# TECHNOLOGICAL ADVANCES IN ROCKFALL PROTECTION IN OPEN PITS HIGH SPEED IMPACTS WITH SPIN

Expert Paper
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**Abstract:** *In surface mining operations rockfall is an ever-present hazard to personal, equipment, and infrastructure. Mitigation of rockfall hazards typically includes geotechnical design of catch benches or berms based on empirically determined widths and sizes. Alternatives, rockfall barriers, are available to reduce the required footprint needed for these traditional measures. For years protection systems have been designed and tested, since 2001 [FOEN, Switzerland] guidelines have been in place to regulate the design and increase the solution safety. Today, rockfall protection systems up to 10MJ of MEL capacity are manufactured. In open-pit mining, there are special conditions that current standardized systems do not meet. As a result of the mining activity, blocks of not very large dimensions may fall, but they are generated from the highest parts of the cut, reaching velocities of up to 45m/s, with an important angular component. This paper provides the background of previous Flycatcher barrier installations, design improvements, and full-scale field-testing results. Multiple full-scale field-testing is occurring in the western US in partnership with the United States National Institute of Occupational Safety and Health (NIOSH), and University of Arizona's Geotechnical Center of Excellence (GCE). Design improvements to the flycatcher barrier are focused on providing performance, limiting impacts on operations, and safer installation. Providing operations, a quick rockfall reduction response. At the same time increasing access to existing highwalls and decreasing road widths, while protecting exposed workers and equipment with efficiency and reduced cost. As mining advances and operations pivot, the Flycatcher will allow for increased tons, efficiency, and safety during mining operations.*

**Key words:** MINING, OPEN PIT, ROCKFALL, FLYCATCHER BARRIER, SAFETY

## INTRODUCTION

The extractive industry is simultaneously one of the human civilization pillars for the resources it provides, but also one of those with the highest accident index. Open-pit mining is a very important aspect of raw materials mining, and it is present all over the world. The quarry exploitation, amongst all extractive industry activities, being considered a high-risk occupation in which, due to the development of their respective professional activities, the workers are exposed to risks that may impact on their health as well as on their physical integrity. The period from the start to the construction of an open pit mine takes several years and includes prospection/exploration, mineral extraction, and waste handling and management. Big machinery like bucket wheel excavators is used to break rock masses out of the ground that usually have low compressive strength (≤20MPa) [12]. For rock masses with high compressive strength (>20MPa), excavation with shovels or drilling and blasting is applied. The downstream haulage system depends on specific mine conditions (e.g. depth below surface, pushback rates, annual production) and environmental influences (e.g. emissions, surface impacts). Open-pit mining operations harbor risks which can lead to standstill operation, injury to personnel, injury to equipment, or negative impacts on the environment. In any case, rockfalls are one of the main dangers that lead to risks. Figure 1 shows the main geotechnical problems that can arise at exploitation and how most of them are associated with rockfalls [16].

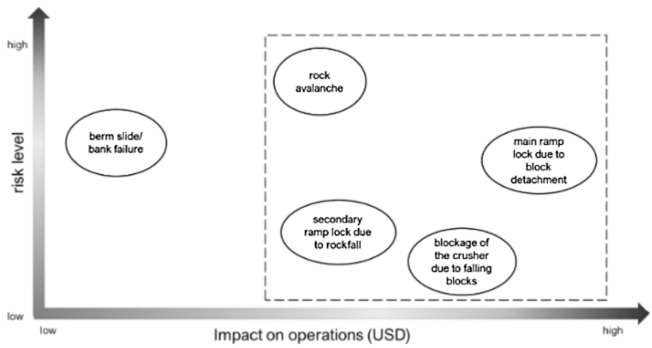



*Figure 1, Main risk at the open pit operations, modified from* [16]

## ROCKFALL CONTROL AND MITIGATION

Since the 1950s, interception solutions have been developed and implemented, in general located perpendicular to the rockfall trajectory. In the first instance, the solutions were rigid and were based on the self-weight of the retaining structure; concrete walls and embankments were built to intercept the path of the blocks [8]. In 1951 and as a systematization of flexible barriers to control snow avalanches, the first barriers with a flexible steel facing (<1770MPa) were developed, with an optimized energy approach, made up of light and resistant materials, capable of absorbing huge quantity of energy [11]. Today's date, these systems have advanced exponentially in the direction of security, reaching very high energy levels. The purpose of this contribution is to show the results of the experimentation and implementation of a specific mobile-temporary barrier model (Flycatcher), dedicated to protection against the very frequent low energy level blocks falls, characterized by their high angular and translational speed. This operative mobile barriers or Flycatchers has been used for more than a decade in open pits and quarries, with different materials and some of them have proven empirically its effectiveness on controlling small rockfalls and its fast installation process, but without any technical support analysis or definition on its limitations nor capabilities. This field test and analysis are the first steps on those directions.

## REGULATIONS

The certification rockfall protection barriers have been a main explanation for the widespread application of rockfall fences in hazard mitigation [2]. Certification ensures that barrier meet performance standards, thus allowing engineers to choose the right barrier type. In 1980, 200 kJ energies could be absorbed with low velocities (less than 10 m/s) and masses of 4000 kg. During the last decade the systems have developed exponentially. In 2001, the first guidelines were published in Switzerland [6], at this time the energy absorption level it was 3000 kJ (25 m/s), Some modifications were made to this first version [7]. Followed by EU guidelines in 2008 the European Technical Approval Directive (ETAG 027) [3] to standardize this activity at the European level, which was published on February 1st, and in July 2018, due to a change in strategy and nomenclature in EOTA, became the current European Assessment Document (EAD-340059-00-0106) [4], whose implementation has had different levels of reception in each country of the European Union. Outside of Europe, regulatory development has been limited, however, with the aim of increasing security, some organizations have adopted the current regulatory recommendations in force in Europe. Today, flexible barriers (tested at speed near to 30m/s), are cost efficient solutions against rockfalls with broad protection capabilities ranging from 50 kJ to 11MJ as shown in Figure 2.

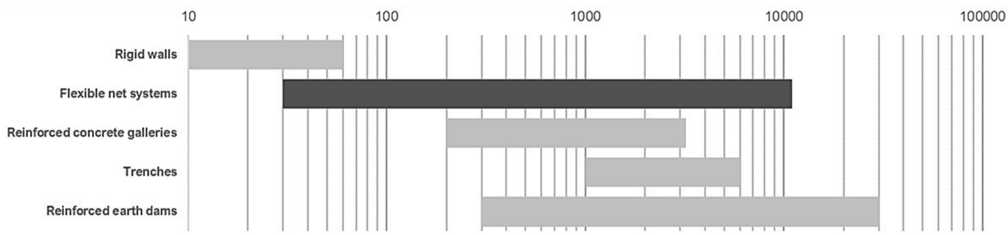



*Figure 2, Energy capacity of different protection systems* [2]

## INTERACTION'S BLOCK-GROUND IN THE PATH AND THE BLOCK-MEMBRANE AT THE IMPACT ROTATIONAL DRAG DESCRIPTION AT GROUND CONTACT POINT

The total rotational drag acting on a block penetrating the ground surface results from two separate torques [2]: one arising from the translational penetration of the block into the ground (translational torque $T_T$ Figure 3 left) and one arising from the rotational spin of the block as it scars the ground surface (rotational torque $T_\Omega$, Figure 3 right). The sum of $T_T$ and $T_\Omega$ provides the total drag resistance. During the ground-block interaction the translational movement of a block into the ground creates a rotational drag because the block has only partially penetrated the ground surface. When interacting with the ground, the soil properties are crucial to determining how the drag is going to be applied on the block.

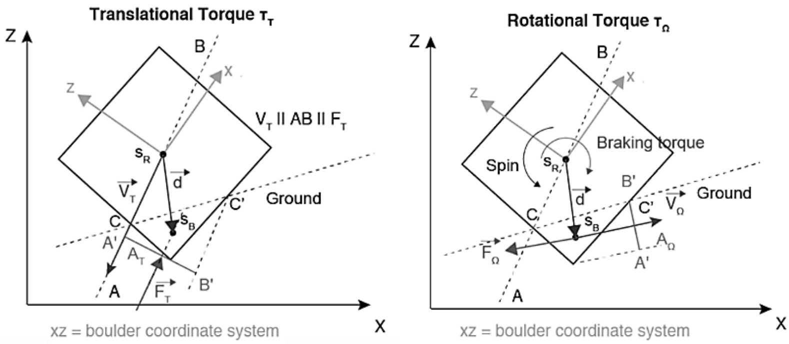



*Figure 3, Representation of the translational drag (left)*
*Scheme considering the rotational drag (right)* [2]

## ROTATIONAL INTERACTIONS AT ROCKFALL BARRIERS

When interacting with a barrier membrane after some ground contacts, the block behavior is drastically different. There, the membrane material has again different properties than the soil, the angle of impact is different, and the block-ground interactions described previously are not valid anymore. Indeed, when watching a sequence of a wheel shaped block/ membrane interaction (Figure 4), is possible to note that instead of letting the block having several airborne phases separated by ground scarring and rebound phases, the membrane has the capacity to stop the block's rotations and overall displacement [2].

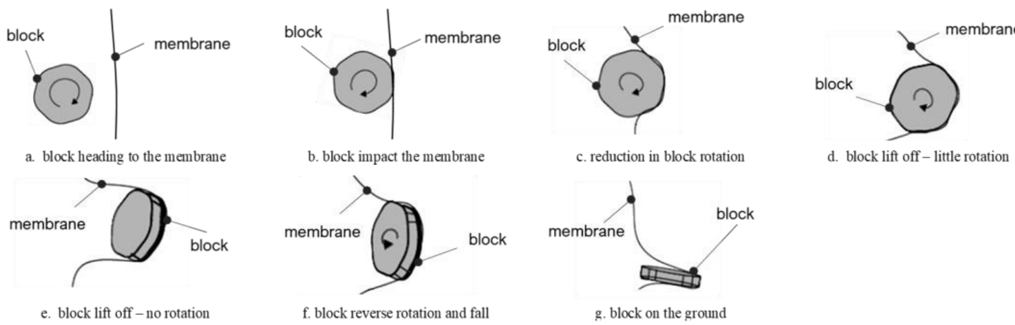



*Figure 4, Block-membrane interaction sequence, modified from* [2]

From the Figure 4 some remarks can be done.

- when impacting the barrier membrane, the rotational velocity of the block decreases (translational velocity decreases too).
- there are still block/ ground interactions, meaning scarring and rebound, as in the situation without an interception membrane. However, the block meets the

membrane and then interacts with the ground, the rebound happening in the direction opposite to the slope, and it can observe a slight reverse rotation of the block. The scarring occurs when the maximum elastic extension of the membrane is reached.

- if a wheel shaped block hits the membrane on the narrow side, it then rotates so that the widest side gets in contact with the membrane. There is a subsequent increase of the surface in contact with the membrane leading to an increase of drag applied on the block.
- when hitting the ground again after the second flying phase, the block tumbles and falls on the flat face, and the movement stops there.

HIGH-SPEED IMPACTS RESPONSE

The potential energy stored in an unstable block at the top of the cut is associated with its mass, location (height from where it is released) and the acceleration of gravity. Once the block is mobilized and until it contacts the barrier membrane[1], this potential energy becomes kinetic energy. The kinetic energy of the block at membrane contact is divided into a translational component and the rotational energy. For simplification, only the energy from the tangential velocity (parallel to the slope) was used for the translational energy, as this is decisive for the energy input in the membrane. The tangential speed can be determined by evaluating the video recordings. The rotation energy can be determined very quickly from the measured rotation rate.

$$E_{kin} = E_{trans} + E_{rot} \qquad E_{trans} = \frac{mv_t^2}{2} \qquad E_{rot} = \frac{J\omega^2}{2} \qquad [1]$$

In the case of translational velocity $v_t$, different combinations of mass and speed can give similar results from the energy point of view, for this reason the tests proposed by the regulatory documents (EOTA 2018) set a minimum value of speed before impact about 25 m/s. What happens when the speed values exceed the established limits? the systems must be checked to ensure that the “bullet-effect” does not occur, and the membrane does not break before the stresses can be transmitted to the distribution and/or anchoring elements, located on the barrier boundary. Impact energy is different from impact pressure, since impact pressure expresses the amount of energy that is distributed in a certain area.

HIGH SPEED FIELD TEST. VARNER, SWITZERLAND

In other to characterize the protection system response to this bullet-effect, some filed tests were performed [9]. The first test dates back several years, in a second-class road connecting the towns Varen - Rumeling in the Kanton Wallis, Switzerland, has been closed due to serious rockfalls in the winter 1999/2000. The commuters of this area are interested to reopen the road as quick as possible. The topography offers a rockface with about 100 m of height above the road with accessibility to the rim of the rockface and with no danger potential below the road (Figure 5 left). The authorities have given their

[1] generic name for interposition nets and meshes.

approval for installing a test barrier about 22 m length (Figure 5 right). The test goal was to proof rockfall barrier with high velocities impacts up to 45 m/s. Two platforms are available, one at 56 m and one at 96m above the barrier. Blocks up to 200 kg have been launched by hand from a channel. Larger blocks have been dropped from a helicopter. The block weight has been determined beforehand, the accuracy of the procedure was limited and often the same location was hit several times. Test configurations membranes are presented in Table 1.

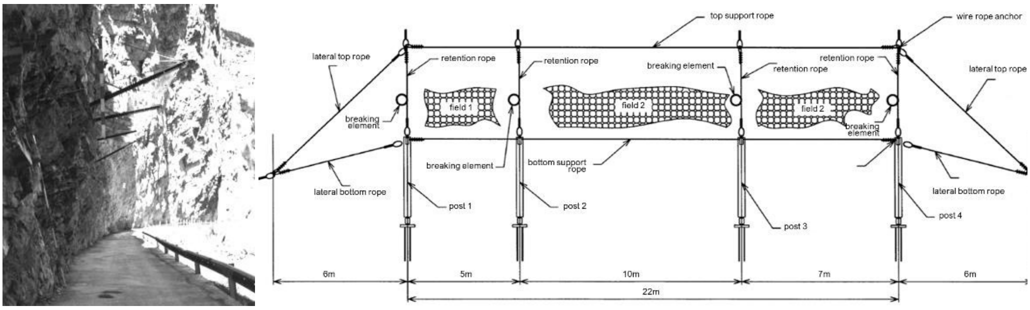



*Figure 5, Barrier setup, lateral view (left) and tested rockfall barrier setup (right)* [9]

*Table 1, Different membranes used*

| Test series | Description |
|---|---|
| 1 - 3 | G65/3 wire mesh (high tensile strength) in all 3 fields on the total length |
| 4 | 5/3/300 ring net in all 3 fields on total length<br>50/50/4 wire mesh (mild steel) in field 2 on top of ring net |
| 5 | 5/3/300 ring net in all 3 fields on total length<br>G65/3 wire mesh (high tensile strength) in field 2 on top of ring net |
| 6 | 7/3/300 ring net in field 2 with G65/3 wire mesh (high tensile strength) on top of ring net, fields 1 and 3 with 5/3/300 ring net |
| 7 | 7/3/300 ring net in all 3 panels on total length<br>G65/3 wire mesh (high tensile strength) in field 2 on top of ring net |

The energy absorbing capacity of membranes is about 25% lower when impacted with high velocity (43 m/s) than in case with the usual velocities (25 m/s) (Figure 6).

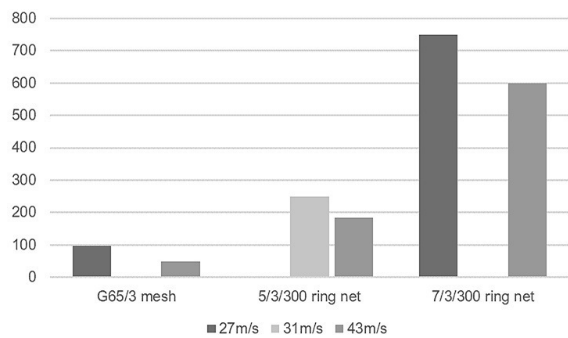



*Figure 6, Energy absorption per membrane type according with the test velocity* [9]

The maximum energy absorbing capacity of the G65/3 mesh could not be determined for 27 m/s (missing data), the represented values (~100 kN), are according to previous tests. At initial series G65/3 mesh can absorb energies of at least 50 kJ (52 kg from 96 m) safely and without any damage. The standard mild steel wire mesh installed on a ring net is penetrated from blocks of 20–30 kg when impacted with velocities of 43m/s.

HIGH SPEED TEST FACILITIES. VAUFFELIN, SWITZERLAND

During 2021, several series of tests [1] were carried out at the DTC facility (Dynamic Test Center, AG) in Vauffelin, Switzerland (Figure 7 left). The test goal was to corroborate the effective functioning of the interposition membranes against high-speed impacts, using a test boulder with shape according to [4] (Figure 7 right).The primary membrane is a ring net 7/3/350 (1770 MPa), the test boulder weight is 14.8kg (150x150x150mm) according to [4], impact speed 60m/s and energy 26.6 kJ, the video equipment consist in high-speed cameras calibrated and set up according to [15]. Test results are presented in Table 2.

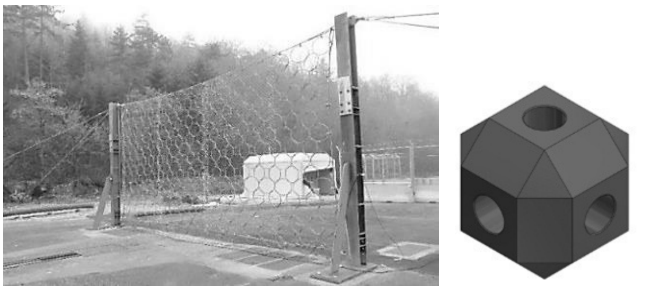
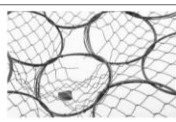
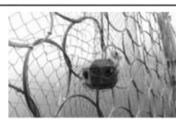
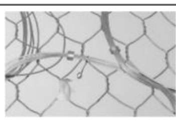
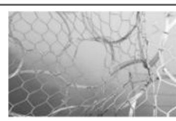
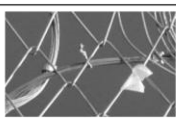
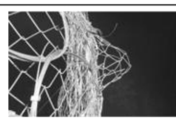


*Figure 7, Primary ring net 7/3/350 tensioned between two steel posts with attached secondary mesh (left) and steel test boulder, shape acc.* [4] *(right)*

*Table 2, Test result summary*

| Secondary mesh | | | Impact | | | | Test result | | |
|---|---|---|---|---|---|---|---|---|---|
| Type | $F_{yk}$ [MPa] | Initial photo | *Height* [cm] | $V_{imp}$ [m/s] | $E_{imp}$ [kJ] | Final photo | $V_{exit}$ [m/s] | $E_{exit}$ [kJ] | $D_{max}$ [cm] |
| 50/50/2.5 chain-link | 600 |  | 238 | 60.4 | 27 |  | 59.2 | 25.9 | failure |
| G45/2 diamond | 1770 |  | 223 | 60.2 | 26.8 |  | 0.0 | 0.0 | 231 |
| 80/100/3 hexagonal | 500 |  | 237 | 60.1 | 26.7 |  | 49.0 | 17.8 | failure |
| G65/3 diamond | 1770 |  | 203 | 61.2 | 28.0 |  | 0.0 | 0.0 | 193 |

In summary, meshes samples [1] manufactured with standard mild steel wire (chain-link 50/50/2.5 and hexagonal 80/100/3), have not been able to withstand the impacts at the required speed level (60 m/s), while the high tensile strength meshes as G45/2 and G65/3 being the most appropriate to withstand this kind of impacts, then they will be recommended as part of systems as interposing facing. Then, these will be the membranes recommended to compose the mobile-temporary barrier model, object of study.

FIELD TEST PERFORMED EXPLOITATION LOCATION

In 2023 during September 14th, a full-scale test was done. The test site was the Bald Mountain Mine, located in Ely, White Pine County, Nevada, United States. This is one of the largest mines in North America by Land Area, footprint of total land permitted (Figure 8). Bald Mountain is an open pit mine with a large estimated mineral resource base located in Nevada along the southern extension of the prolific Carlin trend, over 30 separate pits located throughout mine site and was acquired by Kinross in January 2016. In October 2018, Kinross acquired the remaining 50% of the Bald Mountain joint venture zone from Barrick Gold to consolidate ownership, of the property, the largest private mining land package in the U.S. With approximately 3.7million gold ounces of estimated measured and indicated gold resources (as of December 31, 2022) and a pipeline of high-quality targets. Exploration is focusing on the North area. The operation uses the heap leach processing type. The mine production in 2022 was about 214,094oz, that means about $426,475,248 considering ore price in February 2024 ($1,992/oz). The exploitation is based on drill and blast sequence, the top pit was basically pre-split, the slope of the banks is 52º and electric shovels are used for ore collection. The base geology is controlled by deep-sea sedimentary sequences of limestone and shale, with alternations zones typical of Carlin trend [10].

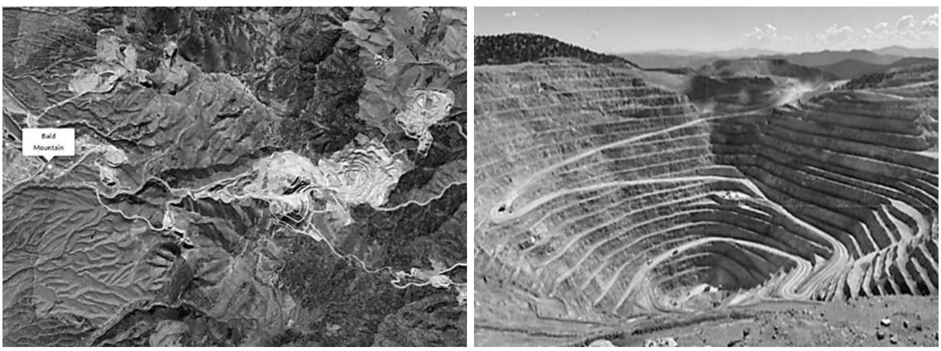



*Figure 8, Top view Bald Mountain Gold Mine (Google 2024) (left) and Overview top pit (right)*

SITE AND BARRIER DESCRIPTION

To carry out the full-scale tests, a Flycatcher-type rockfall barrier was installed at a level of 2164m (Figure 9 left). The barrier is composed of three functional modules or fields using a single layer of high tensile strength G65/3 mesh as interception membrane, limited by four posts (Figure 9 right). The posts can be assembled in three parts as shown in Figure 10, the total height of them and therefore of the barrier is 15 m, above the foundation top level. The foundation is manufactured using mining truck tires as permanent formwork. The distance between posts axis is approximately 15 m.

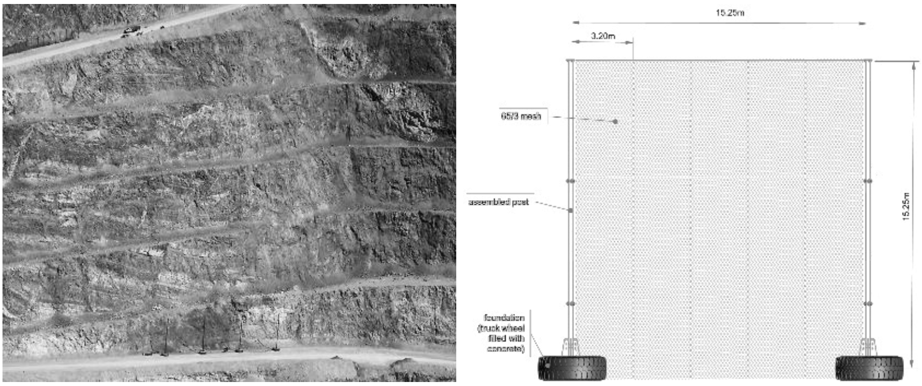



*Figure 9, Installation platform at 2164 m elevation (left) and overview of one single functional module (~232 m$^2$)*

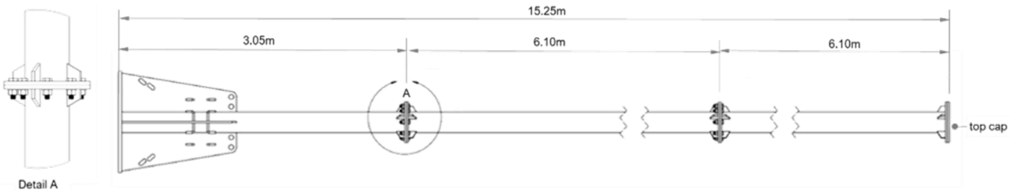



*Figure 10, Post assembly, connection detail*

The upper elevation 2278 m and the bottom is at 2164 m. The bench face angle is around 70º, the medium width is 9.50 m, while highwalls are 24.4 m. Bench profile design according with the modified Ritchie criteria, with an inter-ramp angle of 52º. The plan length of the profile studied is about 110 m (Figure 11).

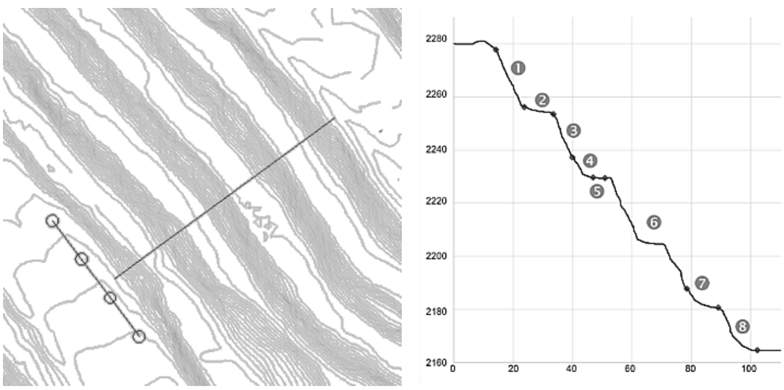



*Figure 11, Top view and profile of the barrier (left) and the rockfall path (right)*

ROCKFALL SIMULATION

It is particularly useful, before carrying out field tests, to carry out some numerical simulations, based on the topographic characteristics of the terrain and its geomechanical properties. A 2D rockfall model was generated using the Rocscience RocFall2 software package [13] to mimic the observed trajectory for the purpose of comparison with the test results. The topographic profile for the rockfall was generated from the point cloud and loaded into RocFall2, which was simplified to reduce the number of nodes along the profile for reduced processing time, and the profile properties were input. It is also necessary to provide as input the estimated physical properties of the profile where the impacts will occur, in this case, and based on experience, coefficients of 0.35 and 0.85 have been used for the normal and tangential restitution coefficients. Then the point from where the launch is made is defined (elevation 2278 m), as well as the shape and dimensions of the design block. In this case, an equant block of 172.4 kg and density 2400 kg/m$^3$ has been used. With this preliminary information, some releases are made, without any protection, to estimate the energy and rebound height, usually focus on the lower platform (2164 m) where the barrier, is expected to be erected. Figure 14 a, b shows simulations where the boulder can be observed at two different times. Next step is locating the barrier and perform the rest of rockfall mimic (Figure 14 c, d).

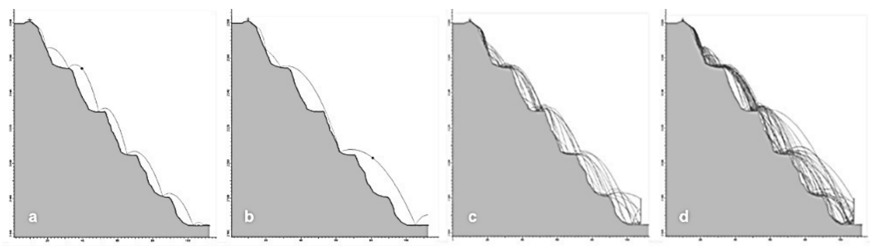



*Figure 14, Rockfall simulation at flight phase (a, b) and intermediate step and end of the rockfall simulation, including a barrier at bottom platform (c, d)*

As a result, graphs of total kinetic energy (Figure 15), and rebound height (Figure 16) along the profile can be represented. Note that the maximum energy value shown for the 68% percentile is approximately 27 kJ, while for the 95% percentile it would be 47.7 kJ. In the case of the rebound height, the highest value for the 95% percentile is 12.1 m.

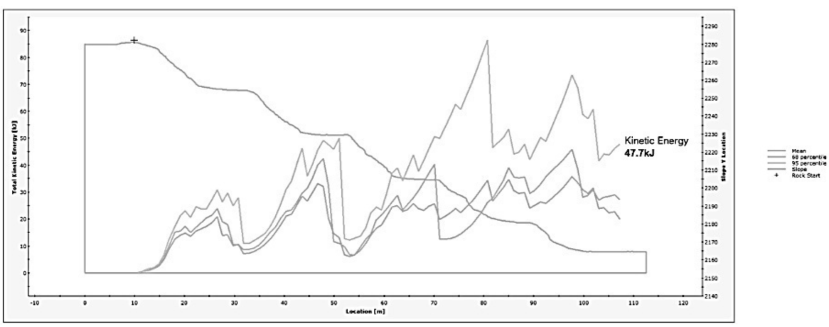



*Figure 15, Total kinetic energy along profile*

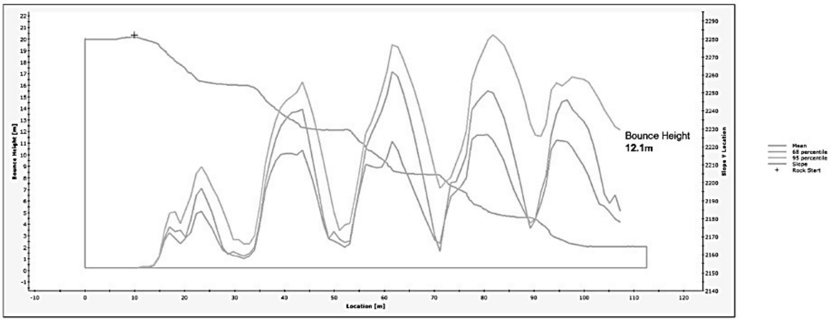



*Figure 16, Total bounce height along the profile*

This is an example of the simulations, demonstrates that the location of the barrier is right, that the blocks arrive at the barrier, with total kinetic energies around 50 kJ and rebound height does not exceed the 15 m assumed by the design.

FIELD TEST MEASURES AND VERIFICATION

Table 3 describes in detail one of the trials, the successive impact and rebound process of the 172.4 kg block that is released from the upper berm at a level 2278 m. For the analysis, the trajectory is divided into intervals associated with the time in which the block detaches and successively impacts the ground surface. This table defines the type of movement characteristic of the section (bounce or roll), detailing the distance travelled horizontally and vertically, as well as the time interval in which said displacement happens, achieving in this way, evaluating the energy. Measurement records provided by [5].

*Table 3, Description of the trajectory of one serial trials*

| **Trajectory** | | **Distance** | | **Time traveled** | | | | **Velocity** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | **Hor.** | **Ver.** | **Total** |
| **Intervals** | | **ΔX [m]** | **ΔZ [m]** | **start [s]** | **end [s]** | **time [s]** | **time elap. [s]** | **[m/s]** | **[m/s]** | **[m/s]** |
| 1 | bounce | 9.75 | 21.70 | 21.26 | 23.27 | 2.01 | 2.01 | 4.85 | 19.71 | 20.30 |
| 2 | roll | 9.57 | 2.79 | 23.27 | 24.47 | 1.20 | 3.21 | 7.98 | 0.00 | 7.98 |
| 3 | bounce | 6.54 | 15.95 | 24.47 | 26.31 | 1.84 | 5.05 | 3.55 | 18.04 | 18.39 |
| 4 | bounce | 8.67 | 8.04 | 26.31 | 27.25 | 0.94 | 5.99 | 9.22 | 9.22 | 13.04 |
| 5 | roll | 4.01 | 0.05 | 27.25 | 27.35 | 0.10 | 6.09 | 40.10 | 0.00 | 40.10 |
| 6 | bounce | 25.83 | 41.85 | 27.35 | 30.43 | 3.08 | 9.17 | 8.39 | 30.20 | 31.35 |
| 7 | bounce | 10.90 | 7.22 | 30.43 | 31.35 | 0.92 | 10.09 | 11.85 | 9.02 | 14.89 |
| 8 | bounce | 17.83 | 9.24 | 31.35 | 33.24 | 1.89 | 11.98 | 9.43 | 18.53 | 20.80 |

The Figure 18 shows the variation in translational velocity [m/s] and kinetic energy [m/s], which characterize the rockfall down the mine slope. The graph describes how the block break each lapse of time during it impacts with the ground surface, recovering energy once the movement continues, during the following flight phase. The maximum translational velocity value in the bounce phase is around 30 m/s with a kinetic energy of 84 kJ at time 9.2 s. Noted that the characteristic values at the impact level (2164 m) are lower, due to the reduction in kinetic energy during each ground contact (normal and tangential restitution). The maximum speed in the barrier is 20.8 m/s, while the energy is 37 kJ at 12 s time. During the two rolling phases, no values have been recorded (blue light areas at Figure 18).

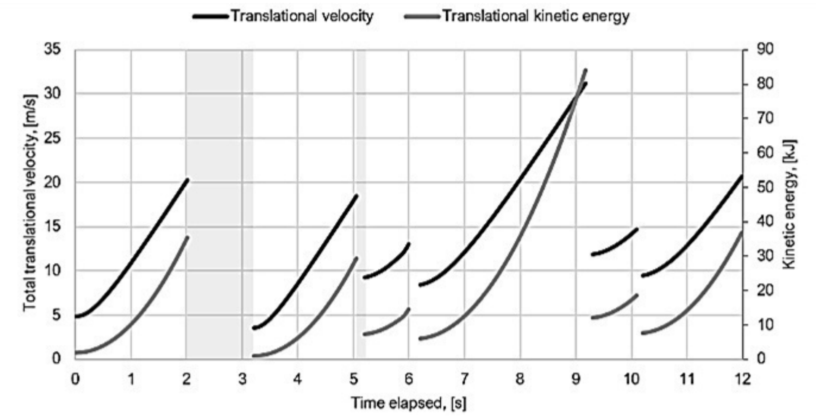



*Figure 18, Maximum translation velocity and energy values for the bounce phase (flying)*

The results obtained in the field largely agree with those of the computer simulation (means calibrated model), the basic statistical values of total kinetic energy [kJ] and rebound height [m], necessary for dimensioning, are near to the estimates. Probably the velocities values [m/s] achieved in this test do not exceed the expectations related to the expected *bullet effect*. The proportion of kinetic energy due to the angular velocity [rad/s] estimated according to the software (Figure 19) is low compared to the total velocity; it would be very helpful in future tests to be able to measure the angular velocity [rad/s] of the tested block to respond to this uncertainty, especially because shearing forces [kN] generated when block impact the membrane.

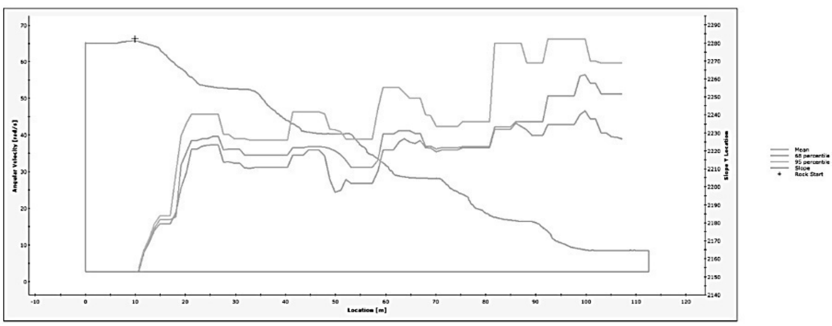


*Figure 19, Maximum translation velocity and energy values for the bounce phase (flying)*

## TECHNICAL FEASIBILITY OF USING THE SOLUTION

The mobile-temporary barrier model (flycatcher) performed right in the full-scale test. Overall, an effective solution to low energy level rockfall events (natural or results of blasting). Protection system stopped a 0.45 m concrete equant block [4] which impacted the system at mid-height (6.5 m), in the middle of the membrane field. Additionally, system retained concrete blocks rolling along the base of the slope, preventing blocks from entering the haul road (Figure 20). The block sizes included in the trials were: 0.15 m, 0.30 m and 0.45 m in diameter (both equant and cubes). Similar characteristic systems installed in South America have been in use and proven effective at retaining rockfall events.

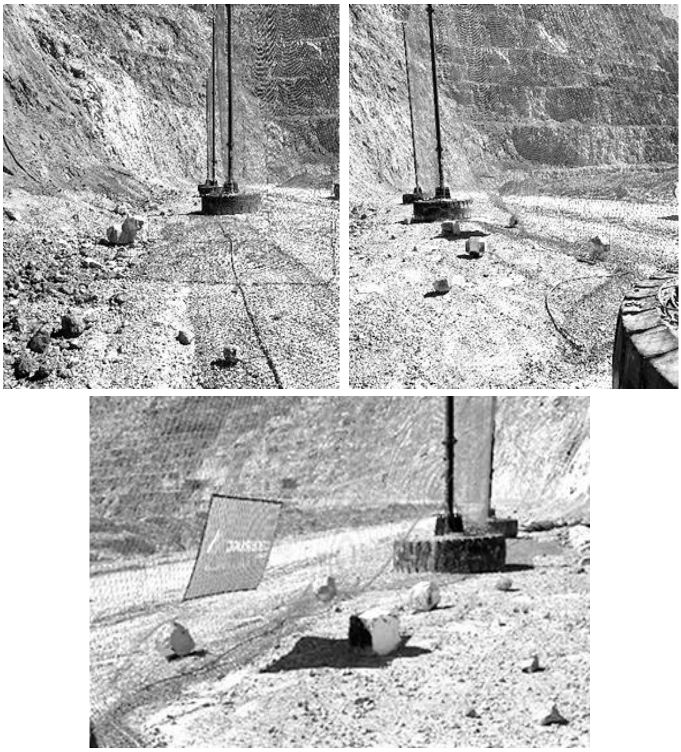


*Figure 20, Different size and shape blocks stopped and the slope bottom*

## PREPARATION FOR ERECTING AND BENEFIT OF THE SOLUTION

Aspects related to the construction process of the barrier that must be considered to guarantee its correct performance are also of vital importance. As much as possible prior to install on bench/ haul road in lay-down area it will fill tires with concrete and attach it the ground plate and posts including, running wheel and side ropes them transport the posts with side ropes and mesh panels. The installation process should be done in two steps: set base and post in place (dozer loader should be used to push into place) and fix and lift mesh panels (forklift or crane could be uses considering width of panels to be loaded). It is very important to guarantee the minimum impact on operations since this will always be associated with exploitation costs. For the transportation and mobilization of the components, it is necessary to have adequate machines due to the bases (post foundations) are very heavy. The proposal is to use for pushing (dozer loader) and crane or heavy-duty equipment for trailer (lowboy) loading/ unloading. The main benefits of this type of solutions in terms of safety and health are summarized in the Table 4.

*Table 4, Flycatchers' advantages related to the reduction in risk*

| Action | Risk reduction |
|---|---|
| Eliminates nearly all aspects of elevated work (working at heights, elevated work platform, rope access, etc.) | Reduces amount of overhead work: crane lifts and potential failed rigging |
| Assembly in laydown yard, Controlled environment. | Reduction of potential hazards: power haulage and level ground that is not in active mining area (reduce likelihood of rockfall hazards from above work area), ability to set working boundary to prevent entry (exclusion zone). |
| Installation time at bench/ haul road | Reduce risk time of exposure (reduced installation time):Slope hazards, mobile equipment/ power haulage on haul road<br>No drilling of anchors or tiebacks/ downs and moving parts, silica, dust, hydrocarbons. |
| Similar operation to setting electrical towers/ trees/ candlestick used for electric shovels. | Reduce risk due to repetitive works and personal experience. |
| Mechanical lifting, in one lift. Not by hand pulling up or setting induvial panels. | Reduced hazard to workers, reduced human resources to the risk exposure. |

In addition to clear advantages from the point of view of safety and health, this new technology allows important steps to be taken in economic and sustainability terms. Listed below are some aspects demonstrates the efficient behavior of this solution with respect to traditions (Table 5).

*Table 5, Flycatchers' economic and sustainability advantages*

| Action | Consequence |
|---|---|
| Reduced impact on operations | Move more tons then increase in bottom Line |
| Low installation time | Reduce potential footprint of protection measures versus earthen berm |
| Reduced execution cost | Lower versus some former versions and standardized rockfall barriers acc (EOTA 2018) |
| Reusable several times | Lower cost |
| Reduced footprint | Less waste moved and increased in bottom line |
| Standardized Parts | Lower cost in repairs and maintenance |
| No anchors, no foundations | No drilling cost |
| Reduced Installation time | Lower contractor erection price |
| Reduced Risk | Lower liability (lower Insurance cost) |
| Potential to use spent tires | Less cost in disposal/ waste (second lifetime opportunities) |

In addition to the location at Bald Mountain under study in this paper, some pilot tests and installations have been erected in mining developments in other countries Figure 21 shows examples: current in Nevada (US), Rancagua (Chile) and Pan-American Silver Arena (Peru).

*Figure 21, Final overview at Bald Mountain in US, trial in Chile and in Peru*

## CONCLUSIONS

The rockfall control in open pit mining is one of the most important safety measures and is a pillar of maintaining the level risk under control, guaranteeing the production and operation. For years, various types of protective measures have been planned, ranging from embankments, to standardized barriers, to mobile barriers like those studied here, installed without following any technical dimensioning guidelines. The analysis of the behavior of the expected design blocks (small boulder dimensions) in terms of translational and angular speed provides objectivity and security in design. The control of the *bullet effect* using high tensile strength flexible steel membranes constitutes the main contribution in material terms. It is very important to point out that during the field tests no damage was caused to the flycatcher system, due to the use of high tensile strength steel wire. If mild steel had been used in the membrane, the *bullet effect* would surely have been produced just as it was demonstrating at trials (Table 2). Comparison between mathematical simulation and the full-scale test demonstrates that the model is consistent. Therefore, the use of this type of solutions against low energy impacts (less than 100 kJ) at high speed is safe and sensible. It would be of interest to perform some additional tests to investigate the influence of angular velocity during impact. Items related to the installation method as well as the technical-economic advantages of this flycatchers, should contribute to its correct use. The flycatcher helps on the safety of pedestrian workers, small vehicles and extending the lifetime of the extraction trucks and big machinery.

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