Prediction of Fragmentation in Block Cave Mine Design – an update of the Core2Frag Program

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Abstract

Several methods have been developed to predict fragmentation based on rock fabric mapping, but data collection for these methods are limited to areas on the surface, and to access levels near the base of the deposit. The Core2Frag program was developed to predict primary fragmentation for block caves using drill core data, which is generally available from all parts of the deposits and ore-bodies from the initial stages of discovery to development, allowing the mine engineering group to evaluate fragmentation and plan mine facilities prior to construction of the mine. These life-of-mine fragmentation and hang-up predictions can be used in the planning, simulation, and cost estimating of mining activities.

This paper focuses on the presentation of the results of fragment size estimation. Previous conventions in presenting the results of block cave fragmentation have used volume-weighted distributions – which can be converted directly into tons, and thus easily used by mine engineers in scheduling. Reconciling these volume/tonnage estimates to visual observations (based on areal estimates), and sieves has been problematic and has resulted in empirical correlations, which have limited success. A quantitative fragmentation estimate has been developed using the block generation logic of the Core2Frag Program by calibrating the results against drawpoint mapping data.. This estimate is based on linear, areal, and volumetric measurements.

The paper illustrates that estimation of fragmentation is fundamentally a sampling problem. One and two dimensional data sets are used to estimate the appropriate three-dimensional size distribution. Drawpoint mapping calibrations from the PT Freeport Indonesia DOZ mine, along with a sampling exercise of a known fragment distribution, demonstrate the challenge of estimating fragmentation from one dimensional data sets.

1 Introduction

In the block cave mining method, the assessment of in-situ and secondary fragmentation is an integral part of the design of the excavations at the extraction level and the selection of material handling systems for transporting the ore to the processing stations. This information can also be used for evaluating the production capability of a deposit designed for extraction using the block caving method. Fragmentation has a bearing on drawpoint spacing, dilution entry into the draw column, draw control, drawpoint productivity, secondary blasting/breaking costs and secondary blasting damage (Laubscher, 1994).

While several approaches have been developed for the assessment of fragment size distributions, the Block Cave Fragmentation (BCF) program (Esterhuizen, 1999) is probably the most widely used method for estimating the fragment size distributions in block cave operations. The program uses the statistical joint set information to create primary fragments.

Since a large amount of drill hole data is generally available during the design and planning stages of a block cave operation, the Core2Frag program was developed by Call and Nicholas, Inc. (CNI) to help convert the drill hole core piece length data into a volumetric fragment size distributions using the orientation of the drill holes with respect to major joint sets (the orientation of the joints is estimated from cell mapping information) and assumptions regarding the shape of the blocks and the location of the core piece within the block (Srikant & Nicholas, 2004). While the methods for assessing in-situ and primary fragment size distributions have been developed using logical approaches and available information from the mining blocks being investigated, the actual in-situ fragmentation is unknown. Preliminary empirical assessments of the processes of secondary fragmentation, which include block splitting, comminution and grinding of the blocks within the draw column, and their impacts on secondary fragment size distributions, were evaluated using a series of decision trees developed during the evolution of the BCF program and have been used in the Core2Frag program as well.

Validating the fragment size estimates produced by the different programs through calibration against field observations is essential for the development of confidence in the prediction of fragment size distributions. However, the only observations that can be used to calibrate the in-situ fragmentation estimates are at the drawpoints at the extraction level of the block caves, which is essentially the secondary fragmentation. Mapping of the fragmentation at the drawpoints at the DOZ block cave was undertaken in several campaigns to help correlate the predicted and observed fragmentation (Srikant, Nicholas & Rachmad, 2004). The fragmentation estimates from Core2Frag and BCF are reported as volumetric estimates by convention and the drawpoint mapping procedures developed for the DOZ evaluate the fragmentation observed at the drawpoints as linear measures.

The following key points are discussed in this paper:

1. assumptions in converting drill-hole data to volumetric block size distributions,
2. mapping fragmentation at the drawpoints, and
3. calibration of the estimates of fragment size distributions.

1.1 BCF Methodology Summary

BCF was developed to estimate primary and secondary fragmentation from rock fabric data. Rock fabric data, consisting of joint spacing, orientation, and length, can be collected by scan-line or cell mapping from the surface or underground workings. The BCF program estimates the fragmentation using a combination of empirical, analytical and rational methods to model the behavior of materials during the primary and secondary fragmentation processes. The generation of fractures due to stresses at the cave back is also included in the primary fragmentation estimates

The calculation of secondary fragmentation in the program is based on the aspect ratio of a rock block, block strength, cave pressure, stress induced by arching in the draw column and the height of draw. The BCF program also includes a Hang-up module which estimates the frequency of hang-ups in the drawpoint based on the fragment size distributions and the dimensions of the drawpoint.

1.2 Core2Frag Methodology Summary

The Core2Frag program utilizes core piece length data from drill holes as well as rock fabric data, including joint orientation and joint spacing, for the development of primary fragmentation within the deposit. The relationships between the joint spacing and lengths of the different joint sets, evaluated from the joint set characteristics gathered from available excavations, outcrops or oriented core drilling programs, can be utilized for estimating the shape of the rock blocks (Figure 1). The assumptions in the Core2Frag program are:

1. Each drill core piece represents an in-situ block
2. All blocks have the same aspect ratio and the block shape is defined by the joint sets
3. The drill hole passes through one apex of the primary block.

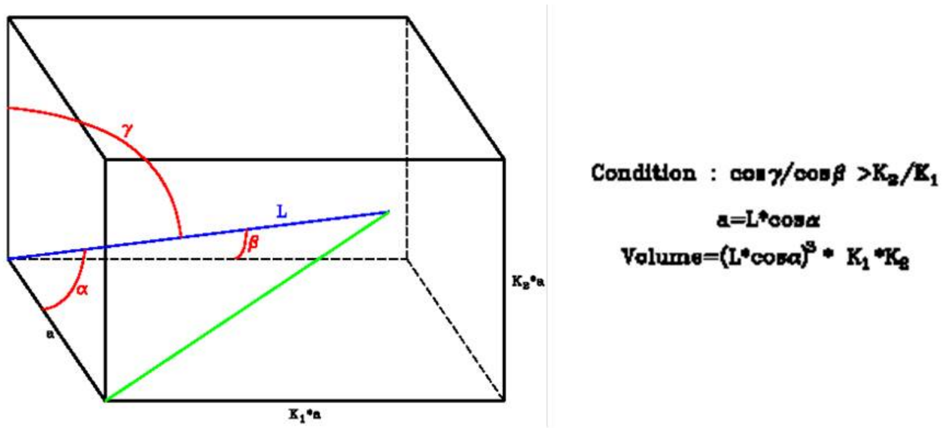

Figure 1. Drill hole intersecting an orthogonal block.

The secondary fragmentation module in Core2Frag assumes that all blocks are broken down to a stable aspect ratio within the first 30 to 100-meters of draw. Additional fines are generated as draw height increases through the following processes:

- Energy to break rock
- Cave height and cave pressure
- Autogenous grinding
- Rounding of block corners and crushing
- Veining and micro-fractures within blocks
- Cushioning / Arching
- Low block strength

The above factors would account for approximately 5-10 % of the coarsest blocks being reduced to fines for every 60-meters of draw. Approximately one-third of the potential energy of a rock block is directed to secondary breakage of the block. Figure 2 shows the BCF primary and secondary fragmentation estimates for the Diorite rock type.

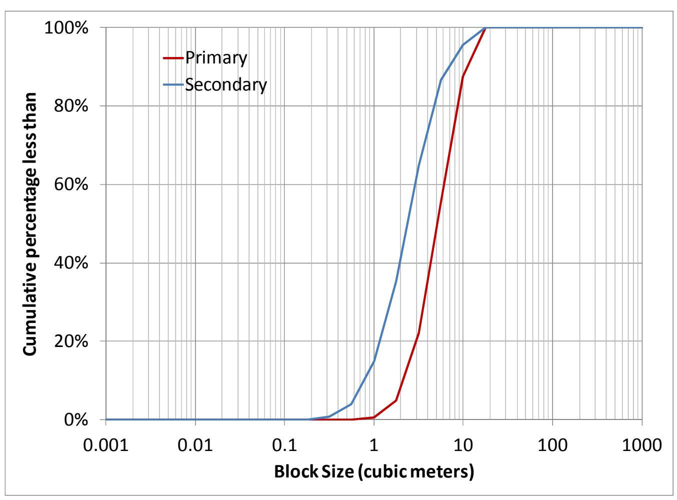

Figure 2. Diorite primary and secondary fragmentation using BCF

The Core2Frag primary fragmentation estimates using drill hole data within Panels 6-9 in the Diorite rock type in the DOZ Mine are shown in Figure 3.

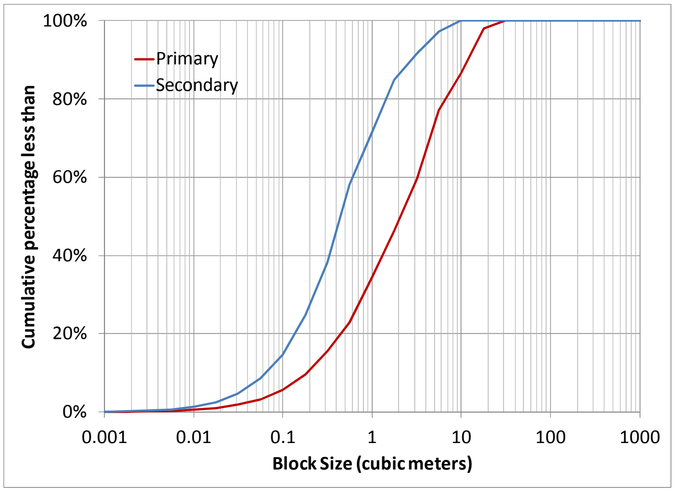

Figure 3. Diorite primary and secondary fragmentation using Core2Frag

2 Fragment Size Distributions

While the use of drill hole data to estimate fragmentation helps differentiate coarser and finer areas within a deposit, the fragment size distributions estimated can be difficult to correlate with field observations. In particular, the estimation of 3-dimensional block sizes from 1-dimensional drill-hole data is yet to be adequately validated against field observations.

The original methodology for Core2Frag assumed that each core piece in the drill hole represented a rock fragment and the volume was calculated based on aspect ratios. The fragmentation estimates were therefore volume-weighted. Figure 4(a) shows a simplified case with a drill hole intercepting three blocks of different sizes - a 1000 cubic meter block, an 8 cubic meter block and a 0.125 cubic meter block. The blocks are all assumed to be cubical in shape with aspect ratios equal to 1. On a volumetric basis, the coarsest (largest) 1- to 2-percent of blocks account for over 98-percent of the fragment-size distribution and a minimal amount of fines.

An alternative to this assumption is to assume that each core piece represents a proportion of blocks equivalent to the length of the core piece, as depicted in Figure 4(b). This is the length-weighted distribution.

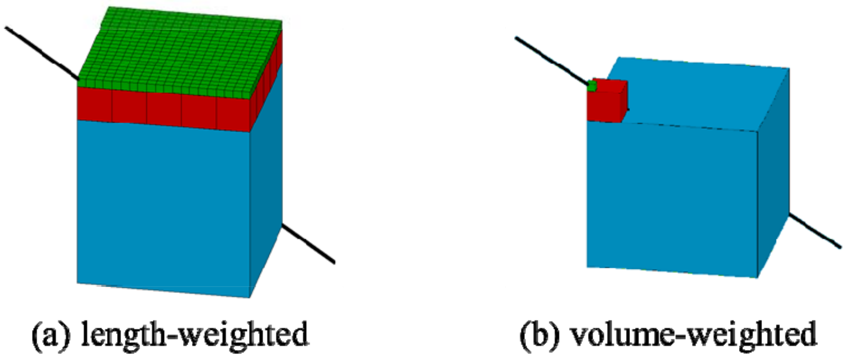

Figure 4. Sample weighting assumptions

The use of the volume-weighted or length-weighted, or some intermediate weighting factor to represent the distribution of block sizes is key in representing the distribution of expected block sizes as shown in Figure 5.

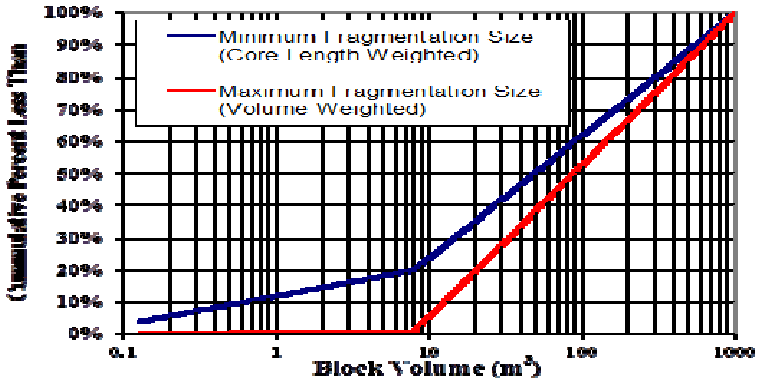

Figure 5. Effect of sample weighting assumption

Visual estimates of drawpoint fragmentation can potentially be used to calibrate the results of fragmentation analyses. However, a limitation of visual estimates is that the visible portion of a muck pile in a drawpoint is restricted to a two-dimensional surface, whereas the distribution of fragment sizes should represent the full three-dimensional distribution of particle sizes. In addition, fines often tend to cover and hide large size blocks (Figure 6) and the actual fragment size distribution could be coarser than that recorded in the drawpoint mapping. This limitation is a consideration in utilization of drawpoint mapping data to potentially calibrate fragmentation analyses.

Figure 6. Fines covering large blocks in drawpoint

3 Comparing measurements to predictions for DOZ Forsterite and Diorite

At the DOZ Mine, a procedure was developed for collecting fragmentation data from the drawpoints using visual estimates of block sizes. The draw point mapping procedure (Srikant et al, 2004) was developed by CNI and PTFI to assess the actual fragmentation size distribution at the drawpoint and to provide feedback for the fragmentation prediction tools. Recognizing that observers can more readily assess block side lengths rather than block volumes in a drawpoint, the procedure relied on estimates of block side lengths as shown in Figure 7, which shows a partially completed drawpoint fragmentation log.

P.T. FREEPORT INDONESIA – Drawpoint Fragmentation Log									
Logged by:	Srikant Annavarapu				Area	DOZ Panel 19		Date:	October 12, 2005
Drawpoint No.	Hang-up (Y N)	Condition Rating (1 – 5)	Fines % <5cm Estimate %	Small blocks 5–50 cm	Intermediate 50cm – 1m Count X2%	Large Blocks 1m – 2 m Count x 5%	Oversize >2m Estimate #	Max Block L x W (m)	Notes
P19-DP12E	N	3	20	20	12 x 2 = 24	4 x 5 = 20	10	2.1 x 1.5	
P19-DP12W	N	1	60	24	8 x 2 = 16	0	0	0.8 x 0.6	
P19-DP138	N	4	20	17	4 x 2 = 8	7 x 5 = 35	20	2.4 x 1.8	

Figure 7. Example drawpoint mapping log

The material size distribution was divided into five categories: fines, small block, intermediate block, large block, and oversize. The first three categories represent the material size that could pass through 1-meter by 1-meter grizzly. The large blocks category represents the material that could be handled by the LHDs without any material size reduction required. The oversize category represents the material that requires either secondary blasting at the draw point or hang-up blasting. The dimensions of the largest block were also recorded. The main concern for the mine was the large or coarse blocks; however, fines information was also important for understanding the compaction issue inside the transfer raise and for analyzing the effectiveness of the secondary ore handling systems.

3.1 Core2Frag Quantitative Estimate

Several campaigns of drawpoint mapping were undertaken at different stages of the DOZ mine and the data was converted to 3-dimensional fragment size distributions by applying observed aspect ratios to the block size categories. The predicted and observed fragmentation within the DOZ Diorite indicated a strong correlation of the length to the fragmentation estimate and a procedure was developed to generate an average fragment size estimate in each size range using both the volumetric as well as the length weighted distributions. The derived Core2Frag Quantitative Estimate shown in Equation (1) below is based on the average of the minimum (length-weighted) and maximum (volume-weighted) distributions.

Quantitative_Estimate (QE) = 0.5 * (Length-weighted estimate) + 0.5 * (Volume-weighted estimate)...............(1)

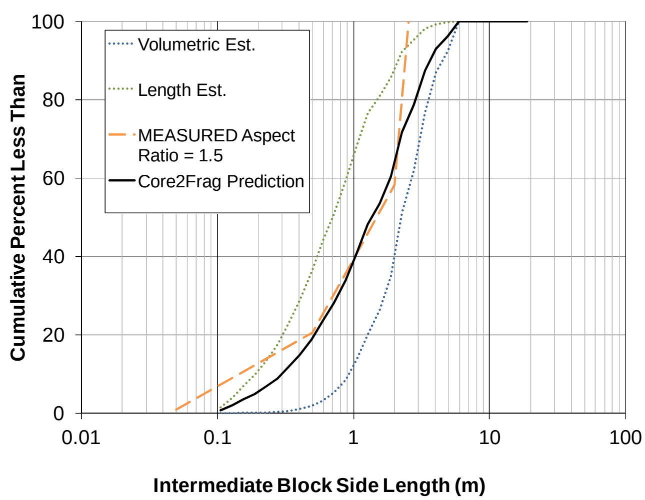

Figure 8. DOZ Diorite predictions vs. Drawpoint mapping results for 0-60 meter draw height.

Figure 8 shows that the QE distribution matches closely with the drawpoint mapping results while the volume-weighted distribution is coarser and the length-weighted distribution is finer than the observed fragment size distribution. The theoretical basis for the development of the quantitative estimates needs to be understood and the authors are undertaking analyses of data from other locations as well to evaluate the factors affecting the correlation between predicted and observed fragment size distributions.

3.2 Sampling Experiment

An experiment was performed with the goal of checking the validity of visual estimates of fragmentation and the accuracy of fragmentation estimates based on 1-dimensional sampling. These checks are needed to validate visual estimates of drawpoint fragmentation and fragmentation estimates based on drill hole data, both of which are impractical to validate in the active mine setting.

The experiment was performed with the use of six piles of sand to cobble-sized material (approximately 40 kilograms of material per pile). For each pile, several engineers and geologists visually estimated the size gradations. In addition, linear transects were digitally constructed across scaled photographs of the material (Figure 9).

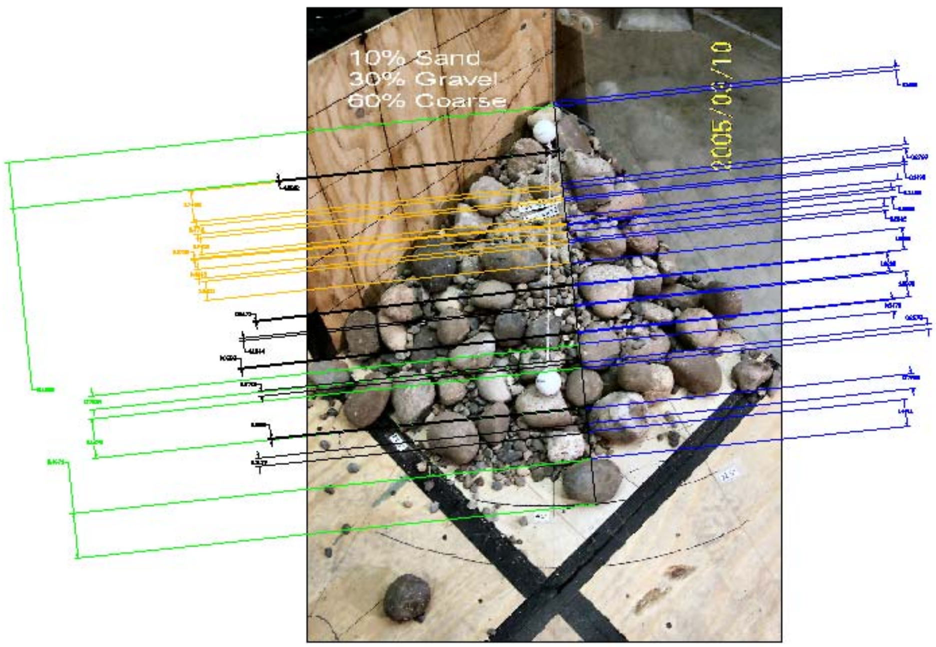

Figure 9. Known fragment distribution

The size range of particles along the linear transects was measured as a means to test the effectiveness of 1-dimensional sampling. The linear-transect distributions were converted to a volumetric distribution for comparison. Sieve results were compared with both the visual estimates and the linear transect results as shown in the table below.

Table 1. Accuracy of visual, linear, and volumetric fragmentation estimates

	Sand	Gravel	Cobble
% Difference: Sieve-Visual Estimate	-1.4%	2.7%	-1.3%
% Difference: Sieve-Linear Estimate	9.5%	-0.1%	9.6%
% Difference: Sieve-Volumetric Estimate	31.7%	23.3%	-54.9%

The results indicate a favorable comparison with the visual estimates and a reasonable, but less accurate approximation based on the linear transect estimate. The volumetric estimate, however, grossly underestimates the percentage of sand-sized material and overestimates the percentage of cobble-sized material. Graphical comparisons of the sieve, visual, and linear estimates are shown in Figure 10 below.

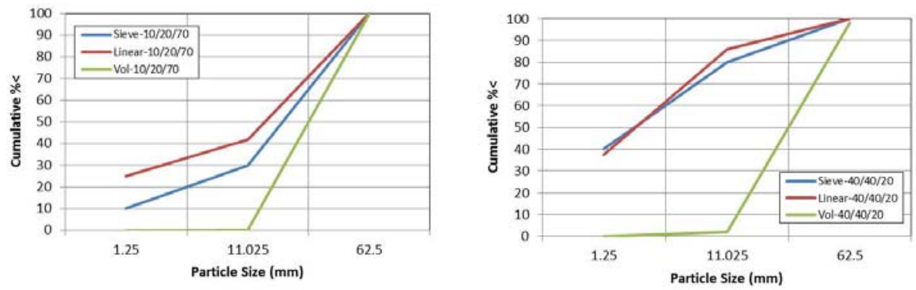

Figure 10. Comparison of fragmentation estimates

An application of the linear fragmentation estimate would be in the case of rock fragmentation where the distribution of core piece lengths from drill data would reasonably represent block side lengths for the estimation of the percent of material that would not pass through a grizzly. The authors suspect that this conclusion is highly dependent on the block aspect ratios and the directions in which holes are drilled relative to block-forming joints, but with drill holes in many directions, these dependencies could be reduced. Though there is significant correlation between the two distributions, the authors indicate that these results are based on a small study sample and additional evaluation is being undertaken to verify the conclusions.

4 Conclusions and Recommendations

There is good correlation with Core2Frag side length fragmentation estimates as compared to the measured drawpoint side lengths in the DOZ Forsterite. The closest agreement on the estimate, and measured fragmentation is the intermediate length of blocks measured at the drawpoint.

Fragmentation estimates have been estimated by volumetric estimates by convention. Volumetric weighted fragmentation predictions overestimate the coarse fraction and underestimate the fines. Averaging the length (minimum) and volume (maximum) fragmentation provided a good approximation in the case of the DOZ Diorite, whereas the DOZ Forsterite comparison was closer to the length-weighted distribution. Ongoing study of drawpoint mapping data is being used to determine how to assign weights to the fragment-size distributions.

The experiment utilizing small piles of sand to cobble-sized material showed that visual estimates and linear sampling (as in the case of a drill hole) can be used to reasonably estimate fragmentation.

A key issue for improving fragmentation estimates is ensuring that we measure actual fragmentation at drawpoints and measure key parameters that are used in fragmentation programs as part of the estimates. Without actual measurements and field data there is no basis for justification of the influence of different parameters used in fragmentation predictions.

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