Optimizing Blast Fragmentation in an Open-Pit Copper Mine

This project was developed for an open-pit copper mine located in Brazil and proposes blast design optimization based on numerical modeling of the blasting process using the code *Blo-Up*. The analysis in *Blo-Up* involved calibration of the model in terms of fragmentation of a documented blasting. This calibration included characterization of the rock mass and of the explosives being used, the real drillhole pattern used, and the designed blasting sequence. The calibrated model allowed testing of different configurations for different blasting strategies to achieve a desired P_{80} size in the resulting muck pile. Due to the versatility of testing different blasting strategies, new opportunities to use *Blo-Up* have arisen in open pit mining in order to optimize blast designs.

Project Background

The open-pit copper mine was facing difficulties finding an optimum drill and blast design to optimize the mine-to-mill chain. According to the mine-to-mill layout, an optimum 80% passing size (P_{80}) for the mining system was around 0.55 m. Based on documented testing at the site, the main difficulty with achieving this objective was the occurrence of over-sized fragments (boulders) that affect the extraction rates and increase the mine costs due to secondary fragmentation requirements.

As part of the Hybrid Stress Blast Model (HSBM) project, Itasca has developed a software tool to model the rock blasting process. The code, named *Blo-Up* (Itasca, 2012), uses a unique combination of three-dimensional continuum and discontinuum numerical methods to represent the key processes occurring in non-ideal detonation, rock fracturing, and muck pile formation. In this context, Itasca suggested using *Blo-Up* to address the problem described above through numerical modeling of the blasting process.

This project was aimed at optimizing the blasting parameters to improve fragmentation as indicated above.

Methodology

As stated previously, the *Blo-Up* code was developed by Itasca as part of the HSBM research project, which is still open. In order to understand the construction of the models, the calibration stage, optimization of the design, and some details on the software and the numerical method used by *Blo-Up* are presented in this section, along with the overall methodology.

HSBM Project

Motivated by the need to better understand the blasting process, a group of mining companies, universities, and explosives suppliers have collaboratively supported the HSBM (Hybrid Stress Blasting Model) research project since 2001. One of the outcomes of this project has been the development of a numerical modeling tool that covers the entire blasting process. In this matter, Itasca has contributed to creating a fragmentation and fracture modeling software named *Blo-Up*.

Blo-Up is currently capable of reproducing general trends in fracturing and fragmentation observed in the field but is not capable of reproducing every detail of a real blast (Furtney, 2011). However, by predicting realistic trends in fracturing according to the variation in blasting design parameters, it is a relevant research and awareness tool for optimizing design parameters.

Blo-Up Software

The *Blo-Up* software is a three-dimensional modeling tool that represent the blasting process through a combination of continuum and discrete numerical methods.

The software works by coupling three numerical components (Figure 1):

- A "Programmed Burn" approach is used to model the detonation process and axial blasthole flow, in which the velocity of detonation, heat of reaction, and product-phase behavior are supplied by an external code.
- A continuum method is used to represent the near-blasthole volume and the detonation process.
- A Discrete Element Method (DEM) allows representation of the rock mass, which models the wave propagation and initial fragmentation through to muck pile formation.

Fragment Size Calculation with *Blo-Up*

The representation of rock in *Blo-Up* is discrete, meaning a lattice node represents a discrete volume of rock. One of the simplifications that speeds up the calculation is that all the lattice nodes represent the same volume. When the size distribution is calculated, the lattice is divided into fragments. When the model is first created, all the lattice nodes are connected, and as fracturing occurs, the springs that connect the nodes are broken. *Blo-Up* keeps track of these fragments and of the total volume in fragments of different sizes. The size of a fragment is the cube root of the volume of a fragment. The volume of a fragment is the number of nodes that

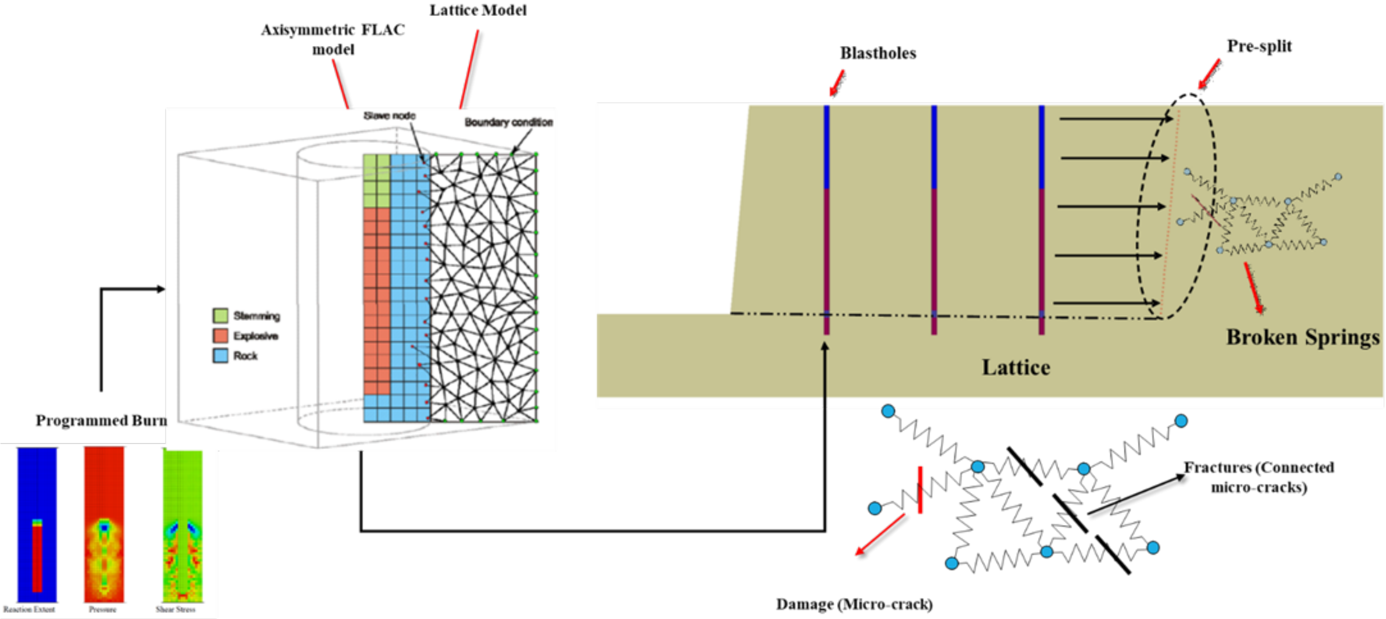

Figure 1 *Numerical components of Blo-Up software.*

make up the fragment times the nodal volume. The nodal volume is the lattice resolution cubed. This means that the minimum fragment size reported always corresponds to the actual lattice resolution (the smallest dimension in the size distribution curve corresponds to the lattice size or resolution of the model). For the tail of the size distribution (fragment sizes below the lattice size), Itasca uses a method to project the curve to smaller sizes by adjusting probability distributions of Rosin-Rammler (Equation 1) or Swebrec (Equation 2) (Ouchterlony & Sanchidrián, 2019).

$$P_{RR(x)} = 1 - \exp\left(-\,ln\,2 \cdot \left(\frac{x}{x_{50}}\right)^{n}\right) \qquad (1)$$

$$P_{Swebrec(x)} = \frac{1}{1 + \left(\frac{\ln\left(\frac{x_{max}}{x}\right)}{\ln\left(\frac{x_{max}}{x_{50}}\right)}\right)^{b}} \qquad (2)$$

Regarding the above, note that the finer the resolution of the model, the better the distribution will be fitted to fine zones but at a higher computational cost (longer running times).

Work Method

The flowchart summarizing the work method for the overall project is shown in Figure 2.

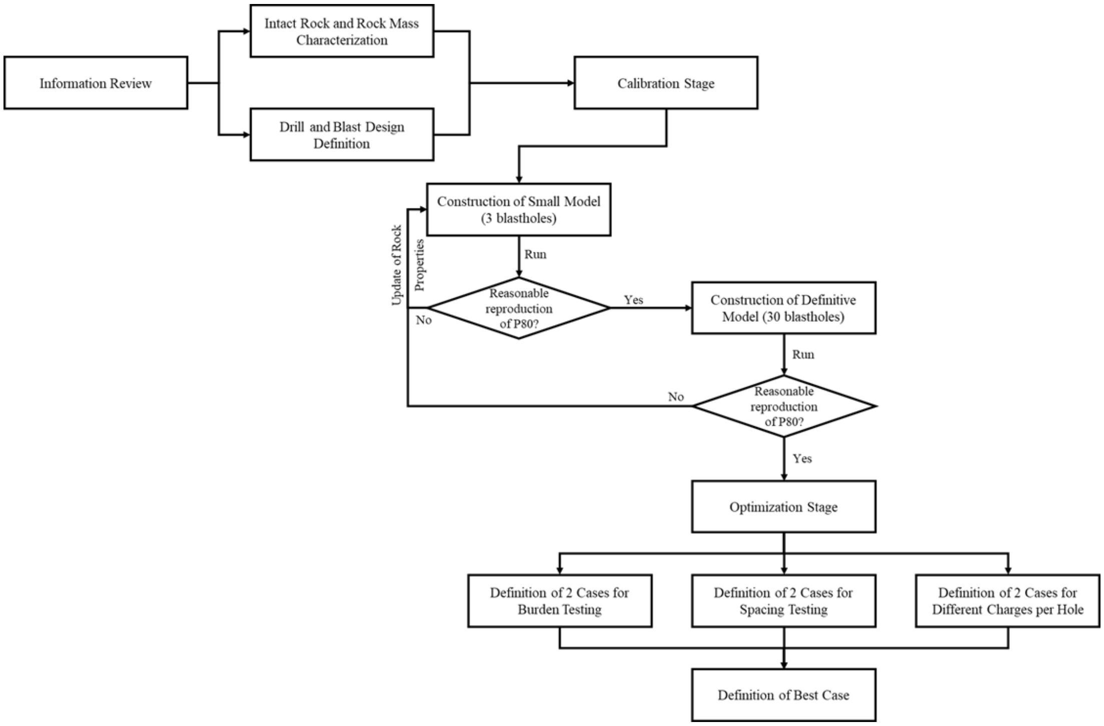

Figure 2 Methodology flowchart.

Calibration and Optimization Results

After the calibration process, the best-case scenario (BC) obtained is shown in Figure 3 and Table 1.

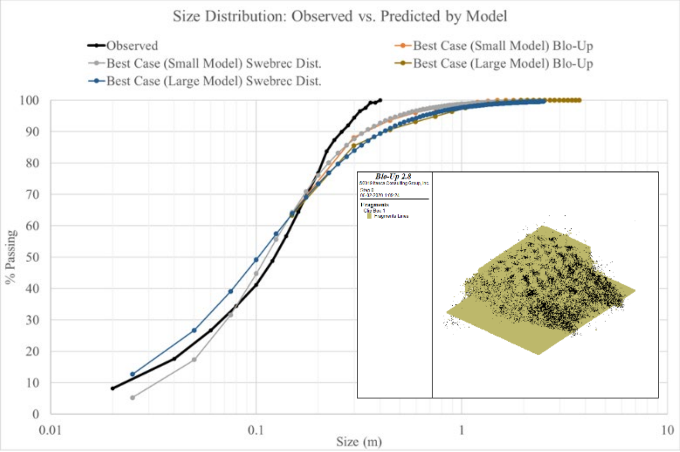

Figure 3 Calibration results - size distribution observed in the Mine vs. predicted by Blo-Up (best-case scenario).

Table 1 Model Performance

Database	P_{80} (m)	Error P_{80} (%)	Total Error (Observed vs. Predicted) (%)
Observed	0.21	-	-
BC Small Model (*Blo-Up*)	0.25	18%	-
BC Small Model (Swebrec Dist)	0.22	7%	4%
BC Large Model (*Blo-Up*)	0.26	25%	-
BC Large Model (Swebrec Dist)	0.25	21%	4%

In Table 1, four models are presented:

- BC Small Model (*Blo-Up*): This corresponds to the data extracted from *Blo-Up* in the best-case small model, keeping in consideration that it is limited in its smaller size by the model resolution.
- BC Small Model (Swebrec Dist.): After a best-fit exercise, the Swebrec-type distribution had a better fit to the data from *Blo-Up* of the Small Model. This model predicts the whole range of sizes, so a Total Error can be calculated, resulting in approximately 4%.
- BC Large Model (*Blo-Up*): This corresponds to the data extracted from *Blo-Up* from the best case in the large model, keeping in consideration that it is limited in its smaller size by the model resolution.
- BC Large Model (Swebrec Dist.): After a best-fit exercise, the Swebrec-type distribution was better fit to the data from *Blo-Up* of the Large Model. This model predicts the whole range of sizes, it is for this reason that a Total Error can be calculated, resulting in approximtely 4%.

The low error was achieved by incorporating two further assumptions: 1) the introduction of vertical blast-induced damage by running the model twice, which attempts to reproduce the damage induced in the rock mass by the blasting that took place in the bench above; and 2) the upper 3 m of the bench were modeled assuming that the rock mass in this zone would have a reduced tensile strength (1 MPa less), in order to account for degradation of the intact rock due to previous blasting, in addition to the induced damage considered above.

As shown in Table 1, in terms of P_{80} the model shows variability related to the scale. When the model extends from small to large, new interactions make the model coarser. The model tends to be more conservative in the range of sizes between 0.2 and 0.4 m, while showing a reasonable representation of the rest of the curve (towards the fines). This overall gives a calibrated model with an error of 4% when compared to the observed dataset.

Fragment Size Calculation with *Blo-Up*

Figure 4 (top) shows the fragment contour of the blasted rocks considering fragment sizes ≥ 0.5 m for the BC Large Model. A vertical cross-section was included to show the fragmentation along the height of the bench, which is shown in Figure 4 (Middle). Both figures demonstrate that larger fragments concentrate in the upper part of the bench, in a volume that includes the damaged area and the area below. Figure 4 (bottom) presents a horizontal section located 5 m below the height bench. The fragment contour shows that larger fragments concentrate in the maximum spans between drill holes. In both views, large fragments can be located at the boundary conditions (back of the model); however, the methodology applied to measure fragmentation filtered data located in these areas.

Optimized Design

After several tests, an optimized design was found to give a P_{80} of approximately 0.53 m. This was obtained by implementing blasting with the following parameters:

- Burden: 6.0 m
- Spacing: 8.0 m
- Borehole diameter: 12 ¼ inches
- Hole length: 16.0 m
- Stemming: 5.5 m
- Charge Length: 10.5 m
- Subdrill: 1.0 m
- Explosive: Fortis Advantage 70 / 100
- Sequence: 5 ms between holes / 75 ms between rows

Recommendations

In forming the blasting design, the following is recommended:

- The collar deviation should be less than 0.5 m in at least 90% of the blastholes.
- Blastholes with subdrill ≥ 1.0 m should be filmed and scanned in order to corroborate the extension of the vertical induced damage of 3 m, which was an important assumption during the calibration.

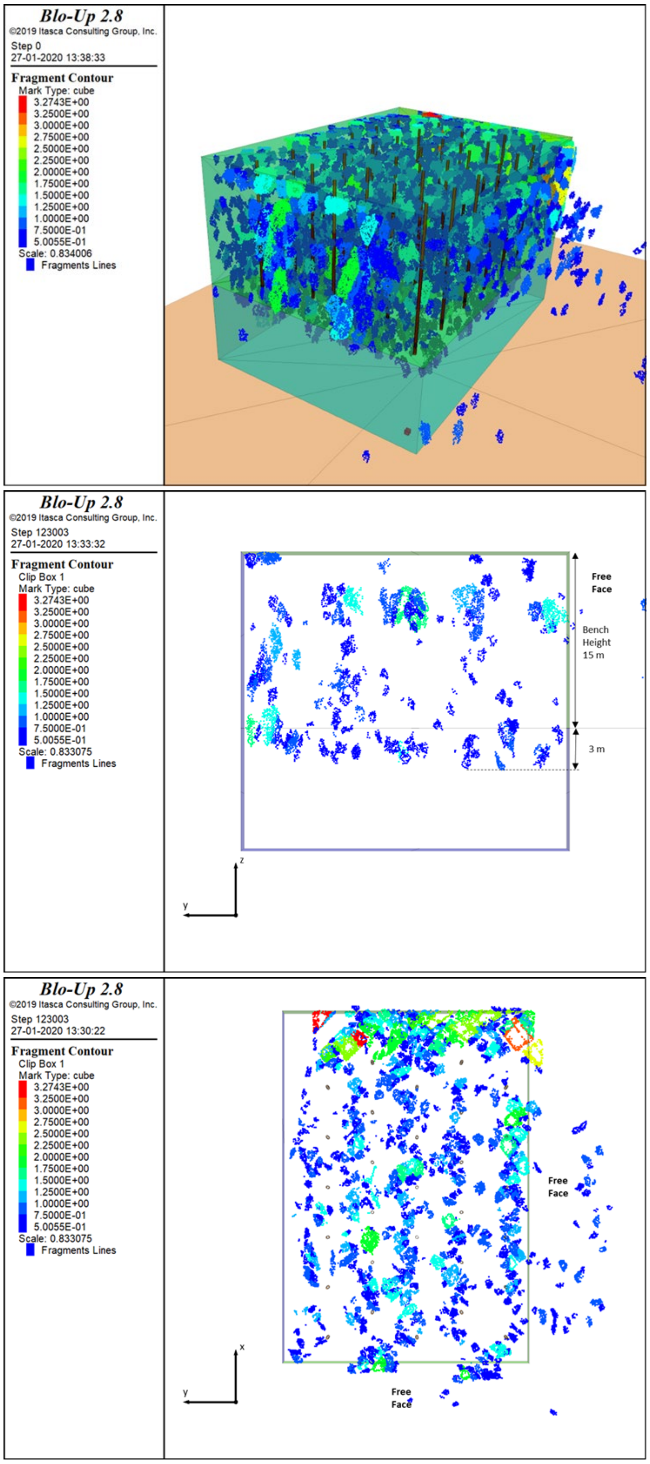

Figure 4 Top: Fragment contour (> 0.5 m) modeled by Blo-Up in calibration case. Middle: Cross-section of the large model in Blo-Up – Fragment contour (>0.5 m). Bottom: Horizontal cut (5 m below bench height) of the large model in Blo-Up – Fragment contour (>0.5 m).

Summary

The best calibrated results were found when a Swebrec distribution was fitted to the *Blo-Up* data, which shows that the overall error of the best calibrated model is 4%. This was made by incorporating two further assumptions:

- The introduction of vertical blast-induced damaged by running the model twice. This intends to reproduce the damage induced in the rock mass by the blasting that took place in the bench above.
- The upper 3 m of the bench were modeled assuming that the rock mass in this zone would have a reduced tensile strength (1 MPa less), in order to account for degradation of the intact rock due to previous blasting, additional to the induced damage considered above.

In terms of optimization of the design parameters, the best case showed a P_{80} of ~0.53 m.

References

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