Ring Blasting Design Modeling and Optimization

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Abstract

Ring blasting designs have to achieve different goals in order to become efficient whether is done in up hole or downhole fashion. Ore recovery/dilution control, fragmentation and drift integrity all have to be taken into account when selecting parameters such as burden, spacing, linear explosive density and stemming. Blast energy simulation allows identifying contours of rock breakage and fragmentation, thus choosing a combination of spacing at the end of holes and appropriate burden. Also, simulations are key to concentrate energy levels on the mid part of the ring while making sure there is not too high of energy concentration around the drift, which integrity is needed for a safe ore mucking.

This paper presents dynamic simulations and models of the main goals in the mine operation: fragmentation and breakage related to ore recovery or dilution control. Every simulation and model is developed talking into account the geotechnical characteristics of the underground mine.

For the fragmentation simulation and prediction model, fragmentation measurements by digital image analysis and blast simulations for explosive energy distribution are compared to achieve the relation of the energy distribution that provides the fragmentation distribution of the blast for the different geotechnical domains of the mine. With this model, customized blasting energy distribution can be modify to achieve the fragmentation required in every domain and mine situation, changing the main blast parameters as burden, spacing, explosive or hole diameter.

Getting the graph of break depth against hydraulic radius is required for the simulation and model of breakage in the mine. With that is defined if blasting is over the maximum hydraulic radius acceptable for the slope. In this situation, to control and simulate breakage, energy and vibrations will be used to achieve a best fit. With the values of energy level will be determined a theoretical energy level related with the break generated in the slope edges. Therefore, for a maximum hydraulic radius will be stablished the maximum energy level admissible. With the knowledge of this energy maximum level is defined criteria of blast design (hole length, explosive, diameters, etc.).

This methodology provides information that can be used in conjunction to design a ring blast to get the best result in fragmentation and damage (dilution and stability), optimizing the blasting activity.

Introduction

Accepting the vital importance of drill and blast processes for the productive cycle of any metallic mining operation, the need of a limited and well-known discipline of design, measurements, control and analysis is critically important. In this occasion, the study is developed in an underground open stope mine.

Ring blasting designs have to achieve different goals in order to become efficient: Ore recovery/dilution control, fragmentation and drift integrity all have to be taken into account when selecting blasting parameters.

This paper presents a methodology of dynamic simulations of the main goals in the mine operation, fragmentation and damage, to obtain results and rock mass behavior trends to be utilized for the designing process. Therefore, in order to control the full blasting process, from the design to the post-blast measurements and analysis, it is necessary to have access to suitable technology for the evaluation of the quality of the results of the blast.

Every simulation and model is developed talking into account the geotechnical characteristics of the underground mine.

For this purpose, blast energy simulation allows identifying contours of fragmentation and rock breakage, to be calibrated against the real results obtained in the field. Again, simulation, measurements and analysis are key to conduct a drill and blast effective process, transforming design into reality.

For the fragmentation simulation, in field measurements by digital image analysis and blast simulations for explosive energy distribution are compared to achieve the relationship between both data. With this information, customized blasting energy distribution can be modified to achieve the fragmentation required in every domain and mine situation, changing the main blast parameters as burden, spacing, explosive or hole diameter. Fragmentation section of the paper involves different graphs mainly utilized to analyze the behavior of each domain. Now that this data is studied, the optimization in terms of fragmentation is able to achieved, as shown in the Case Study.

For the damage simulation and analysis, the graph of break depth against hydraulic radius is required. So that, this info allows identifying if blasting is over the maximum hydraulic radius acceptable for the slope. In this situation, to control and simulate breakage and energy level will be used to achieve a best fit. With the values of toe range energy level will be determined a theoretical energy level related with the break generated in the slope edges. With the knowledge of the energy maximum level admissible stablished for the maximum hydraulic radius, a criteria of blast design is defined (hole length, explosive, diameters, etc.) and optimization can be developed, as shown in the Case Study.

Blasting modeling and optimization has no meaning without field monitoring and supervision, as both are complementary parts of the same thing. Typical optimization refinement process has to incorporate operational restrictions and quality indicators measured during field evaluation.

When all the required simulations, measurements and analysis are explained, a Case Study as an example of the blasting optimization is shown.

Fragmentation Analysis for Blast Design Optimization

The following fragmentation study is the result of detailed and rigorous measurements and consultation with mine staff, to be able to calibrate the predictive fragmentation model of the mine.

This process involves the existence of two different geotechnical domains that require different design approaches. Table 1 shows the characteristics of the ore domains included.

Table 1. Ore domains characteristics

Ore Domain	RQD	Jn	Jr	Ja	Q Barton
DG tipo 1	35.60	10.70	1.47	1.91	2.56
DG tipo2	55.00	8.00	1.45	1.00	9.97

The base of the analysis involves three steps:

1. Simulation of the ring blast designed, by software JKSimBlast and run the explosive energy distribution analysis → Energy Distribution Curve creation – Numerical Data collection
2. Measurement of real fragmentation by digital image analysis, software Split-Desktop → Fragmentation Distribution Curve creation – Numerical Data collection
3. Comparation and study of data collected.

In this occasion, both ore domains are compared reaching clear differences of behavior that allows creating a model or stablishing a trend for each one. Once the trend is achieved, each domain is able to be optimized following the energy requirement for each blast objective and restrictions.

This energy modeling tool is applied because allows a simple and systematic analysis of multiple different cases, including the estimation of the impact of poor design implementation practices.

After the developing of steps detailed above, DG tipo 1 ore domain reports the data of Figure 1 and Table 2:

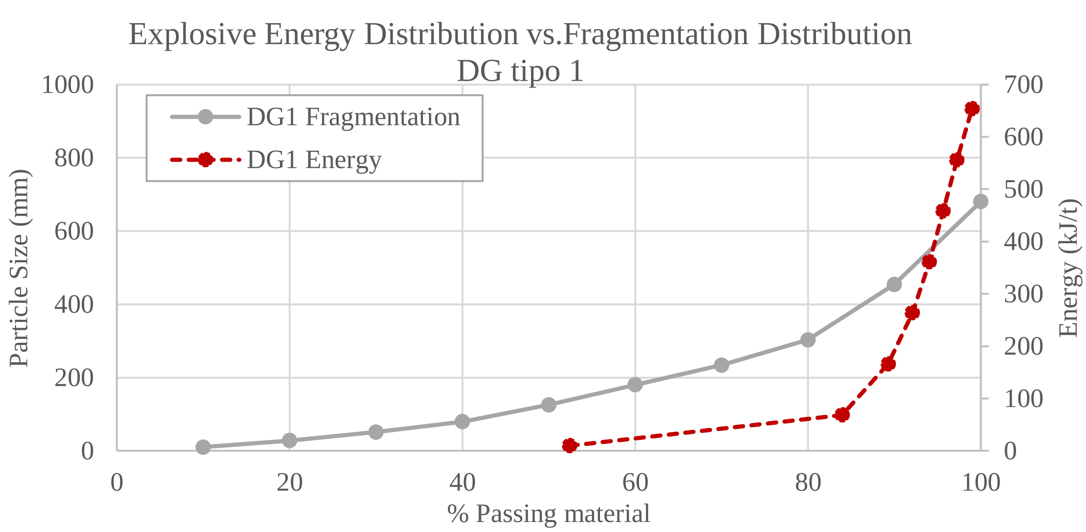

Figure 1. Explosive Energy distribution and Fragmentation distribution of DG tipo 1 ore domain

The same data is collected from DG tipo 2. Now that every required data is collected, Figure 2 and Table 2 shows the comparation.

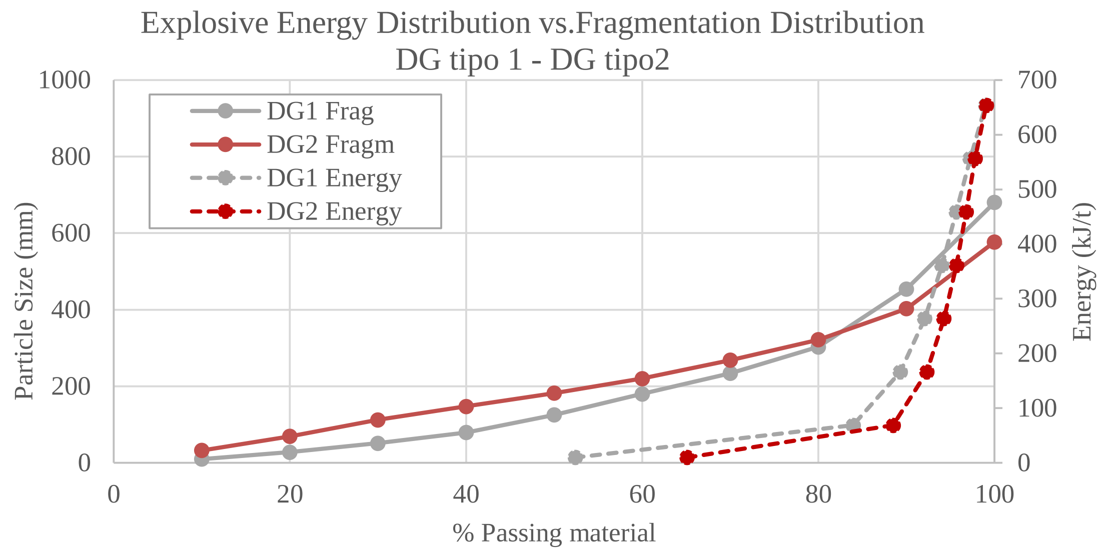

Figure 2. Explosive Energy distribution and Fragmentation distribution of DG1 and DG2

Table 2. Numerical data of Energy and Fragmentation distribution of DG1 and DG2

Energy level kJ/t (kJ/lb)	% Passing Material DG t.1 Energy	% Passing Material DG t.2 Energy
10 (4.5)	52.40	65.11
68 (31.3)	83.96	88.49
166 (75.6)	89.29	92.30
263 (119.9)	92.08	94.26
361 (164.2)	94.05	95.69
458 (208.5)	95.65	96.79
556 (252.8)	97.23	97.80
653 (297.2)	98.99	99.07

	Size (mm)		Size (inch)	
% Passing Material	DG t.1 Frag	DG t.2 Frag	DG t.1 Frag	DG2 Frag
10	10.23	32.79	4.03	12.91
20	28.04	69.56	11.04	27.39
30	51.33	112.58	20.21	44.32
40	79.61	147.72	31.34	58.16
50	125.56	182.37	49.43	71.80
60	180.21	220.20	70.95	86.69
70	234.14	268.42	92.18	105.68
80	302.94	321.64	119.27	126.63
90	454.35	402.89	178.88	158.62
100	680.30	577.27	267.83	227.27

The main difference between the designs parameters of DG tipo 1 and DG tipo 2 is that burden between rings of DG tipo 2 decreases respect DG tipo 1 burden, because of the higher uniaxial compressive strength. Being conscious that explosive selection is fundamental in fragmentation activity, in this occasion, only geometrical pattern parameters are changed, so the comparation is completely valid.

Therefore, the energy from DG tipo 1 to DG tipo 2 increases around 20% as expected for the change of parameters. On the other hand, even with higher energy, as the domain is harder and massive, the fragmentation does not improve in the same proportion. The particle size increases an average of 27%, comparing with particle size of DG tipo 2, which as a blocky material, breaks better. The methodology, in this first step, shows the differences between domains.

Repeating the previous steps for every blasts, required data for each domain, in terms or properties and breakage behavior, can be collected for the appropriate use. Meanwhile, creating a quality database, correctly measured and analyzed, it is possible to get a fragmentation model per domain, which fit to an acceptable level of confidence to be able to evaluate different objectives and design scenarios with the view to obtaining the fragmentation required in an effective manner.

Based on the application of this fragmentation model, different variations of blast designs are studied and evaluated for optimization.

Damage Analysis for Blast Design Optimization

There are three factors involved in blast damage:

1. Rock mass features.
2. Explosive characteristics and energy distribution.
3. Blast design and implementation.

One of the most important parameters to consider in blast designs, as well as drill pattern, explosive, etc., is the geotechnical characteristics of the rock. Ignore or calculate erroneously some of these parameters can generate deficient results of blasts that in stope have a complex solution and generate stability problems.

A common method to assess the stope stability is using hydraulic radius (Equation 1). This parameter is the quotient of stope wall area and its perimeter. Hydraulic radius has a relation with stability number N´ (Equation2), which can be defined for each stope wall.

HR = (H*L)/2*(H+L) **Equation 1**

Where,
H = Stope height (m) (ft.)
L = Stope length (m) (ft.)

N' = Q'*A*B*C **Equation 2**

Where,
Q' = Barton et al. defined as shown in Equation 3.
A = Stress Factor. Replace the SRF in Q.
B = Joint rock orientation factor.
C = Surface orientation factor. Gravity effects on the stability of stope surfaces

Q' = (RQD/Jn)*(Jr/Ja) **Equation 3**

Where,
RQD = Rock quality designation

Jn = Joint set number
Jr = Joint roughness number
Ja = Joint alteration number

The study of theoretical and final real hydraulic radius (HR) and his relation with the energy level of the blast, allows readjust drill and charge designs. It is possible to establish the maximum overbreak on walls of the stope that not produce the change from stable to unstable situation. In some cases, one meter of overbreak can make the stope to be located in the stability limit when is completely exploited.

Figure 3 shows the theoretical and the final geometry of a stope, and Table 3 shows its geotechnical properties. In this case, the value of the hydraulic radius change from the theoretical of 6.7 to a real of 8.

This difference generates that the stope changes from the transition to the collapse zone (Figure 4). In these cases, the time factor and the opening holes nearby that generate a redistribution of stresses in the stope open and (not the most important) effect of vibrations from nearby blasting, may be the trigger of a partial or total collapse of the camera or increase the overbreak.

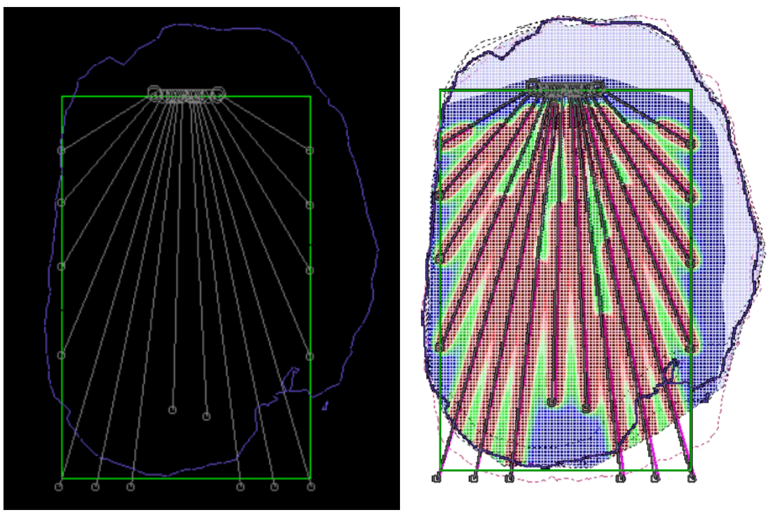

Table 3. Parameters of stope in Figure 3

RQD	Jn	Jr	Ja	A	B	C	Q´
38	10	1.35	2	0.1	0.82	2	2.57

Figure 3. Designed and final stope geometry with Explosive Energy Distribution.

It must be considered that the support designed can be insufficient if the damage is excessive. The effect of the increase in HR depends the overbreak that have relation between energy levels of the blasts and characteristics of rock mass.

Knowing the behavior of the rock according to their characteristics is able to establish a relationship with the energy level of blasting to optimize the design so that the damage generated by the blast is minimized.

This study considered 25 cameras by comparing the theoretical HR and final measurement according to CMS. Stopes have been classified into two groups based on their values of RQD, Jr, Jn and Ja, called DG tipo 1 and DG tipo 2, as shown in Table 1. From here the damage generated by blasting, averaged so that it has a first benchmark for the design of drilling and loading. Figure 5 shows final HR related to induced blast damage.

Although, this monitoring is useful and necessary to make the required adjustments to minimize damage in subsequent blasts.

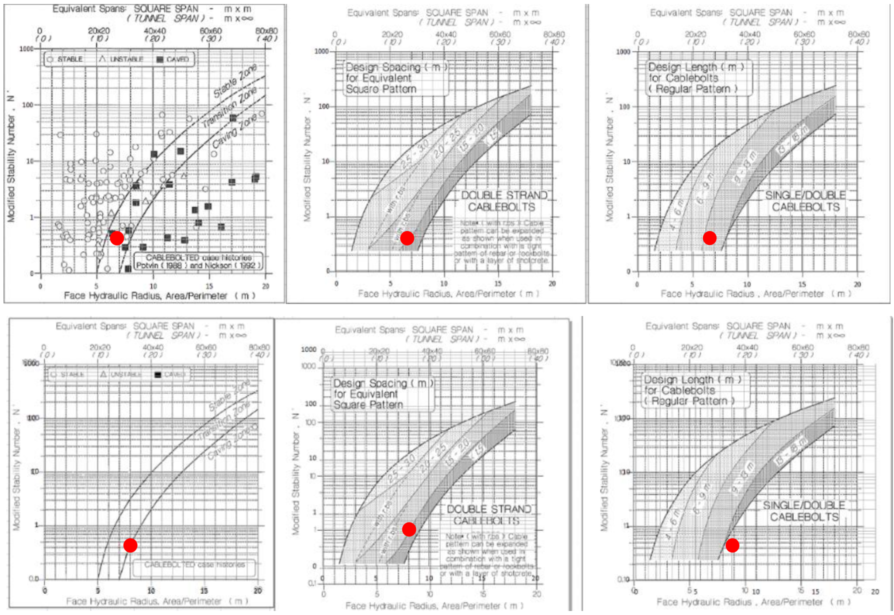

Figure 4. Theorical HR and support (up) and Real HR and necessary support (down)

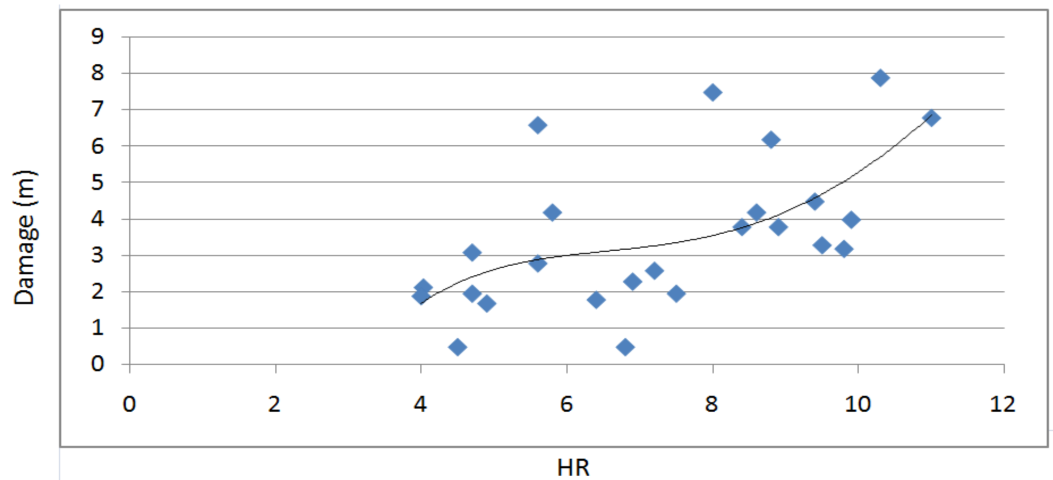

Figure 5. HR for increase of blast damage.

With the data we have for the first group of stopes the HR increases an average of 11.08% and for the second 7.25%.

Acquaintances these levels of damage can readjust the excess energy in the design phase, through modeling or setting a standard, so that the burden, toe spacing and subdrill is adapted.

It is important to note that the rock mass may be affected by nearby blasting and stress states induced by exploitation, so the calculation parameters must be adapted taking into account these factors.

A good practice is to perform systematic measurements in each blast with a laser cavity-monitoring system generated to determine the level of damage and to follow the cavity shape throughout a stope life.

Optimization needs implementation control

Optimizing a blast design needs to take into account real conditions in the field. If the blast design modeling wants to correspond accurately with the reality, a field-refinement step needs to be performed. This field control step will focus on the following (Figure 6):

- Burden between rings.
- Hole collaring accuracy and length. Figure 6 (left) shows confirmation and measurement of bad blast design and worst implementation.
- Actual drill diameter: drilled vs theoretical.
- Hole deviation. Figure 6 (right) shows the results of hole deviation measurements on site. This survey shows a 5.5% deviation while blasting variables are valid only for a 3.5% deviation.
- Loading procedures. Kg/m (lb/inch) of explosive: actual vs design. Stemming lengths and quality.
- Timing tie in and actual sequence

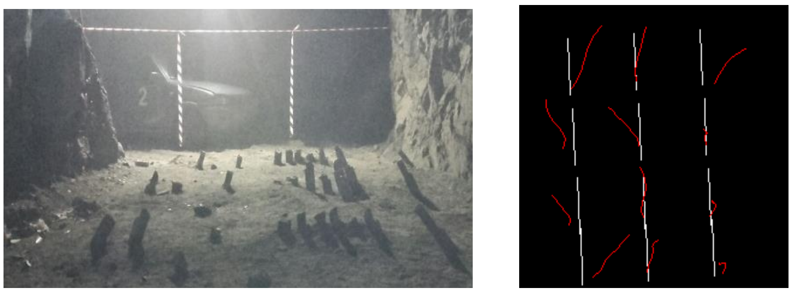

Figure 6. Different in situ measurements

Whether optimization is seeking an improve on fragmentation, better ore recovery rates, dilution control or lower drilling and blasting costs, this process needs to be regularly audited and followed up in the field. Supervision of KPIs mentioned above and a statistical analysis must be performed in order to evaluate the general quality of the operations. Because of this, several blasts, in different ore types and locations, performed by different crews, must be analyzed.

When trying to optimize ore recovery/dilution, hole length and deviation are key to determine if measured values are due design or actual blasting conditions. It is usual to oversee this, and end up compensating implementation fallbacks with overshooting.

Reality can be as extreme as Figure 7 shows, corresponding to a real blast. Left image shows energy distribution simulation of initial design at 102mm (4inch). A poor drilling lead to a poor distribution of energy if it was drilled as right Image 7 shows.

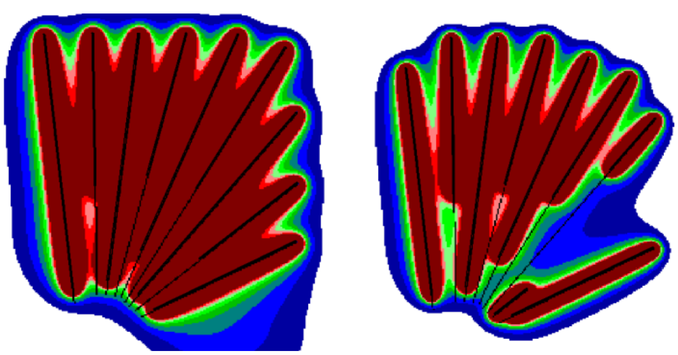

Figure 7. Design and real explosive energy distribution

Specific Case: Optimizing of Fragmentation and Damage Ring Blast

The study is simplified. It involves a comparation of two ring blasts in the same stope (DG tipo 1): a standard design and an optimized one. To confirm the results and improvement, fragmentation and damage simulations, measurements and analysis are developed.
The information provided is only the main results, not the detailed parameters of each blast.

Based on the application of this fragmentation model, different variations of ring blast design can be studied and evaluated, considering alternatives for drilling pattern, combination of reduction in burden and spacing, explosive selection, etc. On the other hand, controlling implementation on site of the design ensure the application of best practices and the best transform from design to reality.

For the new blast, the energy increased and average of 26%.
- Fragmentation results (Figure 8): Improvement of an average of 55% in particle size distribution, getting up to 65% in fines material. The main size of blast decreased below the P80 benchmarking of the mine.

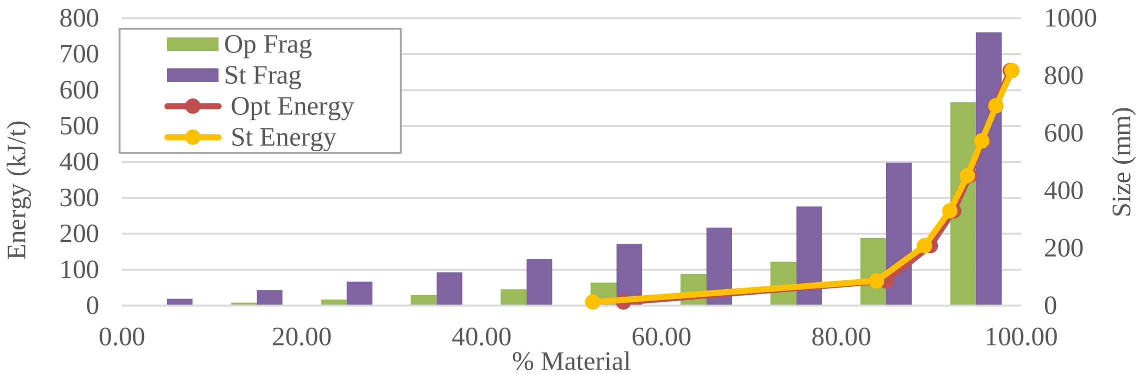

Figure 8. Comparation of Energy and Fragmentation Distribution between two designs: Standard and Optimized

- Damage: comparing with the standard design, which reported an average of 4.6 m (181.1 inch) of damage and an important change in the HR. In the optimized design, with the increment of energy level, the correctly distribution, confinement and implementation, results show not overbreak and HR changes, keeping the stope in its stability state. Figure 9 shows the difference of final stope and energy distribution.

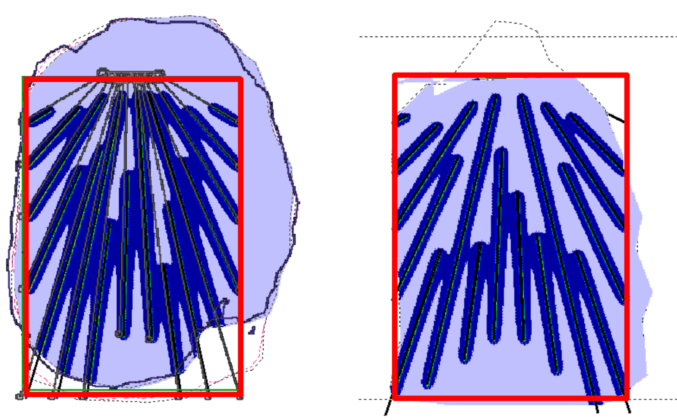

Figure 9. Energy simulation, design and final stope geometry. Standard and optimized designs

Conclusion and Future Work

It is paramount to understand and account for measurement and analysis in assessing and controlling rock mass behavior by blasting, always based on geotechnical information of rock mass. After a proper geological classification, establish a design procedure for drill and blast process is fundamental for efficiency and optimization.

This paper has reviewed a methodology of ring blast design, which explains the best measurements, simulations and analysis to ensure fragmentation and damage best results in underground ring blasting.

This method is useful when the mining operation is committed to a process of continuous improvement in drill and blasting, where the evaluation of the results obtained by simulation and measurements in the field must reflect the characteristics of the design and designs must be optimized using that analysis of the results.

In conclusion, for a general optimization of the process and, particularly of drill and blast activity, it is necessary to know and solve, on one hand, the lack of control in the final geometry obtained by blasting can cause partial or total collapse of the stopes causing delays and production losses and increased dilution. On the other hand, the lack of fragmentation measurement and control downstream can cause cost increase in the full process. However, both optimizations, fragmentation and damage, would not be possible without an accurate and effective field implementation.

The experience gained in this sequence of work should be exploited by formally developing a designing procedure to be integrated into routine mine control. Ring blasting can be optimized according to fragmentation, damage tolerances and safety. More data should be collected, simulated and analyzed to improve the process itself and to optimize the mining activity.

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