ONR 24810 – A Comprehensive Guideline for Rockfall Protection Works: Its Application to Catchment Fences

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ABSTRACT
ETAG 027, the guidelines governing the certification of rockfall catchment fences, has been in place since 2008 across Europe, where the majority of the system producers are situated. It only focuses on two topics – the standardized approval procedure and the assurance of quality by the certification of the factory production control.

A new guideline is now available in Austria that focuses on the site investigation, design, construction and maintenance of rockfall catchment fences, as well as other forms of rockfall mitigation. This document is the "ONR 24810, Technical protection against rockfall Terms and definitions, effects of actions, design, monitoring and maintenance" and is described herein.

RÉSUMÉ
ETAG 027, la directive concernant la certification des systèmes anti-éboulis est établie depuis 2008 en tout l'Europe, où la majorité de producteurs est située. Cette directive traite les deux thèmes: la méthode standardisée de l'agrément et la sécurité de la qualité par la certification du système de contrôle de la production en usine.

En Autriche, maintenant une nouvelle directive est disponible, qui contient l'enquête en site, le calcul de structures, la construction et la maintenance des systèmes anti-éboulis, mais bien sûr aussi les autres mesures de protection contre les chutes de pierre. Ce document s'appelle "ONR 24810, Protection technique contre les chutes de pierre – termes et définitions, effets, calcul de structures, surveillance et maintenance » et il est décrit en ceci.

1 INTRODUCTION

Flexible net rockfall catchment fences have a long history of use in Europe. In several countries, companies were founded that specialized in the commercial production of such systems for which eventually testing or certification became necessary. As their popularity grew in Europe and producer's entered foreign markets, a European-wide standard for testing and certification was implemented: the ETAG 27 Guideline for European Technical Approval of Falling Rock Protection Kits in 2008 (EOTA 2008). Since similar national standards were not in existence in North America, the ETAG 27 guidelines have also become increasingly cited for projects that use rockfall catchment fences both in Canada and the USA.

But the ETAG 27 document is only focused on the material aspects of the systems and does not offer guidelines for their implementation. With regards to Austria, a similar gap in standardized knowledge was observed in other forms of rockfall mitigation and so in an attempt to close this gap, the Austrian Standard Institute (akin to ASTM or CSA) formed a working group to publish guidelines that focus on the site investigation, design, construction and maintenance of rockfall mitigation measures such as stabilisation with anchoring and mesh/nets, embankments, galleries and rockfall catchment fences. The resulting document is entitled "ONR 24810, Technical protection against rockfall – Terms and definitions, effects of actions, design, monitoring and maintenance" (Austrian Standards Institute 2013).

For reasons of space limitation, only a superficial summary of the sections concerning rockfall catchment fences are presented herein. Unfortunately, the ONR 24810 is currently only available in German and so the following discussion is an interpretation of the document whereby one of the author's was involved in writing the original document. A somewhat more in depth summary can be found in Stelzer and Bichler (in press).

1.1 Consequence Classes

One of the primary functions of the ONR 24810 is to provide a framework for determining the level of safety incorporated into different aspects of design for a project. The level of safety is based on consequence classes set by the European Norm EN 1990:2003 "Eurocode: Basis for structural design" (CEN 2005). There are three levels of consequence classes that consider the outcome after failure of a system or system component with regards to loss of life, economic, social or environmental impacts. The three levels are:

- CC3: consequence for the loss of human life is high or where economic, social or environmental consequences are very great

- CC2: consequence for the loss of human life is medium or where economic, social or environmental consequences are considerable
- CC1: consequence for the loss of human life is low or where economic, social or environmental consequences are small or negligible

As will be shown below, the selection of the consequence class affects the magnitude of the factor of safety applied or the geometric or model parameters to ensure sufficient reserve is built into the mitigation measures with respect to the system's loading and resistance performance. Some of the relevant parameters are given in Table 1.

	Consequence Class		
Symbol	**CC1**	**CC2**	**CC3**
$\gamma_{E,kin}$	1.00	1.05	1.15
$\gamma_{T,R}$	1.00	1.05	1.15
α_1	1.05	1.10	1.30
α_2	1.00	1.05	1.10

Table 1. Parameters defined by consequence class.

2 SITE INVESTIGATION

State-of-the-art site investigations techniques are assumed and required to take place for any mitigation project and comprises of both a desk investigation and a field investigation. The necessary base line information is collected so that modeling techniques can be used to determine such important characteristics as block size distribution, event frequency distribution and bounce height distribution.

3 SEMI-PROBABILISTIC DESIGN PARAMETERS

Following the collection of the required data during the site investigation, the semi-probabilistic design parameters can be determined, in particular the design block, the anticipated energy of the impact and the design bounce height.

3.1 Design Block Selection

There are two accepted methods by which the design block is determined. The first is the simplified approach whereby an expert can define the block based on their experience and data collected during the site investigation. This method is only applicable if at least one of the following criteria is met:

- Less than 100 blocks present in the deposition zone
- Less than 100 jointed rock bodies present in the initiation zone
- Consequence class defined as CC1
- Event frequency is less than one event per year

If none of the above conditions apply, then a standard approach is taken where the design block is selected as the 97th fractile of the block size distribution for sites having an event frequency between 1 and 10 events per year and the 98th fractile for sites with an event frequency greater or equal to 10 events per year.

3.2 Modelling of Energy and Bounce Height

State-of-the-art modelling techniques are assumed for the analysis of the energy and bounce height distributions (using the selected design block), with focus on the position of the desired rockfall catchment fence. It is important that any results are verified with the site data to determine the realism of the model. The resulting distributions are then used for the verification of the requirements of the catchment fence as discussed in the following sections.

4 VERIFICATION OF DESIGN PARAMETERS

To verify the specifications of a rockfall catchment fence with regards to its suitability of use, the design values for the energy and bounce height of the design event are compared to the resistance specifications of the structure. If the design values are less than or equal to the resistance specifications, then the system is verified (i.e. $E_d \leq R_d$). In addition, special performance criteria are also often implemented.

4.1 Verification of Energy Capacity

By comparing the design impact energy ($T_{E,d}$) with the resistance capacity of the structure ($T_{R,d}$), the required energy capacity of the structure can be verified. Furthermore, the design impact energy is equal to the 99th fractile of the energy distribution obtained ($T_{E,k}$) multiplied with a partial factor of safety ($\gamma_{E,kin}$ as per Table 1) as shown in Equation 1.

$$T_{E,d} = T_{E,k} \cdot \gamma_{E,kin} \qquad [1]$$

Equation 2 is the calculation of the resistance capacity for the structure and is defined by the MEL energy for a system according to ETAG 27 ($T_{k,\ MEL}$) divided by a reduction factor ($\gamma_{T,R}$ as per Table 1). The reduction factor is dependent on the consequence class.

$$T_{R,d} = T_{k,MEL} / \gamma_{T,R} \qquad [2]$$

The final verification that a particular system is suitable for use is made if the design impact energy is less than or equal to the resistance capacity (Equation 3). If Equation 3 is not valid, then a higher capacity system must be considered.

$$T_{E,d} \leq T_{R,d} \qquad [3]$$

4.2 Verification of Bounce Height

By comparing the design bounce height ($h_{E,d}$) with the resistance height of the structure ($h_{R,d}$), the required height of the system can be verified. To this end, the design bounce height is defined as the as the 95th fractile of the bounce height distribution ($h_{E,k}$), taken at the upper surface of the block (i.e. a half block height must be added), for the location of interest multiplied with a geometric coefficient (α_1) as shown in Equation 4. The geometric coefficient is dependent on the consequence class found in Table 1.

$$h_{E,d} = h_{E,k} \cdot \alpha_I \qquad [4]$$

As an intermediate step, the design bounce height can be compared to the nominal heights of available system on the market as identified by the energy calculations. Available nominal heights are governed by ETAG 27 and are based on the height of the system as tested, whereby:

1. system cannot be manufactured below the tested height
2. system height can only be increased by 0.5 m if tested with a nominal height below 4 m
3. system height can only be increased by 1.0 m if tested with a nominal height greater or equal to 4 m.

Subsequently, the resistance height of the system can be calculated, where the allowable nominal height of the system according to ETAG 27 ($h_{R,k}$) is reduced by a reduction coefficient (α_2) according to the consequence class as given in Table 1 (Equation 5).

$$h_{R,d} = h_{R,k} / \alpha_2 \qquad [5]$$

Finally, the acceptance of a system with regards to suitability of height is made when the design bounce height is less than or equal to the resistance height as per Equation 6.

$$h_{E,d} \leq h_{R,d} \qquad [6]$$

4.3 Performance Criteria

The verifications in sections 4.1 and 4.2 allow the user to define and select a system according to inputs of expected energy and height of an MEL impact but do not consider the effects of an event on the system. In this regards, additional performance criteria can be applied that are also based on information collected during system certification and MEL testing but not evaluated or classified under the ETAG 27 guideline.

One important evaluation is whether or not gaps open near post locations. Such gaps commonly occur since the ability of the net to deform in this area is limited. Many systems using stiff nets require additional components that fail or tear-away during an impact, thus allowing the net to separate from the bearing ropes and/or posts, in order that the primary net does not rupture.

Not only is this an indication of the deformability of the primary net but it also points out areas were projectiles may potentially pass through the system relatively unimpeded. To help classify this, the allowable opening and attachment method is defined according to the consequence class as shown in Table 2. As an example, for a site having a consequence class rating of CC3, no pre-determined failure or tear-away components are allowed to be used for attaching the nets to the bearing ropes and the opening must not be greater or equal to 0.2 m after an MEL impact. If such an opening exists during testing, then the system is disallowed due to safety concerns.

	Unacceptable damages during an MEL test
CC3	- No opening of nets greater than or equal to **0.2 m** below the residual height, between the lower bearing rope and net. - No openings between the end posts and the net greater than or equal to 10% of the nominal height if the end fields are located within the hazardous area - No rupture of the main nets, bearing ropes or retaining ropes **or the strands**. Single wires are allowed to break (as long as it is not through the entire strand). - A rupture of the sewing rope or component used to attach the primary net to the bearing ropes is **not allowed**.
CC2	- No opening of nets greater than or equal to **0.4 m** below the residual height, between the lower bearing rope and net. - No openings between the end posts and the net greater than or equal to 10% * of the nominal height if the end fields are located within the hazardous area - No rupture of the main nets, bearing ropes or retaining ropes. - A rupture of the sewing rope or component used to attach the primary net to the bearing ropes is allowed if a new load bearing net border as non-positive connection to the bearing rope has developed
CC1	- No additional requirements. ETAG 27 certification sufficient.

Table 2. Optional requirements for rockfall catchment fences

Also detailed in Table 2 are other performance criteria such as which components are allowed to fail/rupture. Again taking CC3 as an example, no rupture or failure of the primary nets, bearing ropes or retaining ropes or of any strand of these ropes is allowed during an MEL test.

The information for such performance criteria must be documented during certification but experience has shown that it may not be readily distributed by manufacturers. Manufacturers should provide unaltered copies of the original documentation from the certification process to support claims.

5 VERIFICATION OF ANCHOR AND FOUNDATION DESIGN

The topic of anchor and foundation design is less clear than the design of the superstructure and is highly reliant on the experience of the project engineer and local regulations. Herein, only a few comments are made. A somewhat more detailed discussion can be found in Stelzer and Bichler (in press) or, of course, in the original ONR 24810 document. Like the verifications elsewhere herein, the verification of the anchors should be carried out from both an effect and resistance side.

In determining the design force (E_d) for an anchor on the effect side, the maximum force monitored during an ETAG 27 MEL test (E_k) is used. If multiple ropes are connected to a single anchor, then the maximum forces from each rope are added in a **scalar way and not vectorially**. Applied to this force is a partial factor of safety (γ_E) equal to 1.5 (Equation 7).

$$E_{E,d} = E_{E,k} \cdot \gamma_E \qquad [7]$$

The method by which multiple forces are added is important since if they are summed vectorially (which yields a smaller characteristic force), a pre-defined geometry of anchors and post locations must be observed during construction. This is most often impractical, unrealistic and normally inefficient with regards to costs and may lead to a dangerous situation. As such, manufacturers should clearly indicate how the forces are summed based on the MEL tests during certification.

From the resistance side, the verification of the steel cross section of the reinforcing element of the anchor as well as the surface between anchor grout body and the underground are to be verified. State-of-the-art techniques and local regulations should be observed.

6 CONSTRUCTIVE RULES

A number of constructive rules are also defined in the ONR 24810 that are based on expert opinion and a long history of field experience. Four examples of such rules are:

- *Distance between catchment fence and object of protection:* To ensure that the elements at risk are sufficiently far from the rockfall catchment fence, a factor of safety of 1.2 is applied to the maximum elongation distance as reported for the MEL test in the ETAG 27 documentation but where a minimum of the maximum elongation plus 1 m is observed.
- *Post spacing:* It is not recommended to deviate from the approved tested post spacing for a system by more than ±2 m.
- *Row length without internal anchor:* The length of a catchment fence without internal anchoring (i.e. leading the forces of the bearing ropes into the ground) shall not be more than 60 m.
- *End field placement:* Since end fields are not tested for impacts, the last module should extend beyond the primary hazardous area. If the system has a tendency for the net to pull away from end post ≥10% of the residual height, then this is absolutely necessary.

Other rules concern with such things as the termination of a fence into a rock wall or how gaps beneath a fence due to undulating topography are to be filled.

7 MAINTENANCE AND INSPECTION

The ONR 24810 also recognises the importance of establishing long-term responsible ownership of mitigation measures and so addresses maintenance and inspection procedures for structures.

Following its installation, detailed documentation is kept so that an evaluation of a future state of the structure can be made. In the same fashion, all future inspections are documented so that the history of performance and required maintenance can be assessed.

Four inspection protocols are outlined and summarized below:

- *LU-protocol:* The on-going inspection is a yearly inspection that is carried out by experts or trained personnel. It includes checking brake functionality, elongation and residual capacity, net deformation and damage, damages to ropes, verification of nominal height, evaluation of debris in the system, etc.
- *K-protocol:* The control inspection is undertaken only by an expert and is carried out on a schedule determined by the consequence class: every 10, 7 or 5 years according to a consequence class of low, medium and high, respectively. This protocol includes the LU-protocol but also evaluates possible corrosion of components such as brake elements, nets, ropes, posts and base plates, or any connecting elements. An evaluation of the foundation is also required where corrosion and deformation of micropiles is evaluated and the state of erosion surrounding them along with the general condition of concrete foundations (e.g. evidence of cracking, spalling, flaking, corrosion of reinforcement elements if visible, etc.). Finally, a general evaluation of the state of the system in comparison to the most recent inspection report is made.
- *SK-protocol:* The post-event inspection is carried out by an expert and is in response to an event. It is independent from scheduled inspections and is used to determine the status of the system. It can result in the request for a test inspection.

- *P-protocol:* The test inspection is carried out by an expert or possibly and inter-disciplinary expert team. It is carried out on an as-needed basis when the status of a system or system component is identified in a previous inspection as being unclear and which deems further, more detailed inspections necessary. The nature of the test inspection will depend on the component(s) being inspected and may include more intrusive/involved test procedures to help determine the overall safety or state of the system (e.g. anchor pull tests).

8 SUMMARY

The ONR 24810 is a comprehensive document that covers the site investigation, design, implementation and maintenance of various rockfall mitigation measures. It is a valuable tool for planning mitigation of rockfall hazards in a standardized and safe manner that is simple and effective. Specifically for rockfall catchment fences, it builds on accepted certification procedures to help fill the gap between material approvals and implementation. Though it was written for Austria, its value is wide reaching and could serve as a framework of similar guidelines in other countries.

ACKNOWLEDGEMENTS

The authors would like to thank all of the members of the ONR 24810 working group that contributed to this valuable document.

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