Latest developments to increase the quality of flexible rockfall protection barriers

Armin Roduner
Geobrugg, Romanshorn, Switzerland

Helene Lanter
Geobrugg, Romanshorn, Switzerland

Manuel Eicher
Geobrugg, Romanshorn, Switzerland

ABSTRACT: To ensure that flexible rockfall barriers are able to effectively stop the dynamic impact of rockfall, several guidelines have been introduced worldwide since 2001. However, long-term experience shows that other, “natural”, load cases happen which are not covered by guidelines or certification tests. Proposed substitute scenarios, for these natural load cases, are now treated by means of 1:1 field tests to increase the quality of rockfall protection systems and to offer more safety through additional test procedures. At the same time, the more stringent requirements are intended to meet all the guidelines and practical instructions applicable in Europe. In this paper, the different guidelines are discussed, the load case scenarios and their requirements are described in detail and the adaptations to the rockfall protection systems are presented.

Keywords: Rockfall, 1:1 field tests, Flexible protection barrier, Multiple Loading.

1 ROCKFALL CERTIFICATION PROCEDURES AND GUIDELINES WORLDWIDE

To ensure that flexible rockfall barriers can effectively stop the dynamic impact of rockfall, several guidelines have been introduced worldwide since 2001. They include proof of functional suitability through 1:1 field tests, as well as proof of serviceability. In 2001, the first guideline was published in Switzerland (Gerber 2001), followed in 2008, by a European approval and conformity verification procedure for rockfall protection nets, called ETAG 027 (EOTA 2008). In 2018, ETAG 027 was transformed into a European Assessment Document EAD 340059-00-0106 (EOTA 2018). The EAD specifies standardised and reproducible load cases and is the most commonly used guideline worldwide by designers (Peila & Ronco 2009, Volkwein et al. 2019, MBIE 2016, TRB 2016).

However, long-term experience shows that other, natural, load cases happen which are not covered by the "laboratory-like" tests prescribed in the EAD. The EAD lacks any statements on practical applications in the field. Additionally, the energy uptake of rockfall barriers has developed exponentially. In 1980, energies ranged around 200kJ with low velocities (10 $m.s^{-1}$) (Baumann & Gerber 2018). Today, flexible barriers are cost-efficient solutions against rockfalls with broad protection capabilities ranging from 50 kJ to 11’000 kJ (EOTA 2023) and certification velocities of a minimum 25 m.s^{-1} (EOTA 2018). Therefore, some countries have additional requirements that add to the European standards.

Here, the Swiss, European, Austrian, French, Italian and New Zealand guidelines are roughly summarised. More details are found in (Caviezel et al. 2022). Some examples of protection kit failures will then follow highlighting the missing practical field applications of the guidelines. The methodology of further field testing and “laboratory” testing is then described to assess further realistic load case scenarios. The following scenarios are then treated by means of 1:1 tests to increase the quality of rockfall protection systems and to offer more safety through additional test procedures.

1.1 European Certification Guideline

Following the Swiss guideline, in 2008, the ETAG 027 (EOTA 2008) was the first testing standard that made it possible to compare different rockfall barriers based on their energy level in European countries. The test procedure is based on tests at two different energy levels: Service Energy Level (SEL) and Maximum Energy Level (MEL) (EOTA 2018). The SEL test consists of two consecutive impacts with a third of the maximum energy level without maintenance to the kit. The SEL Launch 1 is passed if there are no ruptures to any kit components. SEL 2 is passed if the block is stopped by the kit and the block has not touched the ground until the kit has reached maximum elongation during the test. The MEL launch is passed if the block is retained by the kit. A detailed description of damages after a MEL impact has to be provided and included in the ETA. The impact location is set for all three launches in the middle of the central functional module (See Figure 1), representing the most favourable impact location for the barrier.

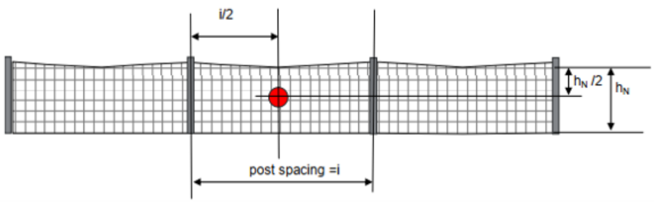


Figure 1. Impact Location of the SEL and MEL Launches during certification tests (EOTA 2018).

1.2 Additional guidelines superseding European Certification

The above-mentioned guidelines are presented shortly here, a more extensive summary can be found in Caviezel et al. (2022). Broadly speaking, they act as a complement to the European Certification to address the limitations of said certification (symmetrically force distribution, no consideration of block shape, block rotation etc…) and cover aspects such as foundations, anchor loads etc that are not mentioned in the EAD.

In Switzerland the uncertainties when testing barriers are accounted for by introducing a safety factor: The forces measured in the approval include not only the more stringent conditions of the vertical drop but also the compensating effects of the central position in which the test bodies impact the net. Eccentric strains nearer the posts or nearer the bearing ropes will subject individual ropes to additional forces which are not yet known.

In Austria, ONR 24810 was published in 2013 and amended in 2021. Partial safety factors are introduced, to mitigate the favourable centric impacts in the middle field during the approval tests, and the optimal symmetrical distribution of forces at the anchors. Higher forces at the anchorage points are also expected here for decentralised impacts.

In France, the CEREMA published the "National Regulation for Flexible Rockfall Barriers” (Bost, 2014) which complements the EAD in the following: Focus on work and not on the product: the product must adapt to the location and not the other way around.

In the case of Italy, project recommendations are added that are detailed in UNI 11211 (2018), which are not directly related to the requirements of the rockfall protection kit, it only proposes the use of SEL instead of MEL as design criteria. Concerning the safety factors, the standard approach follows the basic rules of Eurocodes, amplifying the actions and reducing the reactions.

The New Zealand guideline discusses both approaches of the UNI and ONR with the use of partial safety factors, mainly for the design approaches, and applying a reduction factor on the barrier energy rating (MBIE 2016).

2 NEW ROCKFALL TESTING IN THE FIELD AND IN THE "LAB"

2.1 Failures in the field over the years

Many examples can be found in Caviezel et al. & Mastrojannis (2022, 2022) where certified barriers failed to stop the rock. The main problems relate to force concentration in the posthead area due to eccentric impacts, impacts in the lateral, untested, fields as well direct damages to posts and base plates. The impact source also differs from the standardized test scenario with differently shaped rocks and rock's rotational component.

Bichler & Stelzer (2022) reviewed the performance of a 1000 kJ rockfall barrier over approximately ten years. This example showcases nicely what a barrier must go through during its service life and how far these scenarios are from the standardized certification impacts.

2.2 Research in the field

The current state of research in Europe is well summarised in Caviezel et al. (2022). In short, the work of Heiss (2017) shows that analytical calculation or numerical simulation are not a suitable alternative to 1:1 field testing, mainly because of the complexity of the dynamic processes. According to his research results, asymmetrical hits are absolutely necessary for the evaluation of protective systems. The national research project C2ROP was launched in France in 2016 in which the behaviour of rockfall barriers under natural load cases is also investigated more closely, with 1:1 field tests with lateral impacts as well as multiple loading scenarios.

In 2019 a research project was started, funded by Innosuisse, led by the Snow and Avalanche Research Institute (SLF) of the Federal Forest and Landscape Research Institute (WSL), with a flexible rockfall protection fence manufacturer, Geobrugg, as the industry partner. The aim was to investigate random natural load cases hits into a fully instrumented barrier (see Figure 3) and propose some additional testing scenarios for the standardised testing facility, Walenstadt, in Switzerland. The random hits were meant to show the most important force concentrations in the barrier and the tests led in Walenstadt, allowed to get as close as possible to the same peak loadings while ensuring repeatability. A summary of the testing campaigns is found in Sanchez et al (2019) as well as in Caviezel et al. (2022).

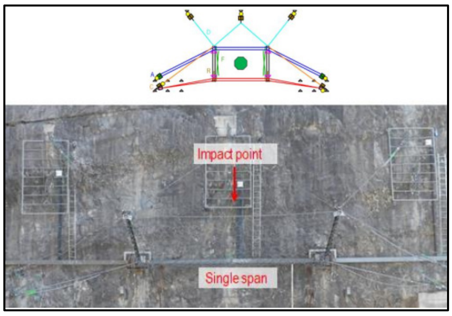
Figure 2. Left: A test block, released by helicopter bounces, rolls and slides down the slope. Right: Fully instrumented flexible rockfall protection barrier experiencing a random rock impact.

2.3 Translation to tests in the "lab"

The test facility "Lochezen" in Walenstadt, Switzerland began operating in 2001. The test site was to certify net barrier systems, as well as conduct research on the mechanical behaviour of barrier components (nets, brake elements, ropes). Over the last two decades, several hundred tests of rockfall barriers have been carried out at this facility, and systems from various manufacturers have been tested and certified. The barriers are installed at a height of 15 m on an almost vertical block face. Normally three fields are installed with 10 m post spacing. Using a derrick crane, the test blocks can be positioned above the barrier and dropped. Sensors capture forces in the barrier components, primarily ropes; high-speed video recordings are used to capture the deformations of the barrier system over time.

3 RESULTS

One of the findings from the full-scale experiments is that it is possible to structure the additional tests for approval in a similar way to what authorities have been demanding since the 1990s. These tests can be carried out in addition to the tests required by the EAD in order to give design engineers and the ultimate owners of the rockfall barriers more certainty about the capacity of the entire protective surface. The proposed additional tests in Caviezel et al. (2022) are on one hand an impact in a single field of a barrier, instead of a three-field system which is equivalent to a border field impact. On the other hand, an eccentric impact is proposed in the middle field of a three-field system, as this impact translates best to the random impacts in the net as well as the rotation of the blocks. These proposed scenarios were taken over by Geobrugg, additionally to the CE certification, and implemented during the development of a new rockfall barrier line (see Figure 4, TSUS Report 2021a). Further tests were deemed of interest to push knowledge further in terms of the uptake capacity of a barrier as well as the proof of constructional adaptations in the field. These test results are described in further detail in the following subsections.



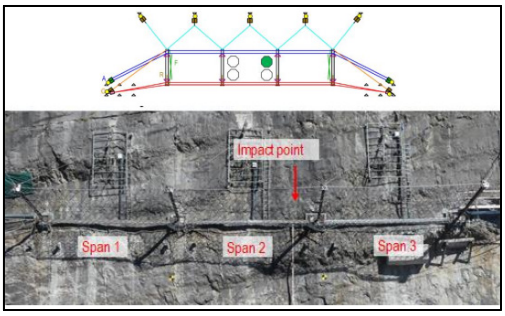


Figure 3. Left: Single span impact at Maximum Energy Level, corresponding to a border field impact. Right: Eccentric impact at Maximum Energy Level, in the top corner, near the post head of the middle field of a three-field system. Example of a 1'000 kJ rockfall barrier (TSUS, 2021a).

3.1 Support Rope Separation

Depending on the site where a barrier is installed, constructional adaptations need to be made to ensure the full functionality of the barrier. When a barrier exceeds a certain length, a separation of the support ropes of the barrier is necessary, to ensure that the forces acting upon the barrier arrive at a timely interval to the anchors on either side, so that the energy-dissipating elements can be activated. In Switzerland, it is customary to do so after a length of 60m. But this setup has never been tested before. A support rope separation was successfully tested in 2021, during the development of the new barrier line, by means of two consecutive maximum energy level tests on either side of the support rope separation (see Figure 5, TSUS 2021b).

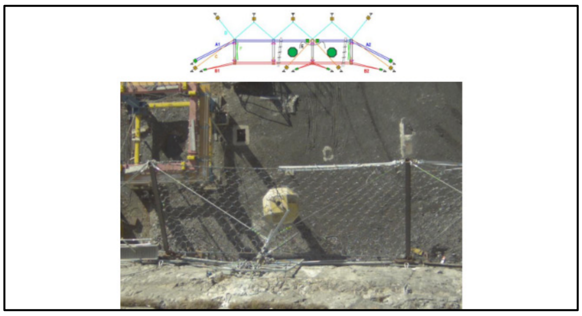


Figure 4. Support Rope Separation Test on a 2’000 kJ rockfall barrier (TSUS, 2021b). The bottom support ropes are led to two anchors on the ground top while the top support ropes are separated and connected at the post head instead of being also led to anchors in the ground. This ensures that no support rope gets hit during an impact.

3.2 Multiple Impacts

Finally, an always-arising interrogation lay in the question of how much rest capacity a barrier has when dimensioned in order to receive Service Energy Level impacts (SEL). Therefore, after certifying a 3’000 kJ barrier with a MEL and two consecutive SEL hits, further SEL hits where launched in various locations, trying to replicate impacts observed in the field over the years as well as during the research project with the SLF. It was decided, after the two SELs in the middle field, to impact twice a lateral field, then a post and a final impact in the middle field again (see Figure 6). The barrier successfully managed to retain all six SELs load cases (TSUS, 2021c).

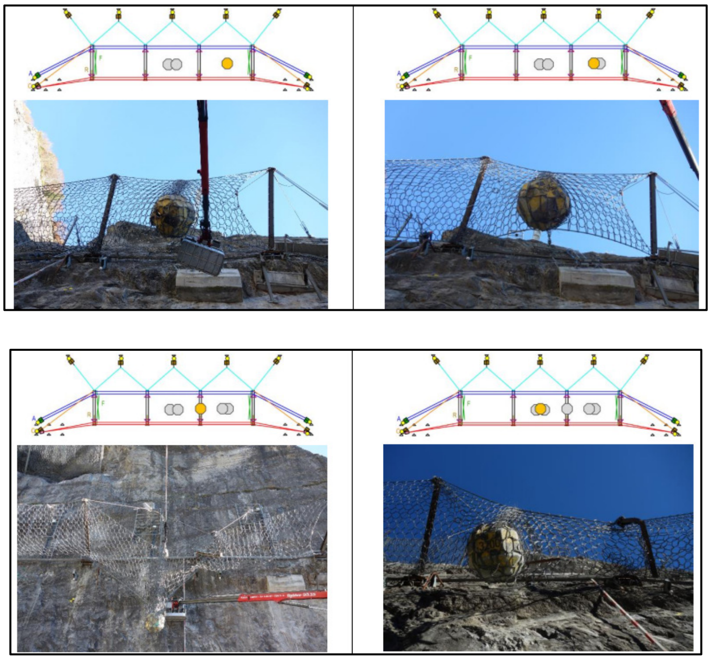


Figure 5. Succession of several SEL impacts in the same barrier without repairs between tests (TSUS, 2021c).

4 CONCLUSION

Over the last 15 years, falling block protection kits have become established as an efficient protective measure, and the solution is recognized worldwide. The energy absorption capacity has increased by a factor of 6 from a maximum of 1’500 kJ to 11’000 kJ. The higher performance of the systems, the new markets and the worldwide established EAD test (EOTA 2018) has created a competition that exists in many markets. This has had a positive effect on the cost-benefit ratio for the available systems in the market. Flexible barriers have evolved from being a specialized solution for specific/narrow energy level locations to cost-efficient systems widely used. But the described testing avoids real conditions and thus, the performance issues lead to failures. Therefore, it is difficult for the planner to determine the most cost-optimized solution for an adequate protection measure. The research project on rockfall barrier service loads by the SLF-WSL and even further testing can answer some of these questions.

ACKNOWLEDGEMENTS

We like to thank the SLF-WSL Institute for Snow and Avalanche Research as well as Innosuisse for the collaboration on the research project Innonet researching on rockfall barrier service loads for rock impacts with spin.

REFERENCES

Austrian Standards International. ONR 24810 - Technischer Steinschlagschutz. Ausgabe 2021-05-01.

Baumann, R. and Gerber, W. 2018. Grundlagen zur Qualitätsbeurteilung von Steinschlagschutznetzen und deren Fundation. Anleitung für die Praxis. Tech. rep. Federal Office for the Environment (FOEN).

Bichler A., Stelzer G., 2022. Long term performance of a rockfall fence. Proceedings of RocExs, 2022, Japan.

Bost M., 2014. Écrans de filet pare-bloc dynamiques : Recommendations pour leurs spécifications. Jan. 2014.

Caviezel A., Munch J., Bartelt P., Lanter, A. 2022. Rockfall Barrier Service Loads for Rock Impacts with Spin. Theory and Experiments. WSL Ber. 125.81 p.

EOTA 2008. ETAG 027 Guideline for European Technical Approval of Falling Rock Protection Kits. Tech. rep. Belgium: EOTA.

EOTA 2018. EAD-340059-00-0106-2018 Falling Rock Protection Kits. En. Tech. rep. Belgium: EOTA.

EOTA, ETA Database 2023. https://www.eota.eu/etassessments, (accessed 10.02.2023).

Gerber, W. 2001. Richtlinie über die Typenprüfung von Schutznetzen gegen Steinschlag. Tech. Rep. Swiss Agency for the Environment, Forests and Landscape (SAEFL), Swiss Federal Research Institute WSL.

Heiss, C., 2017. Überlegungen zur Sicherung von Personen und Infrastrukturbauwerken gegen Steinschlag im alpinen Bereichen unter besonderer Berücksichtigung von flexiblen Steinschlagschutzsystemen. PhD thesis, Montanuniversität Leoben, Austria.

Mastrojannis, E., 2022. Occurrences, causes and probability of rockfall protection fences failures in D-A-CH region and suggestions for optimizing rockfall protection fences test procedures based on analysis of fall body impact positions. MSc Thesis Technical University of Munich (TUM), unpublished.

Ministry of Business, Innovation and Employment (MBIE) 2016. Rockfall: Design considerations for passive protection structures. en-NZ. Guidance. Wellington, New Zealand.

Peila, D. and Ronco, C. 2009. Design of rockfall net fences and the new ETAG 027 European Guideline. Technical Note in Natural Hazards and Earth System Science vol.9, no.4, pp. 1291-1298.

Sanchez, M., Caviezel, A., 2019. Full-scale testing of Rockfall Nets in Real Terrain. WSL Report, en. issue, Birmensdorf.

Transportation Research Board (TRB). 2016. Guidelines for Certification and Management of Flexible Rockfall Protection Systems. Ed. By Ben Arndt et al., Washington DC: The National Academies Press.

TSUS, 2021a.Technical report No. 70210080/01: Summary of evaluation and assessment of eccentric and single span impact tests on ROCCO-1000. Building testing and research institute, Slovak Republic.

TSUS, 2021b.Technical report No.70210080/04: Summary of evaluation and assessment of eccentric and single field maximum energy impact tests and subsequent service energy impact tests on ROCCO-3000.

TSUS, 2021c. Technical report No.70210080/02: Summary of evaluation and assessment of eccentric, single span and support rope separation impact tests on ROCCO-2000.

UNI 11211-4, U. Opere Di Difesa Dalla Cadutta Massi – Parte 4: Progetto Ed Esecutivo. 2018.

Volkwein A., Gerber, W., Klette, J., Spescha, G., 2019. Review of Approval of Flexible Rockfall Protection Systems According to ETAG 027. Technical Note, Geosciences 2019, 9, 49.