Slope Stability 2020 - PM Dight (ed.)

doi:10.36487/ACG_repo/2025_82

Recovery of blue water ramp access affected by rockfall

D Diaz *Anglo American Cooper, Chile*

E Bermedo *Anglo American T&S, Chile*

M Schellman *Anglo American T&S, Chile*

Abstract

The blue water ramp is the only existing access to Donoso 2 Phase at Los Bronces Mine that belongs to Anglo American. This ramp registered a significant number of rockfall events during 2016 and 2017, thus a decision was made at the end of 2017 to close down this access and as a result, Donoso 2 Phase.

In order to safely resume operations at Donoso 2 Phase, a multidisciplinary team has performed work which included a rockfall analysis, coefficient calibrations and in situ tests to verify the behaviour of the proposed solutions, considerations of implementation logistics and subsequent follow up of the implemented strategy. The aforementioned with the purpose of being able to guarantee a safe access to the phase, thus resume the development of the same.

The solution proposed considered the installation of reinforcement mesh in the upper part of the ramp and mixed containment barriers at the base. This solution has allowed maintaining operational continuity at the access point to Donoso 2 Phase. Furthermore, this option has been used as a solution basis for other sectors.

Keywords: *rockfall, containment, in situ test*

1 Introduction

The blue water ramp is the only existing access to Donoso 2 Phase, which makes it critical for phase development. A significant number of events associated with rockfall impacting equipment have been registered at this ramp. The access ramp was closed on Monday 13 November 2017 as a result of a blast that caused material to fall on the ramp, blocking access to the phase. The main objective of this document is to show the methodology, the analysis and the strategy that was developed to allow resuming operation at Donoso 2 Phase in a safe and sustainable manner.

The following are the main stages carried out during the recovery process:

- Recovery of blue water ramp emergency access.
- New rockfall events at blue water access ramp.
- Definitive alternative solutions for blue water access ramp.
- Definition of a solution implementation strategy.
- New request of minimum operational width required.

2 Recovery of blue water ramp emergency access

The first thing that was carried out was the analysis of the current blue water ramp condition, in order to be able to propose options that would allow recovering this access only for emergencies and restricted use. All analyses have been applied through RocFall (Rocscience Inc. 2016) software, and coefficients of restitution from benchmarks for this type of material used at El Soldado and Los Bronces have been used for this stage. Figure 1 shows the plan view of blue water access ramp (Donoso 2 Ramp Access) and the analysis profile used.

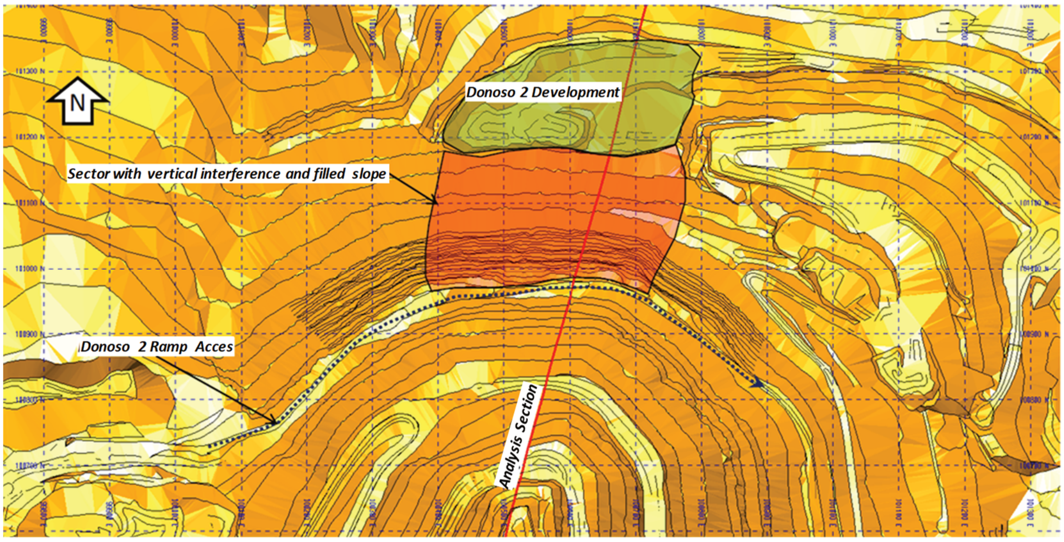


Figure 1 Location at in-plant access ramp and rockfall analysis profile

The rockfall analysis performed includes two scenarios. The first scenario is the current case with existing topography, and the second scenario is with a proposed configuration that is made up of a containment berm that is 4 m high while only maintaining an operational width of 4 m at the ramp. Coefficients of restitution applied are shown in Table 1, which have been obtained in a conservative manner as a benchmark in material with similar characteristics from El Soldado and Los Bronces operations (Bermedo & Schellman 2004, 2017).

Table 1 Coefficients of restitution used

Unit	Normal coefficient of restitution (Rn)	Tangential coefficient of restitution (Rt)	Friction angle (ϕ, °)
Slope on rock	0.50	0.950	39
Fill material	0.30	0.825	35

Based on analyses performed, 100% of rocks of the current case reach the access ramp (Figure 2). In the case of the proposed configuration with a berm, such alternative would allow 5% of rocks to reach the access ramp (96% of berm containment) (Figure 3).

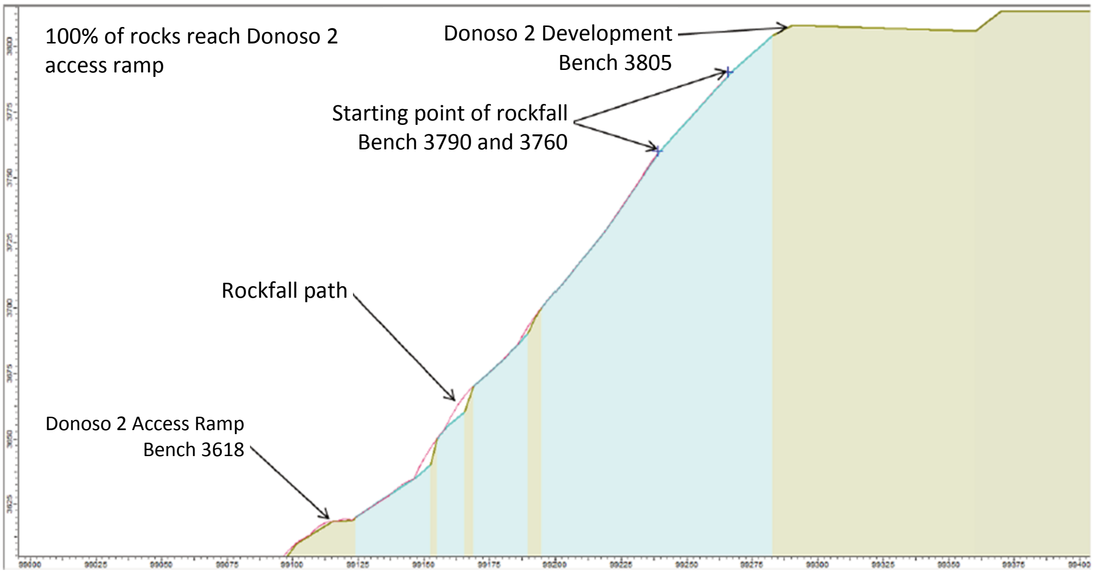


Figure 2 RocFall analysis, base case and case with berm

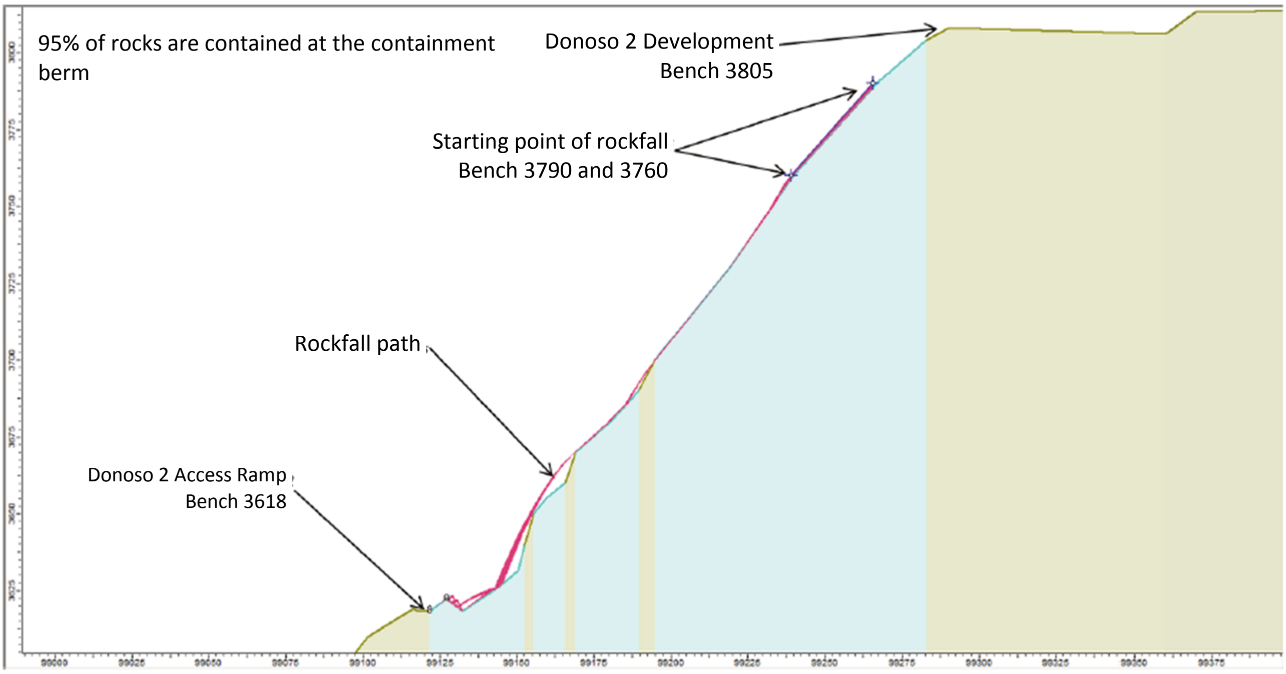


Figure 3 RocFall analysis for case with berm

3 New rockfall events at blue water ramp access

Despite the fact that analyses performed validate that the proposed solution to maintain a 4 m high berm and an operating width of 4 m at the ramp allows the containment at least 95% of rocks, rockfall events that impact traffic along this ramp have continue to take place. In order to understand this, a rockfall analysis considering as-built condition has been performed. When undertaking this analysis, as shown in Figure 4, one can see that 100% of rocks would reach the access ramp. This occurs because the operational width considered in analyses at the access ramp was 4 m; operations have now increased to the ramp to 11 m in order to be able to work with the excavator shovel to build the berm. This has moved the containment berm towards the slope, which in turn reduces its effectiveness regarding rockfall.

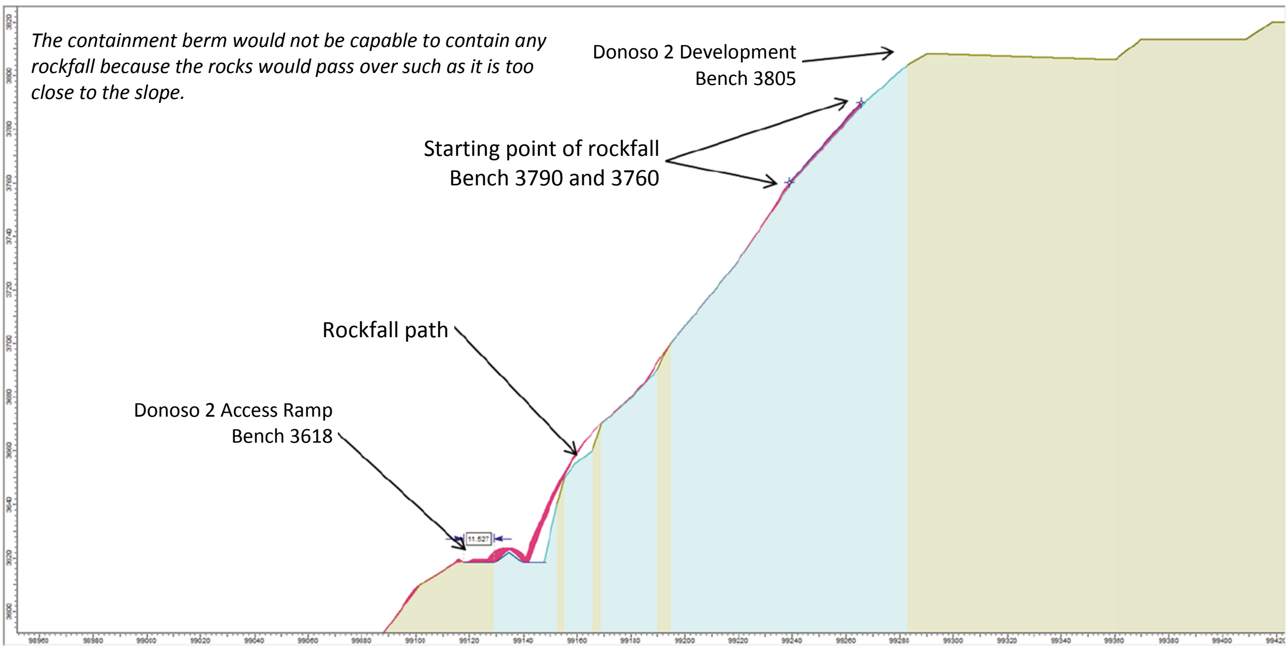


Figure 4 RocFall analysis for as-built condition

4 Definitive solution alternatives for blue water ramp access

During the search for a definitive solution, the operational requirement to maintain an access ramp that has an effective width of 10 m was considered as an input. It must be pointed out that the total width of the blue water ramp from toe to crest varies between 21 and 36 m for the area of analysis. Taking this into account, options that allow achieving the operational width requested, while guaranteeing safety for people and/or equipment, have been analysed. The initial condition analysed is a 4 m high berm at the toe and a 2 m high berm at the edge of the road (road standard). This generates the issue that for the construction of berms with these heights, the base that is used is significant. Thus, a solution to 'gain' operational width from the base of such berms is proposed (Figure 5). If this option is considered, 2.6 m can be gained from each berm, which would mean an additional 5.2 m. Two analysis profiles have been considered, which are shown in Figure 6. The properties used in the central zone of Donoso 2 Phase development are those indicated in Table 1. The results of the analyses for profile 1 are shown in Figure 7 and, for profile 2, are shown in Figure 8. They indicate that the containment percentage, considering a 4 m high berm and a ramp with an operational width of 10 m is greater than 99%. It is important to point out that even when the value achieved for containment 100%, there will always be a probability that a rock may pass over this berm, due to the complex kinematic properties that the rockfall event represents.

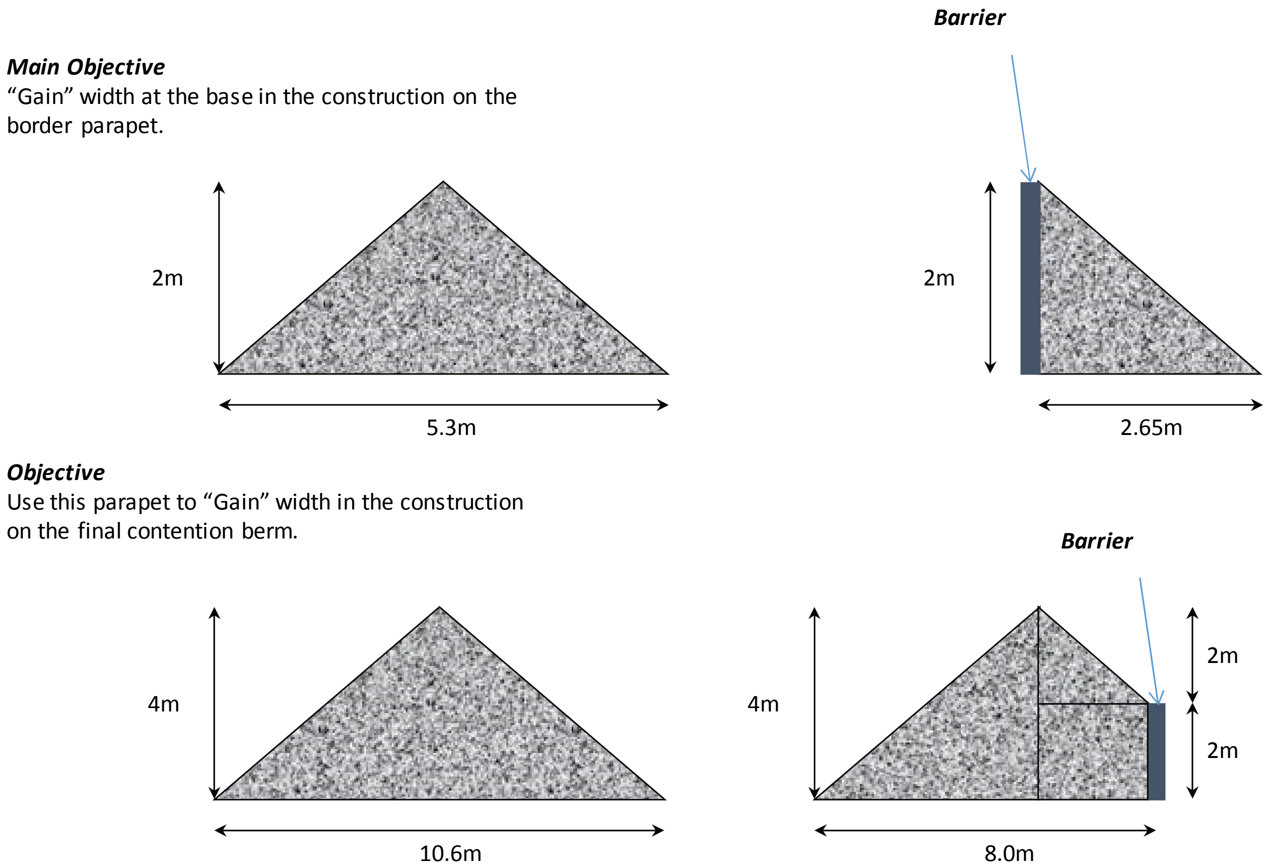


Figure 5 Strategy to gain width in the parapet construction

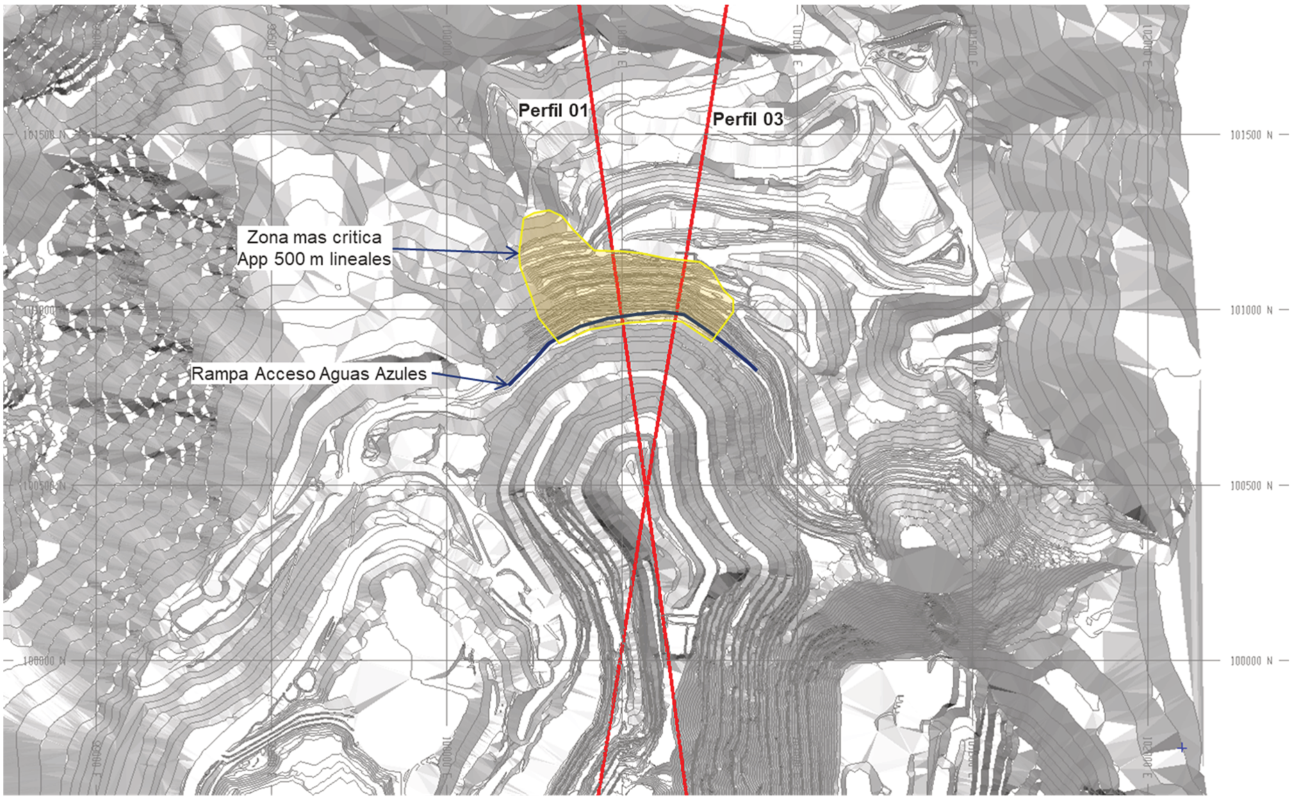


Figure 6 Plan view with two sections considered in the analysis

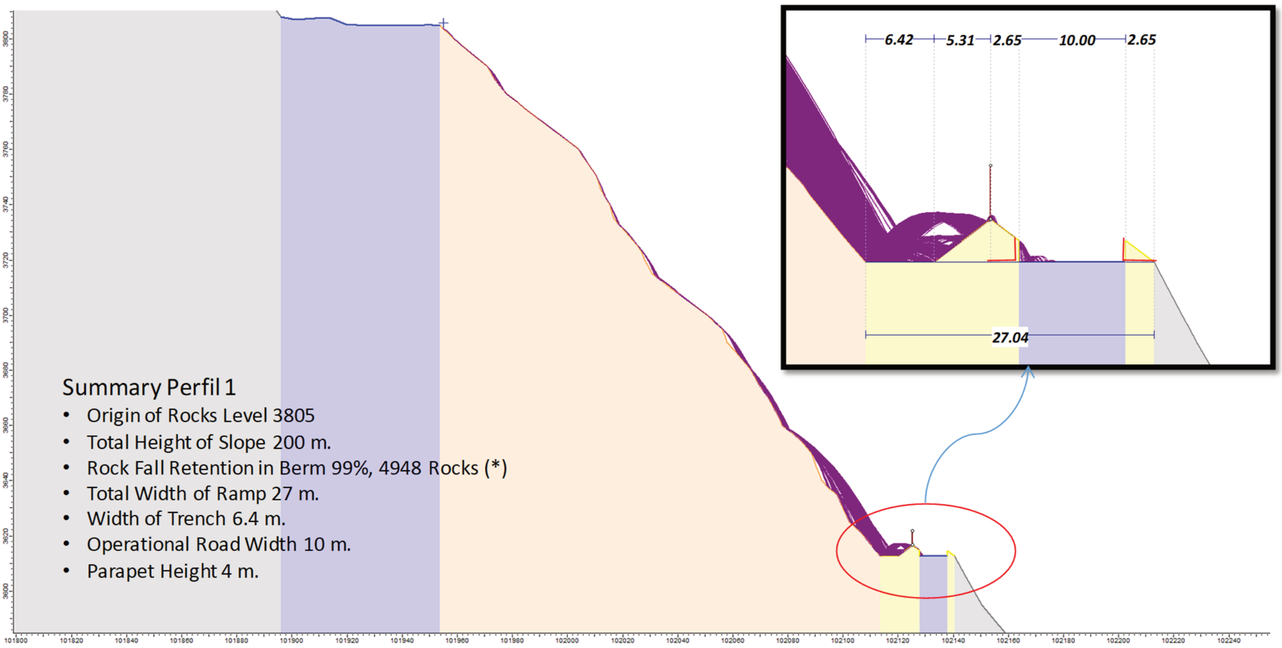


Figure 7 Summary RocFall analysis profile 1

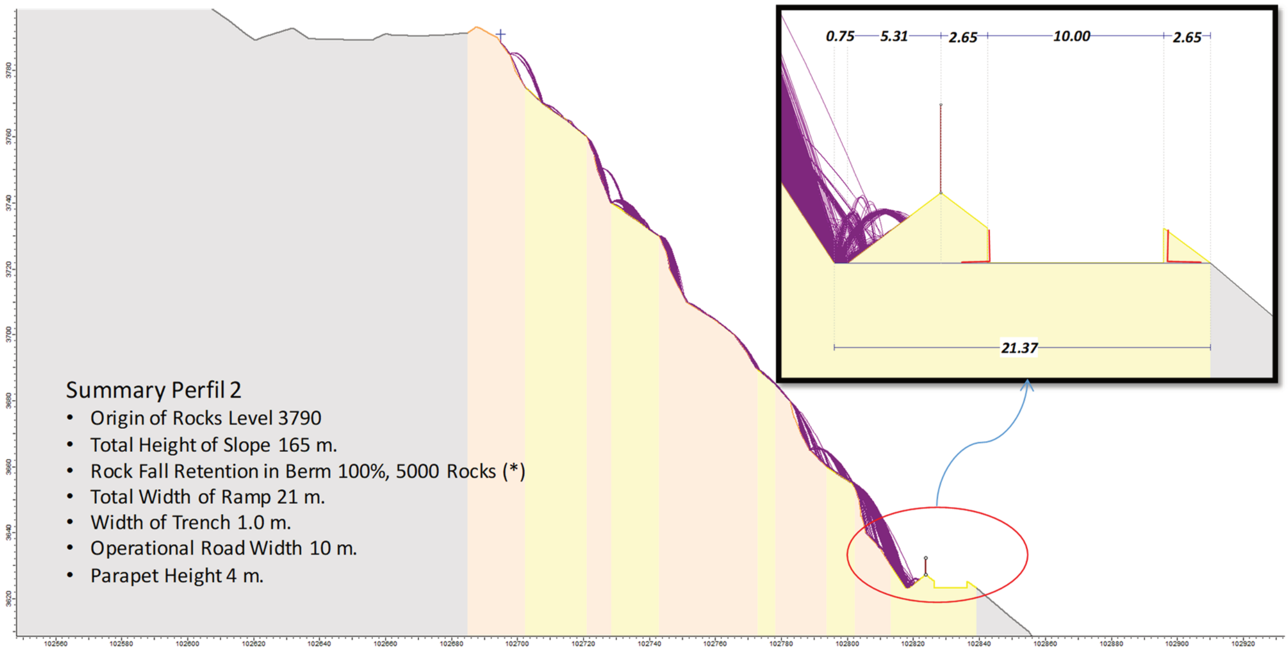


Figure 8 Summary of RocFall analysis profile 2

5 Definition of solution implementation strategy

The implementation of the proposed solution must consider the following aspects:

- Guarantee safety of people and/or equipment during construction process (installation of barriers and construction of 4 m high berm).
- Define the type of barrier to be used in berms.
- In situ tests of barriers.

5.1 Guarantee safety of people and/or equipment during construction process

In order to be able to develop the proposed solution, the whole ramp must be cleaned whereby barriers may be installed and berms may be built subsequently. The cleaning process may be executed by control at a distance and/or remote control, however, people and/or equipment operated manually will participate during the construction process. For the aforementioned, we must see the option that shall allow minimising the risk of rockfall that impacts people and/or equipment. For this purpose, the sector has been reviewed in detail and it has been established that the major source of origin of potential rockfall is in the initial 45 to 60 m, because it is an area of blasted and fill material that is very susceptible to the change of temperature and gusts of wind. A sector of 200 lineal metres has been defined, where mesh will be installed for the purpose of containing and reducing eventual rockfall, as shown in Figures 9 and 10.

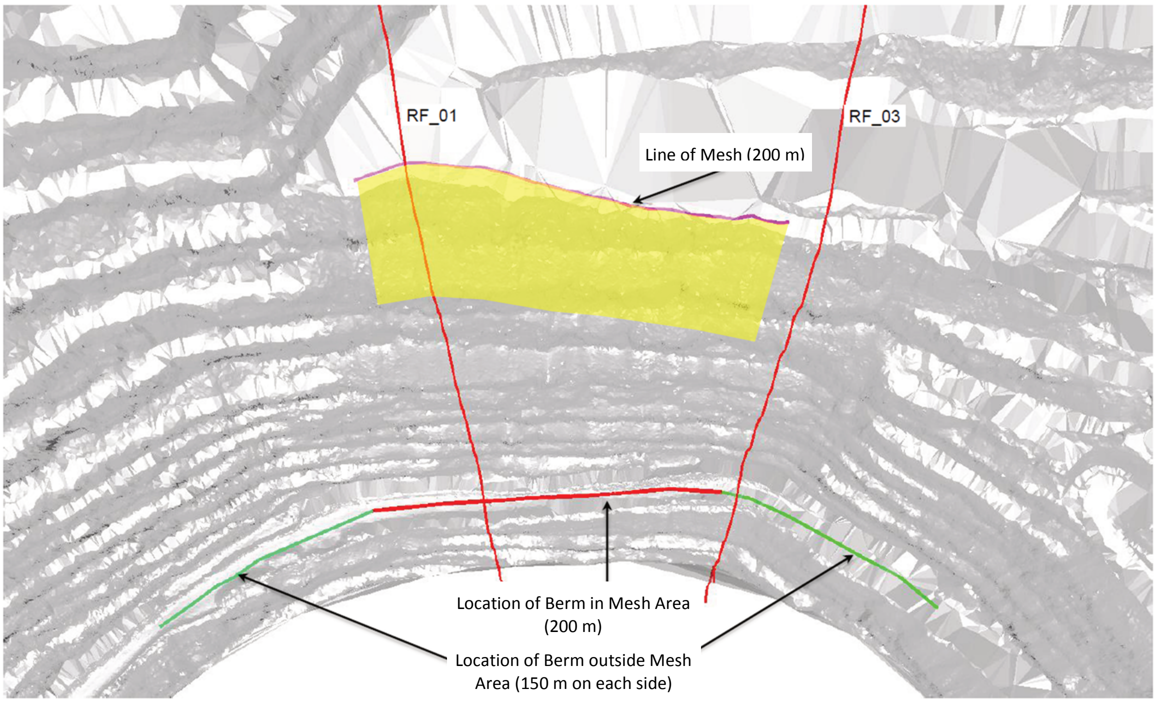


Figure 9 Area of mesh drapes installation

Figure 10 Upper bench mesh In Donoso 2

5.2 Definition of barrier to be used

In order to be able to build the geometry indicated in Figure 5, there must be a system that allows retaining and it shall be capable of supporting the lateral load from the material that is deposited on the 2 and 4 m high berm. Two alternatives have been reviewed for this purpose:

- Edge protector barriers: These are barriers that are built of reinforced polypropylene and their approximate weight is 700 kg. They are 2 m high, 2 m wide and 2 m long, and they are built with buttresses and have been used for this purpose at mines abroad (Figure 11).

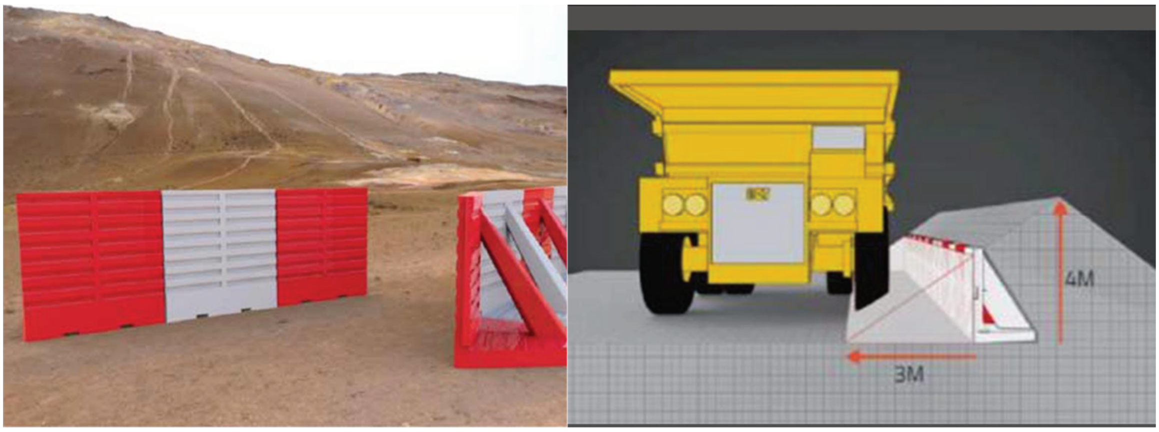


Figure 11 Edge protector barriers

- New Jersey grau (gravity) barriers: These barriers are built of reinforced concrete. Their weight is approximately 3,100 kg, they are 2 m high, 1 m wide and 2 m long. They are currently being used as road barriers (Figure 12).

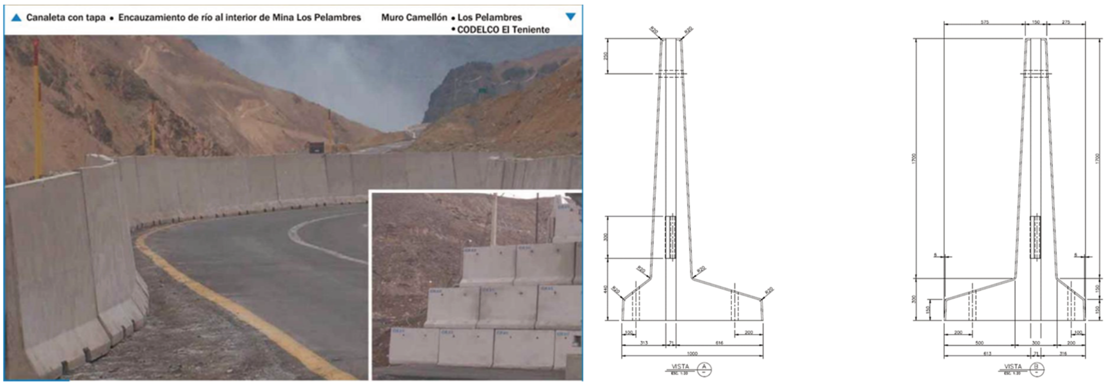


Figure 12 New Jersey graubarriers

Out of the two options analysed, it was decided to perform in situ tests of New Jersey grau barriers, given mainly the time for shipment and construction of edge protector barriers.

5.3 In situ barrier tests

The purpose of performing the tests was to verify the stability of barriers under static conditions (only barrier with material deposited behind it), under static load application (simulating the impact of rocks on barrier material) and under loads application. Three berm wall units were considered for these tests, which will work independently. The maximum height of 4 m will be reached at the central wall and the following tests will be performed:

- Static test, when the material reaches 4 m at the central part: No changes, complies (Figure 13).

Figure 13 Static test – okay

- Dynamic test 1, constant pressure, with loader (Caterpillar 992K) behind the wall: Normal load on material, complies (Figure 14).

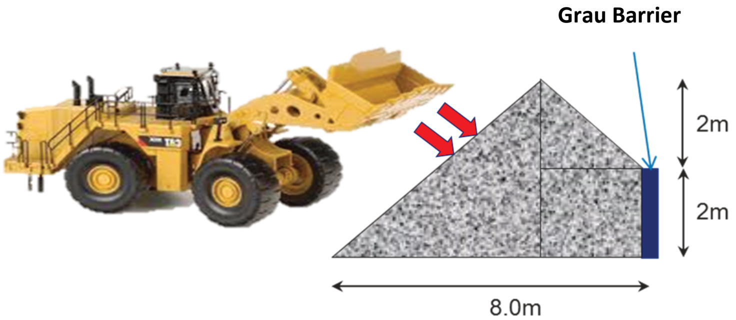


Figure 14 Dynamic test 1 – okay

- Dynamic test 2, pushing with loader (Caterpillar 992K) at low height, behind the wall: Load that is perpendicular to material, complies (Figure 15).

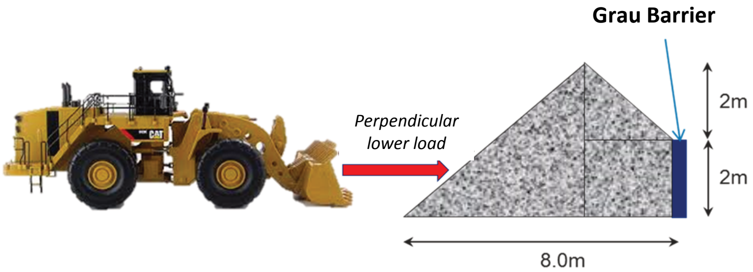


Figure 15 Dynamic test 2 – okay

- Dynamic test 3, push with loader (Caterpillar 992K) at medium height, behind the wall: Load that is perpendicular to material, complies (Figure 16).

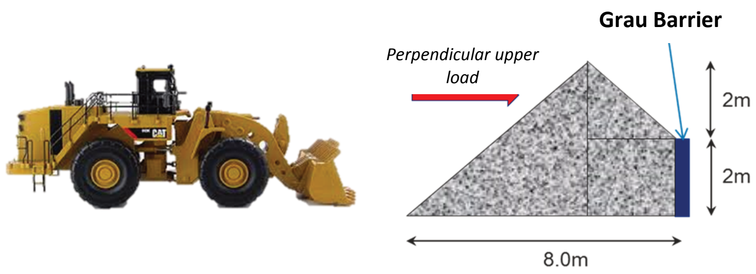


Figure 16 Dynamic test 3 – okay

Tests developed in situ were successful for the static and dynamic case, whereby no failure or cracks on the wall or its base were noted. Furthermore, no deformations or signs of overturning on the wall-berm were noted. Based on the aforementioned, it is concluded that the barriers may be used with a 4 m wall behind them. It must be noted that the aforementioned has been carried out to verify that, in the event of an overload of a berm due to material in the pit (hole), it will not have any stability related issues. Resistance to rockfall has not been considered since such energy will be absorbed by the granular material behind the wall.

6 Re-analysis considering new minimum operational width

At the request of mine operations, the need to increase the operational width of blue water access ramp from 10 to 12 m has been incorporated. This requires a more detailed analysis, which considers a calibration of coefficients of restitution used through a back-analysis.

6.1 Calibration of coefficients of restitution

In order to perform the back-analysis, it was requested that personnel specialised in vertical work drop rocks from the medium–high part of the slope in order to see their behaviour and path (Figure 17). This was carried out several times with small to medium sized rocks. The fall of rocks was registered and analyses were carried out through the RocFall software to calibrate coefficients of restitution of fill material, in order for them to better represent that which was observed in the field. Only fill material will be calibrated, since it represents a major proportion at the slope as most of it is overloaded. Rock type material coefficients will remain conservatively as shown in Table 1. The height of rockfall is approximately 150 m and there is a 2.5 m high berm at the ramp. After the tests, it was noted that a low percentage of rocks was able to pass over the berm of the sector. The results of the base case are shown in Figure 18 and calibration is shown in Figure 19.

The calibration process of coefficients of restitution considers an iterative process where starting from the properties used initially (conservative), an attempt is made with software simulations to reach as close as possible the actual location where the rocks that were thrown landed.

As a summary of analyses, it could be indicated that the normal coefficient of restitution was increased from 0.29 to 0.39. The tangential coefficient of restitution was reduced from 0.82 to 0.5 and the friction angle was increased from 35° to 37°.

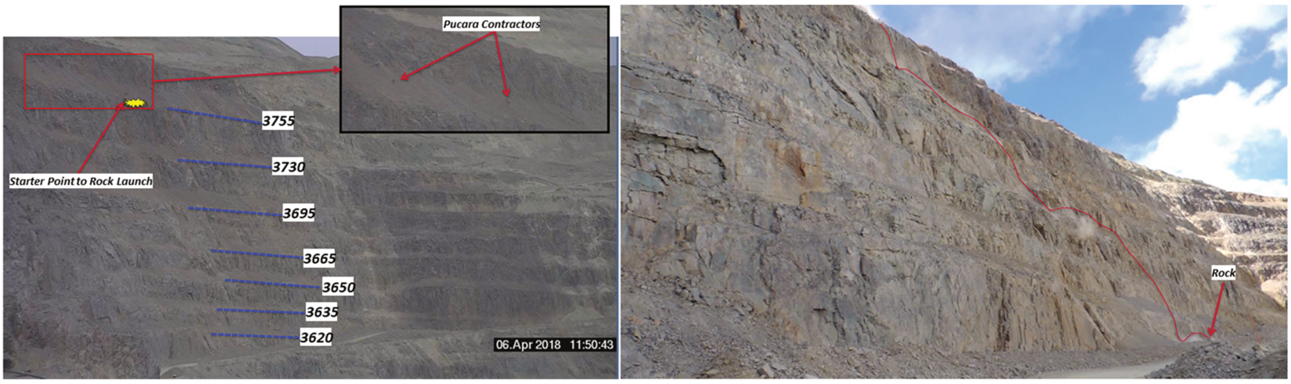


Figure 17 Rockfall back-analysis zone

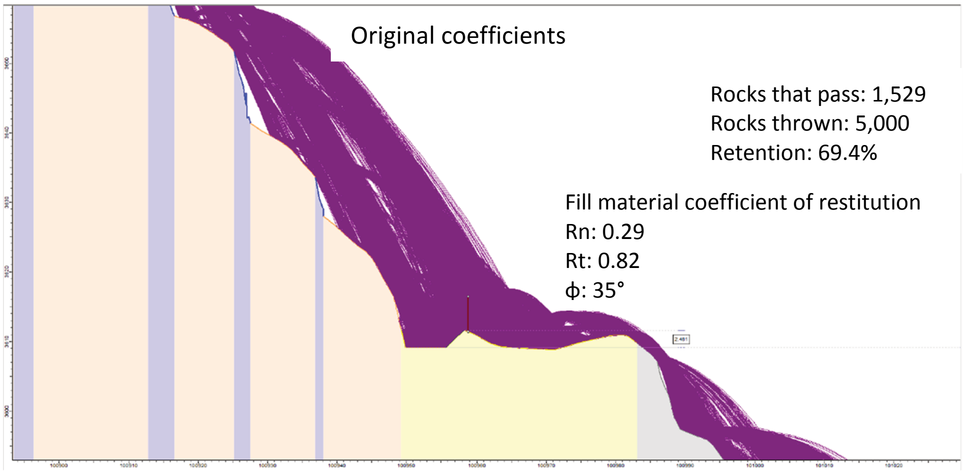


Figure 18 RocFall analysis – base case

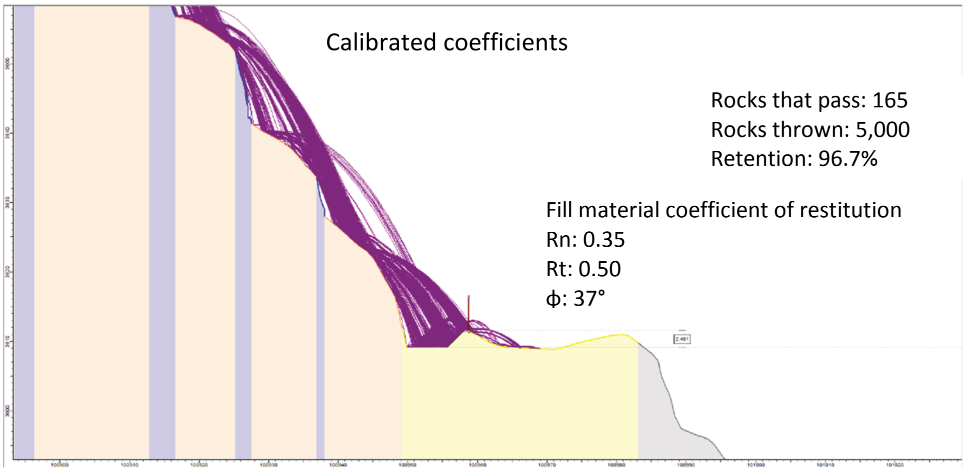


Figure 19 RocFall analysis – calibration

6.2 Re-analysis of blue water access ramp

The coefficients of restitution calibrated in accordance with that which is indicated in the previous point (analysis sections considered, shown previously in Figure 9 and Figure 11, additional sections shown in Figure 20, which include the initial point where rocks fell from) have been considered for the re-analysis of the blue water access ramp. Figure 21 shows as an example of an analysis profile and Table 2 shows a summary of the results of analyses performed.

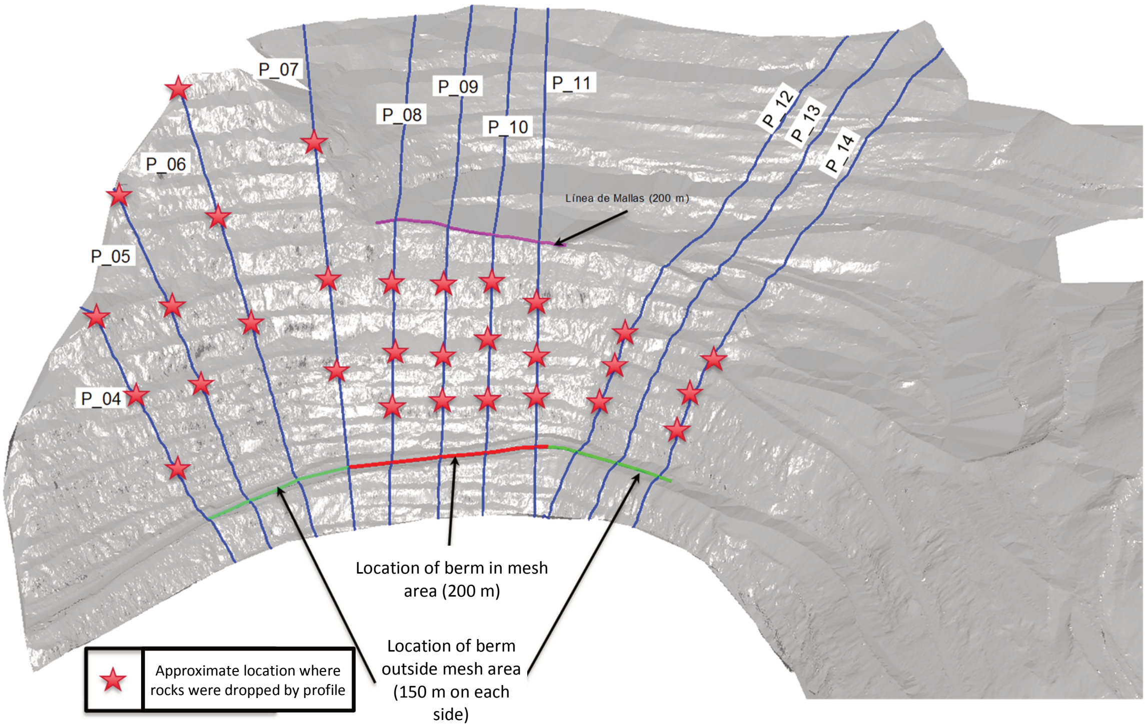
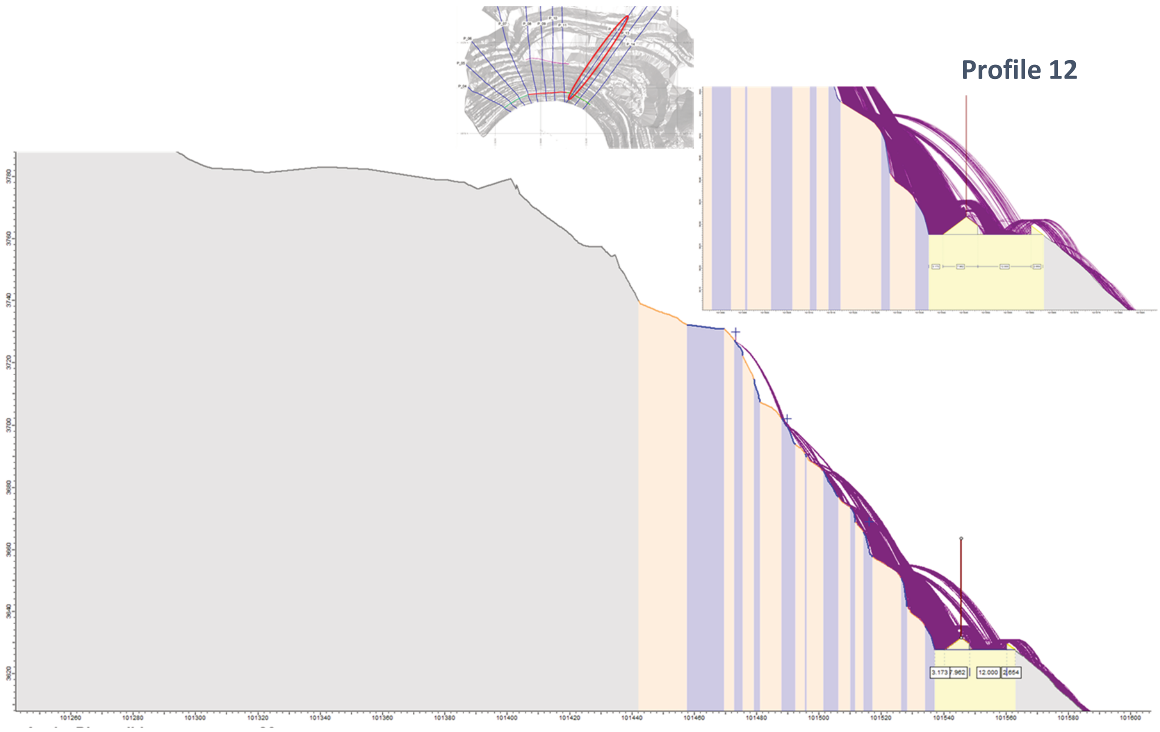


Figure 20 Rockfall analysis sections and location of seeders



Width available: 26 m
Elevation of rocks dropped: 3731 – 3702 – 3665
Elevation of ramp: 3627
Height of rockfall: 105 – 75 – 40
% of rock containment: 92.9%
Containment pit (hole): 3.2 m

Figure 21 Example of RocFall analysis in section 12

Table 2 Summary of RocFall analysis results

Profile	Profile height (m)	Containment pit (hole) (m)	Berm containment (%)
P4	180	4.6	95.0
P5	250	13	95.0
P6	330	13	94.5
P7	270	12.5	91.1
P8	150	11.7	93.3
P9	145	6.2	91.6
P10	140	2.6	94.1
P11	120	3.6	94.3
P12	105	3.2	92.9
P14	100	7.2	94.1
RF_01	197	12.1	94.6
RF_03	168	1.3	92.8

7 Handing over blue water ramp to operations

Once the re-analysis was finalised, tasks to resume transit through blue water were initiated. For this purpose, New Jersey barriers were installed on both sides of the access ramp, while creating the requested operational width. Thus, safe transit to access the phase is resumed, as shown in Figures 22 and 23.

Figure 22 Blue water road access recovery

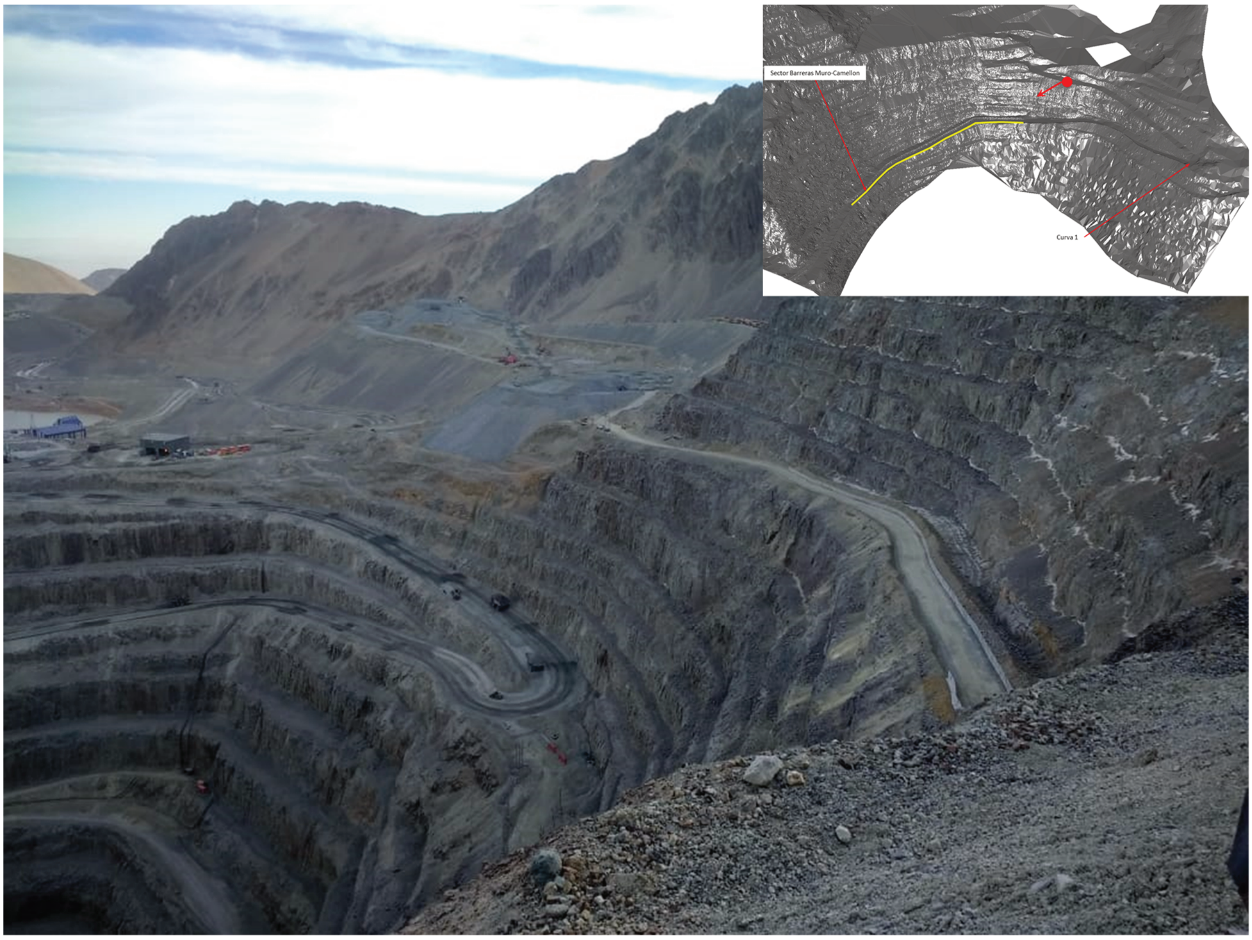


Figure 23 General view of blue water ramp access

8 Conclusion

In accordance with that which is presented in this document, the recovery of the blue water ramp was a rather complex and iterative process that required the involvement of a multidisciplinary team in order to ensure compatibility of safety requirements that were necessary to be able to resume safely the development of the phase. This could be noted by the fact that while analyses and execution of alternatives and solutions were being performed, Donoso 2 Phase shut down from November 2017 to May 2018. Operational strategies have been defined as part of the additional measures to guarantee the survival of proposed controls (barriers and berm), such as controlled contour blasting, permanent cleaning of containment pit (hole) and the replacement of barriers and height of wall if standard is not complied with.

References

Bermedo, E & Schellman, M 2004, *Análisis Caída de Rocas Botadero San José*, Anglo American El Soldado internal report.

Bermedo, E & Schellman, M 2017, *Análisis Caída de Rocas, Rampa Bajo INF 7A*, Anglo American Los Bronces internal report.

Rocscience Inc. 2016, *RocFall*, version 6.0, computer software, Rocscience Inc., Toronto, https://www.rocscience.com/software/rocfall