# Special solutions in hazard mitigation

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ABSTRACT
Certification and guidelines are necessary and valuable tools for increasing the general quality and safety of natural hazard mitigation products and are a sign that the industry has somewhat matured. But sometimes, care must be taken that standardisation does not come at the expense of an efficient and comprehensive solution. Discussed herein are some examples where adapting a standard solution has led to a better, safer solution.

RÉSUMÉ
Des certifications et des directives sont des instruments importants et nécessaires pour améliorer la qualité et la sécurité des produits contre les risques naturels. D'ailleurs ils sont aussi une indication de la maturation de cette partie de l'industrie. Mais parfois on doit faire attention, que la standardisation ne prévienne pas de solution efficiente et complète. Ici quelques exemples seront discutés, où l'adaptation d'un produit standard a mené à une solution meilleure et plus sûre.

## 1 INTRODUCTION

During the past 50 years, flexible net structures have been used for mitigating many types of natural hazards. Some of these products, e.g. rockfall catchment fences, fall under national guidelines or certification regarding their design, testing and manufacturing (e.g. Gerber 2001, Mölk 2005) and are controlled by the responsible agencies. Since the major producers of rockfall catchment fences are distributed in several European nations, which have their own guidelines, and because these producers sell to markets outside of their homelands, the European Union adopted a standardized testing and certification protocol in 2008 ("ETAG 27: Guidline for European technical approval of falling rock protection kits", EOTA 2008). Other structures such as avalanche and debris flow systems are designed according to suggested guidelines (e.g. Margreth 2007, Kwan 2012, ASI 2011, ASI 2013a) or state-of-the-art practices and in some cases may not have a clear authority or the necessary resources to properly evaluate their design and implementation.

Though the details of the existing guidelines are slightly different from document to document, the overall theme is the same: to ensure a minimum level of testing, material documentation and demonstration of fitness for use. The desired result is to make certain the product that the end client receives will function in a predictable manner and at a level harmonious with the manufacturer's claims. But in contrast to this, blind enforcement of standardized/certified systems can result in the loss of functionality and lead to the implementation of mitigation measures that are less effective than otherwise what could be achieved. The following discussion focuses on examples applicable to rockfall catchment fences.

## 2 CERTIFICATION AND TESTING

At the heart of standardization is methodical testing, normally of the system as a whole, whereby all manufacturers must test under similar conditions. Testing for rockfall catchment fences takes the form of 1:1 scale impacts at various energy levels to demonstrate the maximum and serviceable impact energies the system is capable of withstanding. Each test consists of delivering a projectile to the middle of a fence section with a defined mass and velocity. Data resulting from the impact are recorded such as the forces on anchors, elongation, residual height, etc.

The materials used during the 1:1 scale tests are documented and reported. The allowable changes from the "as tested" systems are defined. For example, under the ETAG 27 guidelines and the subsequent CE certification, no changes can be made to the steel cross section of the fence posts and the allowable change in height is limited to up to an additional 0.5 m of a system tested with a nominal height less than 4 m and an additional 1 m for systems tested at or greater than 4 m. In contrast, guidelines set by the Austrian Institute of Torrent and Avalanche Control allowed systems to be built up to 50% higher than tested with an appropriate increase in the steel profile not forbidden. Quality control plans for manufacturing and product delivery also make up a part of some certifications.

However, it should be noted that an evaluation of the level of performance of a system is not strictly undertaken, only whether or not the minimum criteria has been met. As well, only minimal review regarding maintenance and constructability is given if at all.

## 3 REALITY CHECK

Standardized testing and material documentation is an important process by which a minimum level of functionality can be guaranteed, as well as a platform for the comparison of products from different manufacturers. But the standardization of products meant to interact with the extreme variability of natural hazards and irregular topography can also be limiting. The idealized impact of a single, artificial block in the centre of a system, in a perpendicular motion to the fence line and with no rotational energy hardly reflects reality. Furthermore, the well-defined geometry of a test set up is virtually impossible to achieve during installation where the system must be adapted to fit a natural slope.

Some institutes have begun to publish guidelines meant to supplement guidelines such as the ETAG 27. One example is the ONR 24810, published by Austrian Standards Institute (ASI 21013b). This document is a comprehensive guideline for the implementation and construction of the most common rockfall mitigation measures, including rockfall catchment fences (Stelzer and Bichler 2013). In such documents, performance criteria (based on data from certification) and constructive rules (resulting from an evaluation and understanding of how a system reacts to real events) are given.

The unavoidable truth is that regardless of the degree of testing and certification, mitigation structures for natural hazards inevitably must be adapted to site specific conditions and client's needs.

## 4 TYPICAL PROBLEMS

Some of the typical problems encountered when applying a standardized product to a project are listed below, but the list is far from all-encompassing:

*End field impacts* – an impact in the last field of a system is much more difficult to control in a safe manner than for an interior field. Systems tend to be less flexible in this area and some are susceptible to forming large openings near the end posts. But site restrictions such as topography or property ownership often limit extending a system beyond a high risk zone to ensure adequate coverage.

*Near post impacts* – again an issue of flexibility, impacts near posts can cause the failure of the primary net/mesh component if it is not strong and flexible enough. Some systems use break-away components to allow the net/mesh to move freely away from the post without failure, but this in turn forms large openings where only very limited forces are transferred to the bearing elements of the system and subsequent debris can pass through the system unimpeded. They also become an open pathway to subsequent impacts.

*Multiple impacts* – systems are tested only for a maximum energy scenario and, sometimes, a sequential service energy level impact. They are however not tested for multiple impacts occurring simultaneously. Product behaviour such as the opening of mesh and specific failure modes must often be addressed.

*Unique impact scenarios* – sometimes the site characteristics or the characteristics of the event itself can necessitate adaptations of the system, for example where high velocity projectiles, unusually large debris size, or high viscosity material is anticipated.

*Distributed loads* – rockfall is often not the only hazard impacting a system and sometimes consideration must be given to the effects of loading sections with a distributed load such as that caused by the accumulation of snow or impact of an avalanche, mudslide or debris flow.

*Anchor forces* – the reported anchor forces from manufacturer's tests must be used with caution as they are recorded for a specific geometry. If the test geometry is not reproducible on-site, then anchor forces must be adjusted accordingly. In addition, anchor forces are assumed to be applied in the direction of pull, which is often a difficult or impractical orientation to drill anchors.

*Post spacing* – guidelines typically suggest the distance between posts fall in the range of plus or minus 2 m from the "as tested" geometry. In reality, post spacing can be controlled by topography and drilling conditions. In other situations, tighter post spacing is necessary to fulfill secondary loading scenarios such as distributed loads.

*Foundation requirements* – a very common problem associated with the implementation of mitigation structures is the variability of the foundation requirements. Though foundation design is generally not part of the guidelines or certification process, they can often lead to the necessity of adapting base plates for specific conditions.

*Height* – through the use of rockfall simulation software and on-site observations, anticipated bounce heights of debris is estimated. Sometimes, these heights exceed that of allowable manufactured heights of a certified system.

*Variable topography* – the adjustment of a system to fit variations in topography (e.g. undulating, concave or convex surfaces) is a regular practice during installation. This often leads to the need of additional support ropes and/or adaptations to the post itself to put the system in tension and hold posts in their proper position.

*Gully nets* – variable topography can lead to the situation where a gap is formed between the bottom rope of a system and the ground surface for which an additional net and anchorage is required.

*Rock wall connections/Restrictive Layout* – where structures abut near vertical walls or have limited room for the layout of anchors adaptations of traditional anchor layouts and sometimes how the primary components are attached to posts are needed.

*Elongation restrictions* – the maximum elongation of a system is reported during testing procedures and is used for determining the minimum distance between a system and an object of protection, but in some cases space restrictions entail an adaptation to help reduce the elongation of the system to meet the site requirements.

*Maintenance restrictions* – client driven requirements for maintenance can result in the need to alter a system such as the addition of components to limit unnecessary activation of energy dissipation elements, aid in the removal of debris following an event, or allow access through a system.

*Material requirements* – the requirement to use local materials, e.g. "Buy America" regulations, means that the systems manufactured are not certified. This is especially true for all systems manufactured in North America.

Changes such as those listed above would result in the system not meeting the certification requirements and therefor would not be manufactured in accordance with the applicable guidelines. With this said, it does not dictate that the system is any less safe and in fact could well be more safe than if strict adherence to the certification or guidelines was observed.

## 5 CASE STUDIES

### 5.1 Height: Omis, Croatia

The growing population and increasing tourism of Omis, Croatia has resulted in a significant surge in traffic on the local roads and highways. To help alleviate the congestion, a new 1.5 km tunnel was constructed. As part of the new route, the protection of local buildings and infrastructure from rockfall events was deemed necessary. It was determined that events up to 5000 kJ were possible with unusually high bounce heights.

A series of rockfall catchment fences were implemented to mitigate the hazard. Standard ETAG 27 certified systems were used where possible but in two regions, at the optimal position for the structures, bounce heights exceeded that of the available systems on the market. To safely mitigate the rockfall events, systems up to 8.5 m height were required.

A decision by the project engineers was made to construct 3000 kJ hinged systems with heights of 7 m and 8.5 m and 5000 kJ hinged systems with heights of 8 and 8.5 m at these sites (Figure 1). According to ETAG 27, the respective systems are only certified for heights between 5 – 6 m and 6 – 7 m. To help offset the increased tendency for the post to buckle due to its length, a heavier profile was verified and used for their fabrication. Other, on-site adjustments to the layout, e.g. anchor spacing, were also necessary to accommodate the increased height.

If strict adherence to the ETAG 27 guidelines would have been observed, then adequate protection would not have been possible.

### 5.2 Foundation Requirements: Fraser Canyon, British Columbia and Niagara Falls, Ontario

At a site located in the Fraser Canyon, British Columbia, rockfall events have caused significant problems for the Trans-Canada Highway with over 60 recorded events since the highways construction (Simons et al. 2009). In an effort to mitigate future events, the British Columbia Ministry of Transportation and Infrastructure constructed a double-sided MSE wall in 2008 that was designed for a 10,000 kJ impact. The structure stands up to 8 m tall with a basal width of 7 m and 5.5 m width at its top.

Figure 1. An example of an 8.5 m high post that exceeds the allowable height under current guidelines.

Since its construction it has been impacted by several smaller events and adaptations were made to improve the life expectancy/maintenance of the system, such as hanging blasting mats on the backside of the system to protect the wire mesh facing from high-frequency, low-magnitude events. In 2010, a significant impact occurred whereby a boulder of approximately 1 m3 impacted the top of an outside (road side) gabion, which forms the rim of the wall. It penetrated the structure and subsequently crossed the highway.

As such, a further revision was deemed necessary. In 2011, the Ministry tendered the design for a rockfall catchment fence to be installed along the top of the wall (Figure 2). The design should take into account a 2000 kJ impact as well as a distributed avalanche load of 25 kPa along the entire length of the structure. Further requirements were that the system have a fixed-rotation about the axis of the post (i.e. a hinged connect between the post and base plate was deemed impractical) and that a traditional foundation for the posts such as soil/rock anchors or a concrete base was not allowed since it may compromise the integrity of the wall system. Instead the post needed to be secured to large steel cap plates that would serve as the foundation but also as protection of the top of the wall.

The selected system was based on a WLV-tested, fixed-rotation, 2000 kJ rockfall catchment fence. A variety of adaptations were necessary to meet the client’s needs, though the foundation requirements were the most significant. In order to secure the posts, a pin system was designed that connects each post to a counter plate

Figure 2. Fixed-rotation system installed on a double-sided MSE wall.

welded to the cap plate. The counter plate consists of two, vertical and parallel steel fins with an approximate 100 mm hole through their centre. The base of the post has three fins with the same orientation and holes. To mount the post, it is slid into position and a 100 mm steel pin is inserted, passing through all five fins and secured with a bolt (Figure 3).

Though foundations are not part of the test or certification process, the changing of the post details to meet the foundation requirements is not allowed if an ETAG 27 certified system would have been specified. In turn, a standard bolting pattern as a method of attachment to the cap plate would have resulted in a much weaker connection. As such, the decision was made to adapt a tested system to make it safer.

A second example of where foundation requirements led to the selection of a non-standard system comes from a site in Ontario where a series of 100 and 250 kJ rockfall catchment fences were necessary to secure an area at the base of a steep slope comprised of a mixture of natural and man-made features. The optimum positioning of the system was by placing it on top of a pre-existing concrete wall (Figure 4). Since the existing wall was old and no records were available, it was decided that the transfer of force from the fence to the wall was not allowed. As such, a system incorporating a floating base plate was required, which was based on ETAG 27 certified systems.

The floating base plate consists of a standard base plate with two additional fins and a slot (Figure 5). Two tie back cables are installed to the base plate and are led to the upslope retaining anchor that also secures the head of the post via two additional tie back cables. The slot in the base plate is for a temporary bolt used during installation to keep the plate in position. During an impact, the base plate is free to move slightly forward while the forces are led to the anchor by the ropes.

A traditional rockfall fence would have necessitated the use of the existing concrete wall as a foundation and there was no guarantee that it could accommodate the loads in a safe manner.

Figure 3. Adapted base plate for connection to foundation.

Figure 4. Floating rockfall catchment fence on pre-existing concrete wall.

Figure 5. Adapted base plate for floating foundation.

5.3 Elongation Restrictions and Restrictive Layout: Niagara Falls, Ontario

Also from Ontario comes an example where limitations on the construction foot print of a rockfall catchment fence led to adaptations meant to help control the elongation of the system. At this site, a combination of 500 kJ and 1000 kJ systems were necessary to protect vehicle access to a vital site (Figure 6). The road is endangered from a rock escarpment above it, but the land between the road and the initiation zone has restrictions that eliminate the possibility of constructing mitigation measures on the slope. As such, it was only possible to erect a barrier immediately adjacent to the road, and where no upslope tie back anchors could be installed. The result was modified fixed-rotation, WLV-tested systems.

Since standard rockfall fences would not allow sufficient residual width of the road to remain open during the design event, adaptations were required to help minimize the elongation. The only 1:1 scale tested system on the market that met the required 1000 kJ capacity and construction restrictions has an elongation of 6.0 m during a Maximum Energy Level event and an approximate elongation of 4.2 m for a Service Energy Level event. Given that the access road was on average 8.5 m wide and that a residual width of 5.5 m following a Service Energy Level event was needed, the desired elongation was approximately 3 m. This means a 25% reduction of elongation was necessary.

To achieve this reduction for the 1000 kJ system, additional bearing ropes were added along with a reduction in the post spacing to 8 m (Figure 7). Similarly, an additional bearing rope was added to the 500 kJ system. The appropriate changes to the anchorage and foundations were made in order to accommodate the extra anticipated forces.

Should standard rockfall catchment fences have been installed, there would exist a much higher chance that during an event access along the road would be obstructed.

Figure 6. Fixed-rotation rockfall catchment fence installed at edge of access road.

Figure 7. Reinforced catchment fence with additional middle bearing ropes.

5.4 Distributed Loads and Maintenance Requirements: Coffee Creek, British Columbia

Near Nelson, British Columbia, an example of adaptations of a rockfall catchment fence to accommodate snow loading conditions can be found. At this site, a hinged 3000 kJ rockfall catchment fence was deemed necessary by the British Columbia Ministry of Transportation and Infrastructure to protect Highway 31, running alongside Kootney Lake, from falling rock and debris originating from bluffs above the road. In addition, the fence crosses an avalanche path that is approximately 80 m wide (Figure 8). The subsequent loading scenario required that the fence be designed to withstand a static load of 54 kN/m over the lower 3 m of fence height and a dynamic load of 49 kN/m over the upper most 1 m.

To be able to withstand the given design loads, several adaptations were required to the ETAG 27 certified system: the post spacing was reduced to approximately 8.4 m, a larger beam profile was selected for the post and additional tie back cables were used to secure the middle of the post as well as the post head (Figure 9). The middle tie back cables were fitted with brake elements to help absorb energy but also to allow movement of the post during an impact.

Figure 8. Rockfall catchment fence crossing avalanche path (photo courtesy of Jim Guinn, Mountain Rock Stabilization).

Figure 9. Reinforcement of post using retaining ropes connected at mid-height.

Other adaptations were defined by the client to help reduce maintenance, these included the addition of a high-tensile supplementary mesh, a shield on the base plate that protects the anchors and locks on all the brakes to help stop their activation due to seasonal snow loading.

A standard 3000 kJ rockfall catchment fence could not withstand the anticipated loading scenarios and so would likely be destroyed or damaged during a strong winter. In addition, much more frequent routine maintenance would be required.

5.5 Unique Impact Scenario and Variable Topography: Minnesund, Norway

In Norway as part of the E6-Dovrebanen highway project, a corner of a round-about required a barrier to prevent cars and semi-tractor trailers (in particular logging trucks) from leaving the road and ending up on a railway located approximately 15 m down a steep embankment (Figure 10). In addressing the problem, it was important to the client to minimize the visual impact of any structure.

Figure 10. Rockfall catchment used for preventing vehicles from landing on railway (photo courtesy of Marco Toniolo, Pfeifer Isofer).

In the end, it was decided to construct a hinged 5000 kJ barrier, based on an ETAG 27 certified product. Alterations were required to adapt the system to the required height, the rough topography as well as the convex curve of the road. One of the restrictions was that the top of the fence should be level and not exceed a defined height. The result was the need for posts of varying heights between 6.0 and 8.5 m with heavier than normal beams (Figure 11), as well as special anchor plates to safely guide the lower bearing ropes along the ground surface so that no gaps are formed and the rope is protected during an impact. Large diameter cables were also required on the downslope side to prevent the posts from falling upslope due to the curvature of the fence line and also from forces during an impact.
A standard rockfall catchment fence would have required all posts to be of the same height and so would either not have provided sufficient coverage or would have obstructed the view.

5.6 Restrictive Layout and Unique Impact Scenario: Austria

Another example of adapting a rockfall catchment fence for a non-natural hazard mitigation comes from an aluminum alloy factory in Austria. During the cooling process, if the ingots cool too quickly, tension can built up in the bars and result in an explosion. The ingots are approximately 5.0 m x 1.2 m x 0.5 m in size so large projectiles are possible. At this particular site, it was deemed necessary to protect surrounding buildings and workers from the threat of flying objects.

A WLV-tested 500 kJ fixed-rotation rockfall catchment fence was used as the basis for the design. Major adaptations were made with regards to the posts, bearing rope configuration and anchorage. These adaptations are primarily the result of layout and access requirements. The fence must enclose a building and so make 90 degree corners as well as have access through the fence for workers (Figure 12). Lastly, lateral anchorage for bearing ropes was not possible due to space constraints.

Figure 11. Varying height of posts to adapt to topography.

Figure 12. Custom building enclosure for protection from explosions.

Without the adaptations, a rockfall fence could not have fulfilled the project requirements. In addition, the safety of the site could not have been improved in such a cost-efficient manner.

## 6 CONCLUSIONS

There is no doubt that guidelines, standardization and certification of hazard mitigation products is necessary and beneficial. But as it is not wise to blindly follow your car's navigation system without knowledge of where you are going, it is unwise to apply guidelines and certification requirements without forethought and consideration to project specific needs and the inherent limitations of standardization. There is no substitute for insightful engineering practices and each project should be evaluated on an independent basis for what the safest and most effective solution is, given an understanding of the problem and the unique characteristics of the site. The guidelines and certification are a part of this process and not the whole. Anything else could result in an oversimplification of the hazard and risk, which could produce an inadequate solution.

The rockfall catchment fence industry has progressed from novel ideas of protection to a systematic approach to risk reduction where the safest mitigation comes from open and thoughtful communication between the client, their engineers, the manufacturers and installation contractors and not from a piece of paper.

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