energy level. The ring net has to withstand higher local forces due to the concentrated impact area. However the tree got pressed through the high-tensile ring net without damaging the net. The tests were further used for the validation of the FE-Software FARO that was developed by the Swiss Federal Institute of Technology ETH in Zürich especially for dynamic impacts [1] (Fig. 3). The calculated results show a high correlation with the 1:1 tests.

CONCLUSIONS

It can be concluded that it is possible to design flexible rockfall barriers to meet extreme loads as high-speed rockfalls, falling trees, snow slides or similar hazards based on the systems already approved according to the existing testing guidelines. But it is important to execute according field tests on a realistic level for mass, velocity and impact area and then validate the numerical model in order to design the systems to the specific site conditions. The work presented here allows doing so with high-speed rockfalls of velocities up to 45 m/s and falling trees with energies of up to 600 kJ.

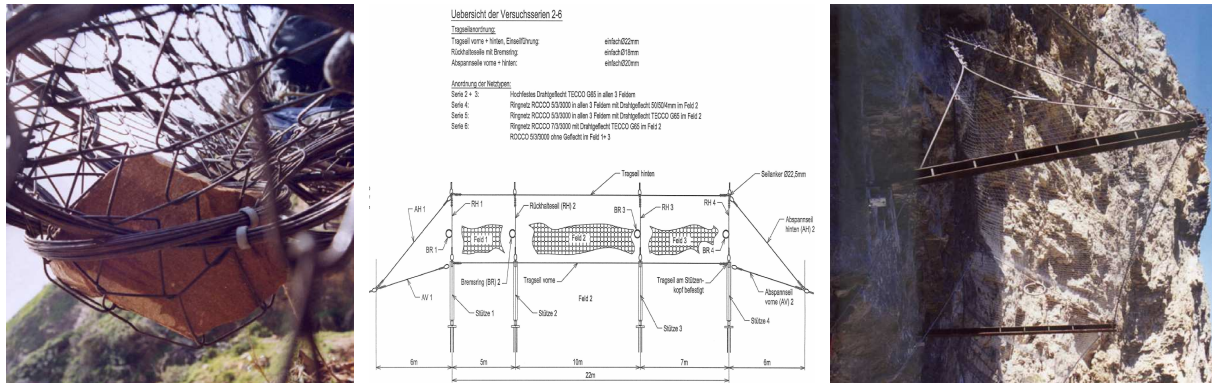


Fig. 1 High-speed rockfalls: Hazard in reality (left, [4]), drawing of the test setup (center) and installed test barrier at Varen (right)

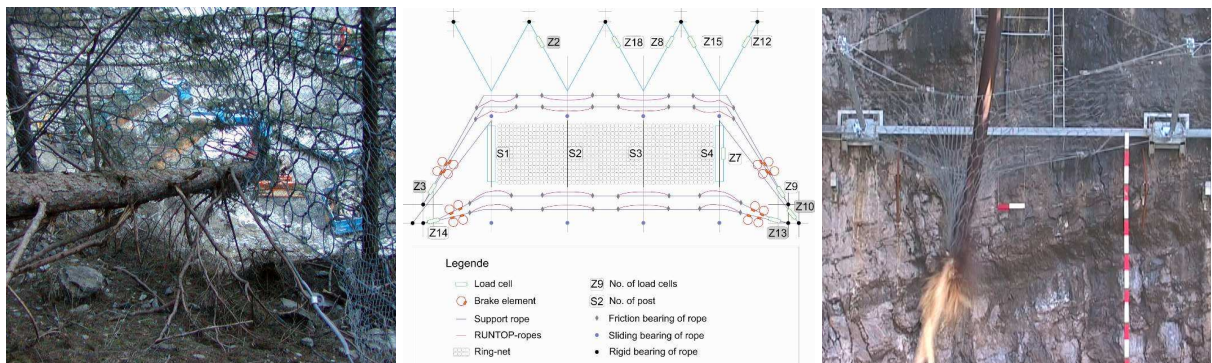


Fig. 2 Tree Fall: Hazard in reality (left), drawing of tested system (center) and impact test in Walenstadt (right)

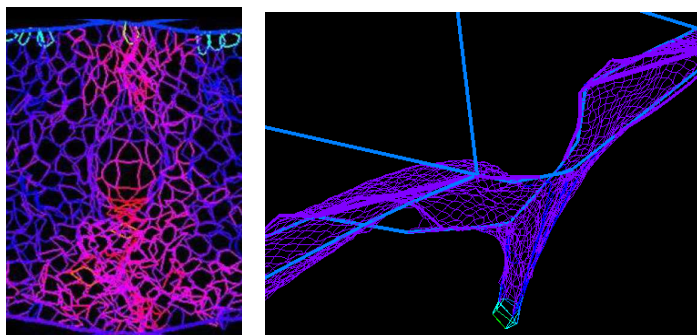


Fig. 3 Numerical modelling with software FARO of a high-speed rockfall (left) and a tree impact (right)

REFERENCES

- [1] Anderheggen E., Volkwein A., Grassl H.: Numerical Simulation of Highly Flexible Rockfall Protection Systems, Fifth World Congress of Computational Mechanics, Vienna, 2002
- [2] Gerber, W.: Guideline for the approval of rockfall protection kits. Swiss Agency for the Environment, Forests and Landscape (SAEFL), Swiss Federal Research Institute WSL, Berne, 2001
- [3] Margreth, S., Roth, A.: Interaction of flexible rockfall barriers with avalanches and snow pressure, Cold regions science and technology, 2007
- [4] Volkwein A., Melis L., Haller B., Pfeifer R.: Protection from Landslides and High Speed Rockfall Events – Reconstruction of Chapman's Peak Drive. Proc. Structures and Extreme Events, IABSE Symposium, Lissabon, 2005