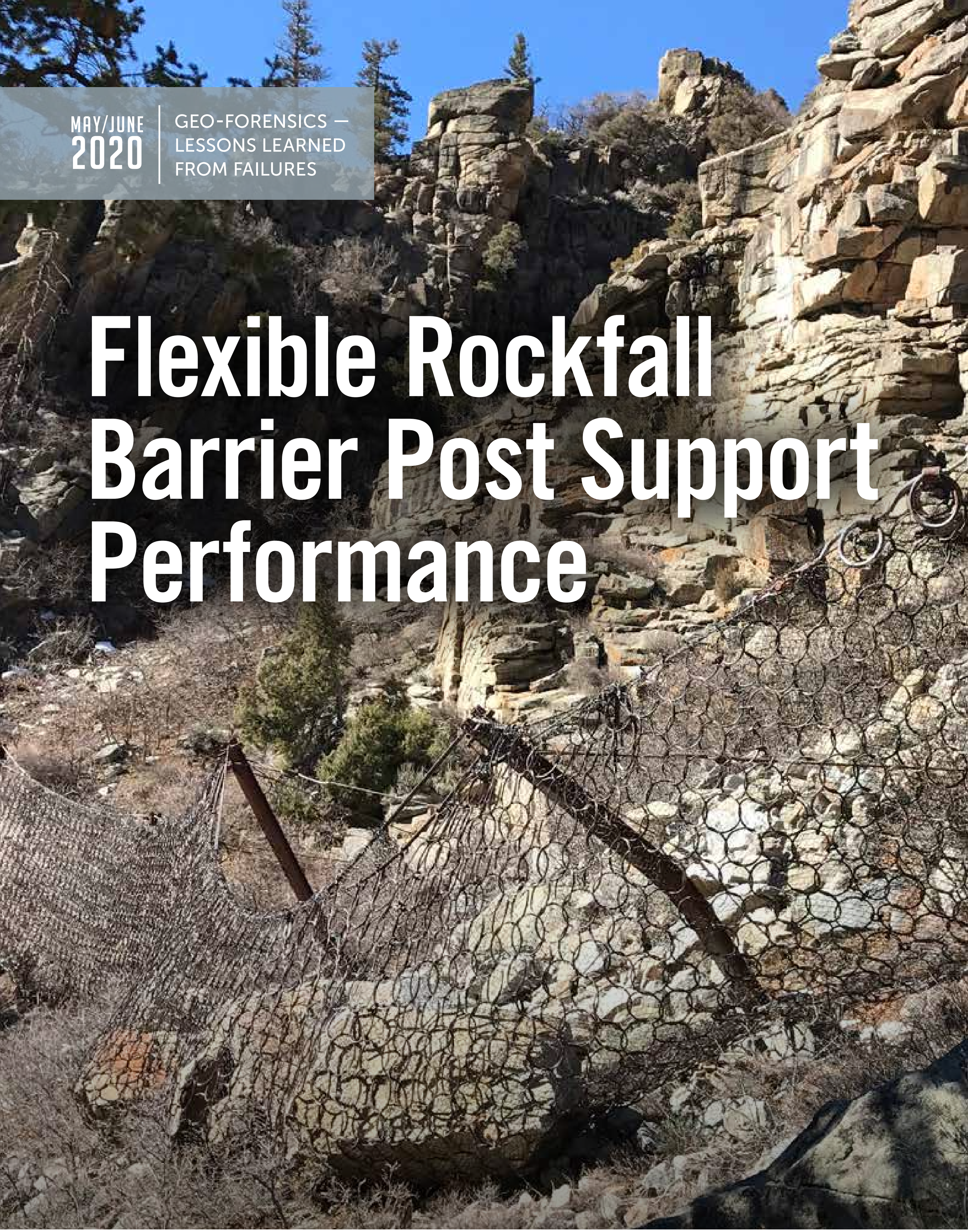
Flexible Rockfall Barrier Post Support Performance



Rockfall barrier impact at Glenwood Canyon, CO (above I-70), showing continued performance even after impact. (Photo courtesy of Colorado DOT).

Deflection as a Positive Attribute

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Rockfall has plagued infrastructure for centuries, whether generated by natural weathering of unaltered rock slopes or due to jointing and weaknesses in constructed rock slopes. Rockfall in the U.S. has been formally studied since the early 1960s, when Arthur Ritchie, chief geologist with the Washington State Department of Highways, assessed inadequacies with the state of practice relative to catchment ditch design. Since that time, rockfall analysis has become more sophisticated with the use of 3D simulation and rockfall runout models. Several international manufacturers have developed flexible rockfall barrier (fence-like) systems, the designs of which are continuously updated and improved based on testing and field performance. Most flexible rockfall barrier manufacturers also offer debris flow and avalanche barriers using similar elements.

Figure 1. **Flexible "hybrid" type rockfall barrier during testing. (Photo courtesy of Tom Badger, Golder Associates, Inc.)**

Figure 2. **Temporary rockfall canopy above tunnel portal, Atlanta, GA. (Photo by Scarptec, Inc.)**

At a time when flexible rockfall barriers should be economical and readily available, their costs are being driven up by ancillary design requirements for barrier post foundations and anchors that support them, as well as unrealistic serviceability assumptions that ignore the temporary and replaceable nature of the barriers — much like guardrails. In some cases, owners expect high-capacity barriers to possess unrealistic "no deflection" performance criteria during a rockfall impact and to require no maintenance following a significant impact. Using examples from two sites from North America, this article focuses on flexible rockfall barriers, given their widespread industry use and adaptability to challenging site conditions. The article aims to demonstrate that barrier post foundation system deflections and long-term maintenance are not mutually exclusive considerations, and that adaptation of reasonable performance assumptions can help reduce initial capital costs and long-term maintenance demands on the installed systems.

Historical Context

When left unmitigated, falling fragments of rock can have potentially devastating consequences where rockfall debris can affect infrastructure. Fortunately, there are numerous tried and true rockfall mitigation methods that can be employed to reduce impact risk to people, equipment, and valuable assets. Some of the common techniques make use of slope scaling, rock reinforcement, "dental" shotcrete, anchored mesh or mesh drapery, and rockfall barriers.

Flexible barrier-type structures have gained wide acceptance across the geohazards mitigation industry, and they are being used to mitigate hazards from debris flows, avalanches, and landslides, in addition to rockfalls. Recent design and construction trends show that foundations for flexible barrier systems are being designed using extremely conservative assumptions (e.g., no allowable deflection or high "stiffness"), which can result in oversized, overly expensive systems.

Rockfall barrier post supports have historically consisted of a small, unreinforced concrete block (e.g., 0.8 m^3). Field experience with these foundations is significant and shows acceptable performance during large and beyond-design energy impacts. More recently, post support design trends have resulted in the development of much larger foundation systems, due in part to industry advances in modeling capability and instrumentation. Geotechnical engineers find themselves needing to design large (or deep) foundations to satisfy the model-generated maximum impact (i.e., energy) load and the characteristic foundation load(s) provided by barrier manufacturers according to certification tests.

There's available industry guidance for testing, certification, and asset management relative to rockfall barriers, as described in the National Cooperative Highway Research Program's *NCHRP Report No. 823*; however, guidance for post support design is limited. In the absence of uniform post support design criteria and construction guidelines, some rockfall barrier designers have relied on design guidelines from allied disciplines like structural and transportation engineering. Such guidelines are not entirely applicable because flexible rockfall barriers are expected to yield, whereas building and bridge foundations are not.

Typical Flexible Rockfall Barrier Elements

Flexible barriers typically possess these system elements:

- Structural mesh/nets — Steel nets forming the primary interception structure that span along the fence line between posts.
- Posts and baseplates — Steel posts that support the nets and transmit impact/debris loads to the ground. Hinged or fixed base plates are available.
- Support ropes — Aid in supporting the netting between posts and distributing loads throughout the barrier system and to the ground anchorages.
- Flexible rope anchors — Passive anchors associated with support ropes at the barrier ends or upslope "tie-back" anchors.
- Braking elements — Steel elements that dissipate energy through permanent deformation.
- Post base supports — "Foundation" elements that transmit unattenuated loads to the subgrade.

When considering the functionality of these systems, three primary types of barriers are available: catchment fences, attenuators/hybrids, and galleries.

A catchment fence is a common barrier intended to retain rock debris falling nearly perpendicular to the barrier/fence line. These may also be referred to as "dynamic barriers." Attenuators/hybrids (Figure 1) are essentially dynamic barriers with a draped mesh tail that redirects retained debris downslope. Finally, galleries (Figure 2) are specialized catchment fences constructed as canopies to protect features below the installation.

Common to all the flexible-net barrier systems is their use of deflection, plus elastic and inelastic deformation, to attenuate and distribute the rockfall impact forces to the anchorages and post support system. Preliminary engineering and feasibility-level evaluations need to account for this deflection distance with respect to the proximity of features at risk, including passing vehicles or infrastructure. This consideration contrasts with rigid barriers, which are designed to have minimal (if any) deflection. Rigid barriers are frequently designed with the assumption that very limited long-term monitoring and maintenance will be performed.

Flexible barriers are classified by their maximum energy capacity as demonstrated by manufacturer testing, with available barriers rated

Figure 3. **Rockfall barrier post supported on bedrock at Georgetown Canyon, CO, showing continued post-strike performance. (Photo courtesy of Colorado DOT.)**

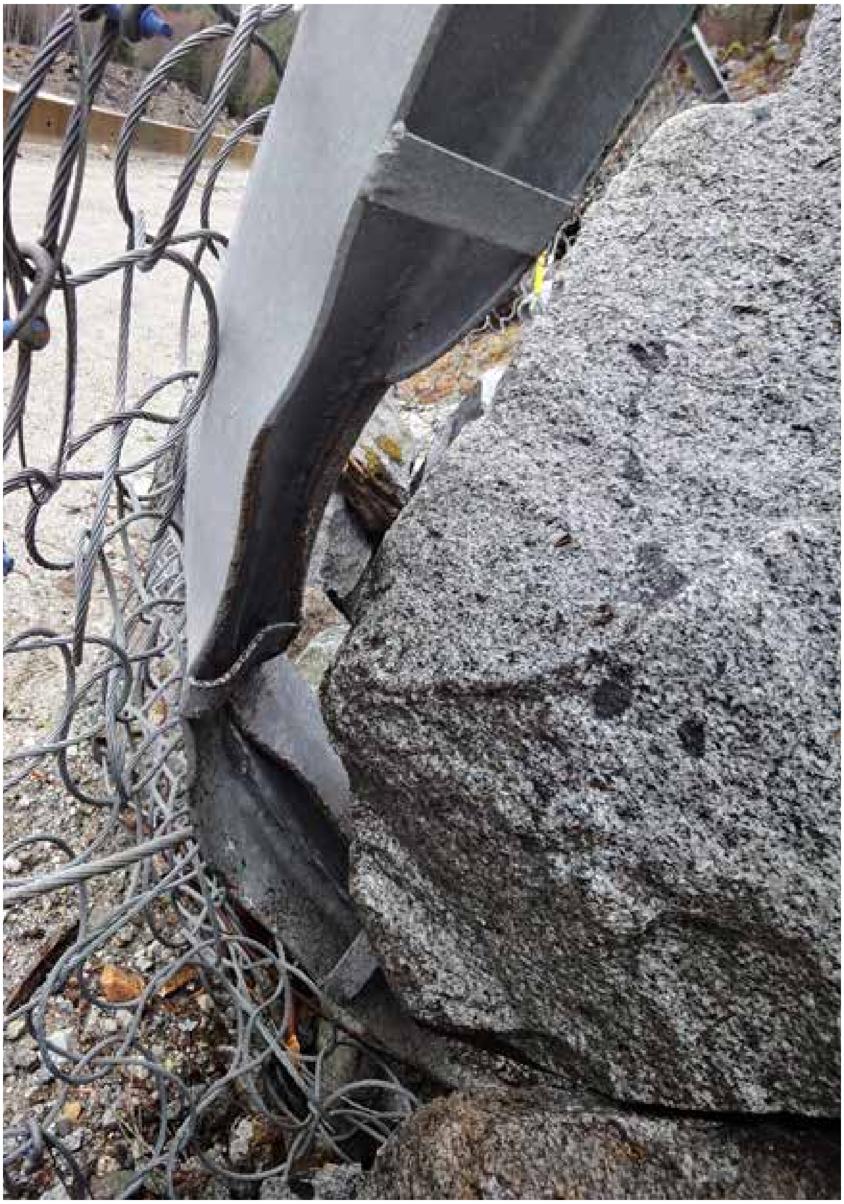

Figure 4. **Rockfall barrier post impact in British Columbia, showing continued performance even after impact. (Photo courtesy of Trumer Schutzbauten Canada Ltd.)**

between 100 kJ and 10,000 kJ. This capacity applies to the *entire system*, not just the netting material, which is a frequent misconception.

Post Base Support and Anchorage Elements

Barriers are typically supplied with many of the internal components designed and tested by the manufacturer; however, the foundations and anchors are designed by the owner's engineer based on local ground conditions.

The foundations for flexible barriers should not be thought of as foundation elements for conventional structures. Rather, they're a series of shallow, barrier-post support elements that are expected to periodically yield/deform and be maintained. The authors contend that the word "foundation" should be discouraged with regard to flexible-net barriers and that "post base support" (PBS) be used to avoid confusion.

Geotechnical designers might be tempted to design PBS elements by reverse engineering the rated capacity of the rockfall barrier. For a barrier with minimal allowances for deflection of the PBS elements, this results in massive loads on the post bases, and assumes that the full impact load is distributed to the subgrade supports. In reality, flexible rockfall barrier systems distribute a significant portion of the impact load across the system before reaching the post supports. Therefore, rockfall barrier designs must be calibrated based on reasonable assumptions and appropriate engineering geologic judgement.

Often, there's an inherent desire to consider a direct post hit and how that affects the post base support design, but it's impractical to design for this case. Instead, the design should be based on characteristic loads recorded during certification testing of the systems. While damage of a single post has been observed in the field (Figure 3), it doesn't always lead to failure of the entire system. Further, because the probability of direct post impacts is significantly lower than impact within the exposed netted area, it's our opinion that this case should not govern PBS design.

Beneficial Attributes of Deflection and Displacement

In the structural engineering world, the word "deflection" is often associated with a negative result. For geohazard mitigation designers today, "flexibility" and "deflection" are the core functionality attributes of flexible barrier systems, and, in fact, are the very reason the systems work. When considered in design and system placement, internal deformation and deflection become a major part of the overall energy dissipation process.

Designers might assume that a rigid and unmovable PBS provides support conditions approaching those tested during certification, thereby increasing the chances that the system will perform to a minimum standard. However, the minimum can be met, or even exceeded, by other means. In fact, shallow post base support elements often exhibit performance well beyond the design load, sometimes even exceeding the maximum system capacity specified by the manufacturer (Figure 3). This behavior is often attributed to the fact that the PBS may display significant displacement during the impact event, thus absorbing excess impact energy. In contrast, by designing the PBS to deform during design impact events, the designer creates a more efficient coupling between the superstructure and the PBS, which allows the entire system to perform as the flexible system it was intended to be.

These types of field observations are further supported by instrumented full-scale post impact testing performed by the Colorado Department of Transportation (CDOT). CDOT demonstrated that for a given impact energy, post support systems were allowed to deflect rather than being rigidly fixed, resulting in greater than 70 percent reduction in forces applied to anchorage elements.

Notable Examples

A rockfall barrier in British Columbia rated for 1,000 kJ was impacted multiple times by events much larger than its capacity. In this case, a very small concrete leveling pad was used (i.e., 15 in. square by 49 in. deep) in combination with two, 16-ft-deep soil anchors to support the barrier. In two extreme rockfall events, the posts suffered direct impacts (Figure 4). The first impact caused significant deformation of the foundation, but all debris was contained. After the event, the fence was repaired, and a new post was set on the damaged foundation. A second, even larger, event occurred in an adjacent field, and once again the system held, but the impact completely destroyed a PBS. Even so, all of the debris was retained. In both cases, any conventional foundation design capable of performing similarly would have been robust and very expensive.

Successful performance of light to moderate post support elements can also be seen in an example from a flexible barrier impact in Colorado (Figure 5). A barrier rated for a maximum energy impact of 2,000 kJ was struck by an even larger event involving multiple blocks. This barrier was constructed with four #8 thread bar anchors supporting each post. The anchors were installed to depths of 2.4 to 3.1 m in a combination of soil and rock. The fallen rocks impacted the center of a net panel, and the system successfully retained everything. Due to the severe loading above the system's rated design capacity, one post, a section of net panel, and several braking elements within the impacted section deformed to their maximum design extent and required replacement. However, an inspection of the relatively light anchor system supporting the post revealed that the anchors were still serviceable, and a new post was simply installed on the original base plate during repairs.

Serviceability & Long-Term Monitoring and Maintenance Demands

All installed rockfall mitigation elements require periodic monitoring and maintenance (M&M) to help maximize their long-term performance. An M&M plan can be incorporated within the owner's overall geotechnical asset management program. Geotechnical monitoring of slopes and installed rockfall protection elements is completed by an engineering geologist or geotechnical engineer; maintenance is typically completed by a specialty rock remediation contractor.

Rockfall barriers accumulate rock fragments and other debris over time, reducing the system's capacity and possibly overstressing elements or causing permanent deformations. Serviceability with flexible barriers is key and requires that the infrastructure of posts and net panels form an open "throat" to intercept falling rocks. Rockfall impacts may result in localized damage to the barrier system that require event-specific inspections. At some point, the system may be considered ineffective and must be brought back to an acceptable level of functionality by carrying out routine maintenance, including the PBS elements. Thus, periodic monitoring is required to gauge the condition of the barrier and slope.

Key Considerations for PBS Design

Based on the observed performance and response of flexible rockfall barriers during rockfall events, some key takeaways include:

- Flexible rockfall barriers often exceed performance expectations when deformation of PBS systems is permitted.
- Systems that have partially lost local functionality, such as when a single post has been lost, can still be effective.
- During planning and design, project cost efficiency must include both short- and long-term monitoring over the project's lifetime.
- Be sure to obtain relevant design and serviceability parameters for each specific rockfall barrier from the system manufacturer.

Geotechnical professionals tasked with evaluating flexible rockfall barriers during initial feasibility studies and design should consider assessing, and then checking via peer review, the validity of their design basis assumptions by asking these critical questions:

- How realistic is the design criteria for kinetic energy, bounce height, and impact force assumptions? Remember, unrealistic rockfall-model input assumptions are a frequent precursor to the specification of overly conservative barrier designs!
- Are other rockfall mitigation methods available, like scaling, anchors,

Figure 5. **Rockfall barrier impact at Glenwood Canyon, CO, showing continued performance even after impact. (Photo courtesy of Colorado DOT.)**

dowels, and anchored mesh or mesh drapery, that could be used upslope to reduce kinetic energy/impact forces acting on a proposed rockfall barrier?

- Will a portion of the impact forces be distributed to upslope or lateral support anchors?
- Does the design consider system serviceability and M&M demands over the lifetime of the barrier? GS

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The AGHP's Post Base Support Committee is collecting examples of real-world PBS designs and their performance in order to establish guidelines that help engineers and contractors select efficient and cost-effective PBS designs for their projects. Those interested in becoming involved can visit geohazardassociation.org.

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