Stronger and lighter – evolution of flexible rockfall protection systems

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Summary

Flexible protection barriers for natural hazards have made big steps forward towards a more effective and more efficient design. These developments can be attributed to an increase in world market competition in addition to new codes and guidelines and an improved knowledge of the performance of such barriers. This contribution presents the history and the latest developments in flexible rockfall protection barrier technology, their benefits and their drawbacks.

Keywords: *Natural hazards; rockfall; protection; flexible barriers; risk.*

1. Introduction

Today's flexible rockfall protection systems normally consist of a steel mesh that is supported by steel cables guided over steel posts (see Fig. 1). The steel mesh catches the falling rocks and transmits the loads to the supporting structure. The posts either have a support fixed to the ground or are kept in position using upslope anchored steel cables. So-called brake elements are integrated into the various steel cables providing a large deformation capacity that extends the flexibility of the barrier. This flexibility extends the braking distance and braking time. This again leads to a peak load reduction in all components and especially in the anchorage to the most expensive part of a barrier. This typical setup is the result of a long-term evolution regarding the capacity of flexible retention systems. In the 1980s, several studies sought the most promising, economical and effective barrier type. From this work a matching combination of the above mentioned components was established in preference to other systems such as cable-supported pendulums consisting of car tires [1].

Fig. 1: A typical rockfall protection barrier "in action"

At that time it was already essential that the different protection barriers can be assigned to different load cases. The impacting rock boulders/blocks and their movements are characterized by the block's mass, its shape, the translation and angular velocity. The highest load concentration is obtained, provided the mass-shape relationship is the most compact one and the kinetics is concentrated only in the translational movements. This means that, e.g., a spherical body with a mass m (density ρ of natural rock) and speed v has been used to characterize rockfall. Combined with just one significant load specification the kinetic energy $E_{kin} = ½\, mv^2$ is normally used. The impulse $I = mv$ would also be possible but is seldom used. Typical rockfall events range from 30 kJ (80 kg or 40cm rock sphere at 100 km/h or 28 m/s) up to 10 MJ (equivalent to 32 tons at 25 m/s).

Figure 2 shows an overview on how to provide protection for different magnitudes of rockfall event. From here, the development of the energy retention capacity of flexible protection systems can also be traced. Early systems were able to retain about 50kJ, whereas today 5000 kJ are state-of-the-art. In the following sections it is explained how this development took place with some background material and the consequences.

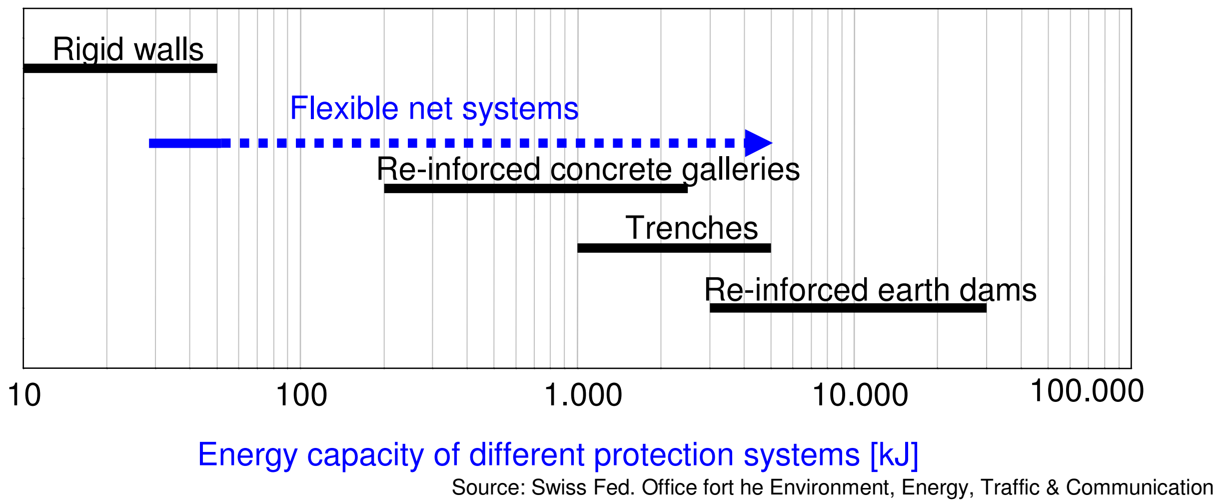

Fig. 2: Protection measures against rockfall with different impact energies and evolution of retention capacity of flexible net systems.

2. Evolution of flexible net systems to protect against rockfall

The need for rockfall protection systems comes, on the one hand, from the rapidly increasing use of Alpine regions. This is due, e.g., to the all-season use of a road, need for higher security level due to increased traffic along a road, further risk reduction, additional buildings in formerly endangered zones, etc. But also a changing geological situation might cause additional protection in formerly safe areas.

On the other hand, the need for protection systems exists not only in the Alps, which have already been made almost completely safe. Much more potential exists worldwide in countries like China, India, Chile, etc. In such countries the size of the areas that have to be protected is often much larger than typically in Europe. Thus there is an enormous market potential for the companies developing and producing flexible barrier systems, which they have developed with much success.

This success encourages producers and clients to develop and to order more versatile and effective systems. Usually, this increased performance involves high-energy retention capacities. Today, impact energies of 5000 kJ can be retained and it is to be expected that a further increase will probably follow within the next years.

Of course, developing markets attract new companies. Just in China already there are about 20 barrier producers. This results in fierce competition forcing the companies to develop highly competitive barriers. This means that the barriers either present a unique selling position such as the above mentioned stronger barriers or they become more efficient, i.e. lighter and cheaper. For example, in 2006 the first 5000 kJ net barrier worldwide needed more than 100 energy absorbing brake elements for a 30 m long barrier. Only 5 years later, the same energy can be retained using only 12 brake elements placed optimally within the barrier.

3. Evaluation of barrier capabilities

3.1 Testing

Due to the complex dynamic behavior of a flexible barrier impacted by a rock block it is essential and the only way to fully prove the functionality of a system by means of full-scale field tests. Different test methods have been established. The boulder is either guided along a cable car installation and impacts a vertically erected barrier more or less horizontally (Fig. 3a). Or the block falls vertically into a horizontal barrier (Fig. 3b).

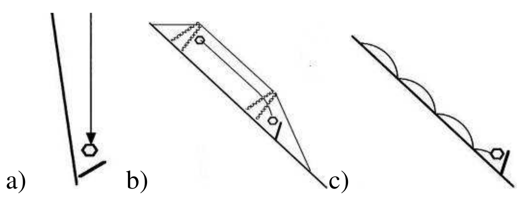

Fig. 3: Testing of rockfall protection systems: a) free fall testing, b) oblique cable guided testing, c) testing with naturally moving blocks

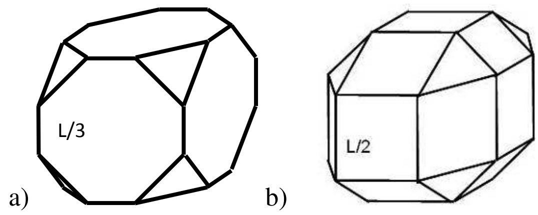

Fig. 4: Standardized test blocks according to a) Swiss and b) European guideline

Testing of naturally moving blocks (rolling, jumping) is not recommended because the repeatability of the tests is not given due to natural variation of the impact kinetics (Fig. 3c). Today's testing is usually carried out using standardized rock blocks (Fig. 4) according to Swiss and European guidelines (see section 4).

Today's measurement capabilities allow an extensive analysis of a barrier after testing that usually lasts only about 0.1sec. Typically, load sensors measure forces in the ropes of up to 400 kN. High speed video recordings with a time resolution of about 250 frames per second film the braking action of the impacting blocks. The back-analysis of the trajectory delivers the braking distance and the impact velocity by derivation of the displacement curve over time. A further derivation of the accelerations is too inexact and should be obtained by additional acceleration measurements. Vice versa, double integration of measured acceleration data will deliver only a very inexact displacement curve.

3.2 Simulation

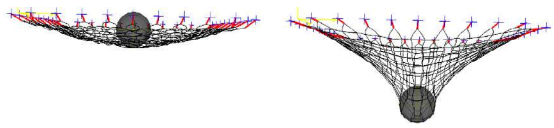

Fig. 5: Numerical simulation of a sphere into a steel net [3].

Flexible rockfall protection systems of course can also be simulated numerically. Due to the highly varying structural system dynamics, the large deformation (braking distance roughly equal to barrier height) and mostly non-linear material properties an explicit time integration using the Finite or Discrete Element methods is recommended [2,3, Fig. 5]. However, it is very important that the simulations are validated and verified by comparison with full scale tests. Then it is possible to use simulations for the following applications: parametric studies to show the effects of structural changes on cable forces, braking distance, remaining barrier height, etc., for either a more efficient development of new barriers or optimization of existing barriers; simulation of special load cases that are not possible in full-scale testing.

4. Standardization

An increasing availability of net systems makes it difficult for the client to choose/select the right product. Due to the differences between the products of different manufacturers their barriers cannot be compared if there is no common standard. Usually, the client of protection barriers for natural hazards is the public financed through taxes. Therefore, it is highly important that the money spent is not wasted and that the chosen barriers fulfill the needs.

The first standard on rockfall protection net barriers worldwide was published in 2001 in Switzerland [4]. Only barriers that fulfill the requirements of this guideline will be subsidized by the government. A list of all barrier types accredited up till now is published in online [5]. The approval of the barriers is given by the Federal Office for the Environment (FOEN); the testing is done by the Federal Research Institute WSL commissioned by FOEN. The standard contains different criteria: it is checked whether the installation/erection of the barrier is according to the systems manual. The barrier, consisting of three fields, must retain small rocks (10 cm + 300 kg) in the outer sections. The central section of a prototype must resist a 50 % and a 100 % rockfall event according to the given energy retention capacity. The impact velocity is 25 m/s, so the mass changes for single vertical free-fall rockfall events. Between the main falling weight tests the barrier can be repaired. The necessary personnel and material expenditures are recorded to estimate maintenance costs throughout the barrier's life-time. The braking distance of the boulder must stay below a given limit depending on the energy class. This should help the planner of a barrier to fit it correctly into the landscape without the danger of a retained block lying on roads or railway tracks. A remaining barrier height after an event is important to retain any additional blocks. The anchorage of the barrier is not part of the guideline. Therefore, the forces in the cables are recorded during testing in order to obtain a load case for designing the anchorage in the form of foundations or drilled anchors.

In 2008, an European standard, the ETAG 027 [6, 7] came into force. It was developed because other countries apart from Switzerland also required officially qualified protection systems. According to the multi-national agreements between EU and Switzerland the European guideline replaces the Swiss guideline.
After a successful certification of a barrier it can be signed with the CE-mark issued by a notified certification body. For that, it has to be tested by a testing body, approved by any official national approval body if the necessary inspection by a notified inspection body is established.
In principle, the contents of ETAG are similar to the previous Swiss guideline in that the barrier must retain a 100 % rockfall event. However, the partial load test consists of two 33 % tests performed without repair works in between needed for the removal of the first 33 % block. The European guideline places higher demands on the identification and testing of the single barrier components, factory production control and is more detailed regarding corrosion protection. On the other hand, it does not consider the testing of small-size rockfall events, the performance of the outer barrier sections or maintenance works. The European standard allows vertical and oblique testing.

Compared to the Swiss guideline developed for just one country a similar guideline for the whole European Union took several years to be prepared. Because many different interests of the individual members have to be taken into account the ETAG 027, more or less, only represents a minimum standard. This means that additional requirements demanded by individual countries have to be formulated in National Application Documents [e.g. 8]. Since 2009, the first barriers are being checked and approved according to ETAG 027. This also reveals some deficiencies in the guideline that are covered by an actual comprehensive document (valid since 2011) issued by the Technical Board responsible for ETAG 027. Its contents will be integrated in the next version of ETAG 027.

A very important advantage of a common standard for different barriers is that now a comparison can be made. Thus, the results of all barriers for a particular energy class can be compared not only regarding investment costs but also for their performance. This considers, among other things, the loads on the anchorage, the braking distance or the remaining barrier height. A comparison also reveals whether a barrier brakes the impacting block more softly and steadily or more abruptly with higher peak loads. However, because most products have some additional benefits, e.g., regarding installation, maintenance, corrosion protection, etc., it will probably never be possible to fully compare different barrier systems. And, in the end, the standards only define one load case. If nature generates a different type of impact an already approved barrier might react in a completely different way, due to normal product variation, to the tested prototype, modification of the barrier geometry due to field topography, etc.

5. Summary and outlook

Compared to other protection systems, flexible protection systems have proved to be lightweight and easy to install and maintain. This reduces the material and installations costs to, e.g., a tenth compared to concrete galleries with the same energy capacity. Therefore and in case a flexible protection system is suitable regarding rockfall energy, rockfall trajectory characteristics and further load cases (e.g. gallery roofs perform better against avalanches in winter) they are usually, or often, a good solution.

The evolution of the net systems today allows for a very precise prediction of the behavior of barriers for a given load case. This now also allows a consideration of additional load cases, such as snow loads [9, 10], debris flows [11] or shallow landslides [12] as illustrated in Figure 6. Therefore, the range of application is extended and effective protection is an alternative, even at short notice, e.g. as a relatively fast solution for endangered slopes after heavy rainfall or earthquakes.

Fig. 6: Further usage of flexible protection measures against snow loads, debris flows or rockfall.

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