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A scoping study method for determining the viability of block caving a hard rock orebody

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KEYWORDS: Block caving, Hard rock orebody, Extraction, Tonnage.

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ABSTRACT

A method is described for determining the viability of hard rock orebody extraction by block caving. Using a very limited amount of geotechnical data, the procedure enhances Laubscher's empirical stability graph method by using the complex structural modelling system (ChaSM) to assess cavability and block cave tonnages.

Introduction

In considering the selection of suitable mining methods, block caving has gained popularity over other extraction systems in recent years (Butcher, 1999). This has been ascribed to the fact that block caving is the lowest cost per ton mining method, with orebodies that were in the past considered unsuitable for caving, now being successfully mined. However, even though all orebodies will cave, a problem exists in the evaluation of economic viability — it is necessary to be able to predict both when the orebody will cave and what will be the sizes of the initial ore fragments (and the associated tonnages) that report to the drawpoints. This problem is compounded by the fact that, during the scoping study phase of a project, only limited geotechnical data may exist on which to base an assessment of whether block caving is viable or not. Empirical and numerical methods of cavability assessment do not account for the full effects of geological discontinuity trace lengths, nor for the stress regime. Those require significant geotechnical data to be available. The result is that uncertainty may exist as to whether block caving is an economic option. This uncertainty is complicated by the fact that limited experience exists with the caving of more competent orebodies.

This paper describes a method for assessing cavability, and for predicting the size of initial ore fragments and the tonnages reporting to block cave drawpoints, using only the level of data normally available during a scoping study. Fragment size and tonnages are assessed by identifying potentially unstable blocks and wedges in the undercut back using statistical joint data. The effects of lateral confining stresses are accounted for by comparing the in situ stress orientations with the joint orientations. To evaluate the accuracy of the method, a back analysis exercise was conducted to predict cavability and initial tonnage for a mine in which the actual behaviour is known. The method is then applied to cavability and tonnage predictions for a hard rock orebody.

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Modelling Method

In order to assess cavability, initial cave fragmentation and block tonnage, the ChaSM approach (Stacey, 1999) was used. In the application of this method, the dimensions and numbers of unstable blocks in the undercut back are obtained from statistically generated joint patterns, and used to estimate the block cave initial fragmentation and production tonnages. The cavability of the ore deposit is assessed using a combination of Laubscher's mining rock mass rating stability graph (Laubscher, 1994) and the block stability method (Haines, 1984). This is to determine the total unstable area of undercut back blocks at the initiation of caving. Figure 1 shows the method in the form of a flow diagram, illustrating the modelling method logic.

Collection of Geotechnical Input Data

The method requires that two types of geotechnical data are collected namely: Mining Rock Mass Rating (MRMR) values from rock mass classification; and joint data to derive representative statistical distributions for describing orebody characteristics for ChaSM analysis (Fig. 1).

In this respect, the following are considered as the necessary orebody geotechnical characteristics required to be collected: joint dip direction; joint dip angle; strike length continuity; dip length continuity; joint spacing; intact rock strength; rock quality designation (RQD); rock mass fracture frequency; joint condition on both the large and small scale; and rock weathering.

In terms of a scoping study, limited geotechnical data may exist. However, some of the information listed above may be obtained from: scan-line surveys conducted in exploration adits; logging of exploration borehole core; scan-line surveys on outcrops; scan-line survey data from nearby mines; joint orientation data from geotechnical core; interpretations from geological exploration core photographs; and commonly observed joint statistical distributions (Priest and Hudson, 1976, 1981).

Once the geotechnical data have been collected, the next stage in the process is the creation of a plan and cross-sections showing block cave undercut back jointing (one possible scenario). The size of the plan created is determined from Laubscher's stability graph using MRMR values. The plan and sections are known as generated discontinuity patterns or ChaSM plots.

Fig. 1. General method flow diagram — ChaSM (cavability assessment).

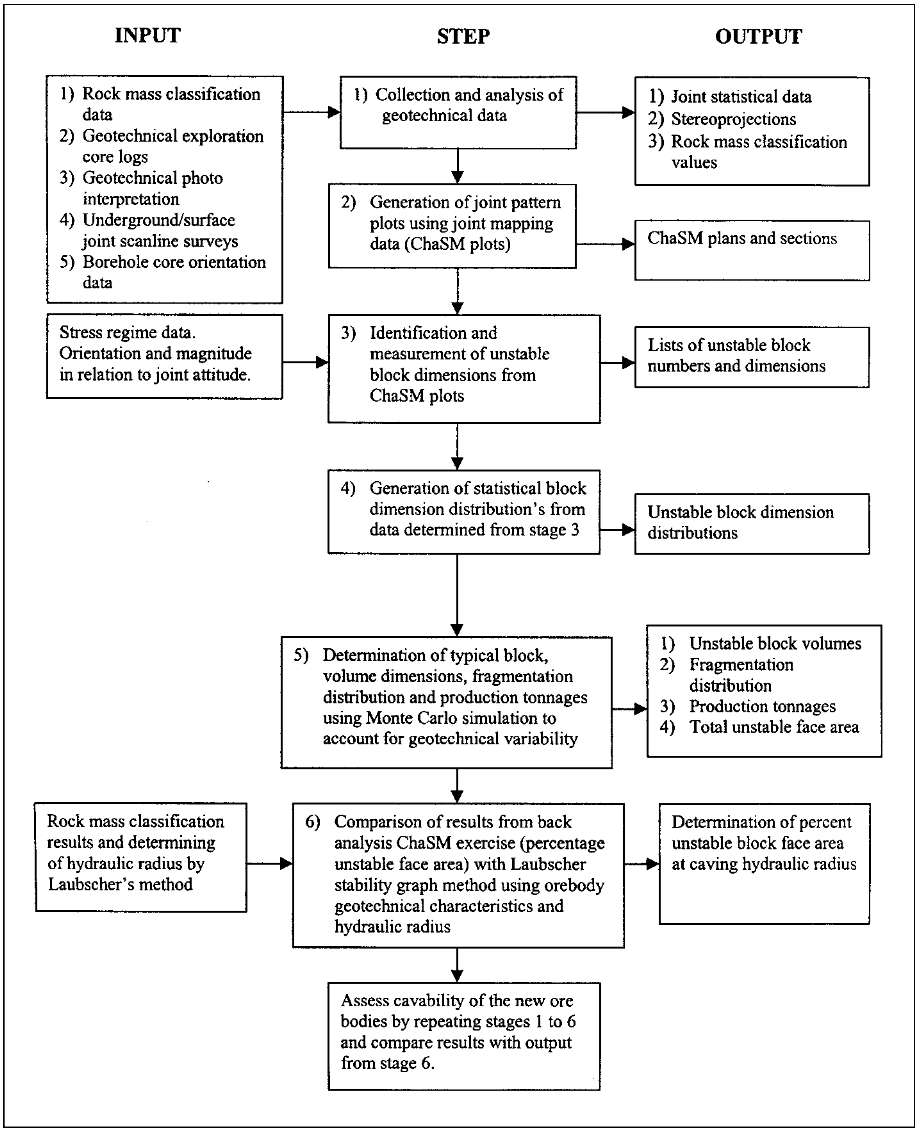
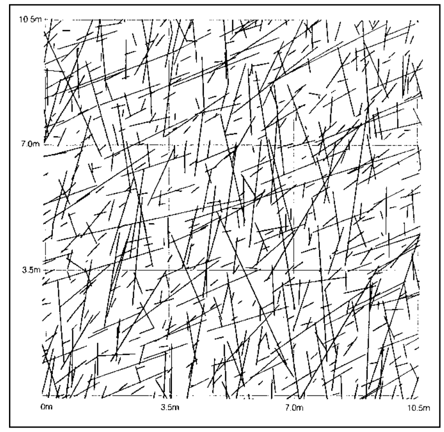


Fig. 2. Example of a ChaSM plot.



Generation of Joint Discontinuity Patterns

The method of generation of discontinuity patterns from joint statistical data is given by Haines (1984) (Fig. 1, Step 2). Figure 2 gives an example of a ChaSM plot.

Identification, Measurement, and Calculation of Unstable Block Dimensions and Failure Volumes

In order to determine the dimensions of unstable back blocks and to calculate the initial block cave production tonnages, it is necessary to identify and measure the dimensions of potentially unstable blocks that occur in the generated ChaSM plots (Fig. 1, Step 3). To obtain block volumes, joint pattern sections are also generated so that the typical depths to which blocks extend into the back can be measured. The identification and measurement of block dimensions is carried out by physical measurement from the ChaSM plans and sections. This may appear to be an unnecessarily laborious process, but it has the advantage of giving the user a much better "feel" for the structure of the rock mass.

It should be recognized that only potentially unstable blocks are measured. In this respect, only blocks where maximum and minimum principal stress components do not act sub-parallel to the joint trace direction or sub-normal to the joint trace surfaces (for those joints that form blocks or wedges) were considered unstable (Fig. 3). In this manner, the two dimensional directional stabilizing effects of mining stresses on undercut back blocks are accounted for. It should be noted that at scoping study level, information on the in situ stress will be very limited or non-existent. A very approximate estimate is therefore adopted in an attempt to take into account the effect of the major stresses on block stability in plan only. This requires that the boundary of every identified potentially unstable block occurring in the pattern is scrutinized in terms of its orientation to the principal stress components. This is achieved by the construction of a stress direction rosette (Fig. 4) that can be superimposed on every identified block. The effects of joint frictional forces were not considered due to the fact that joint friction conditions are accounted for in the rock mass classification. This part of the method assumes that the confining stresses act as the main stabilizer, and conversely, mobilizer, in the undercut back.

After the dimensions and numbers of unstable blocks had been determined, the information obtained was used to generate statistical frequency distributions of block face area and heights. Since the block dimensions were only obtained from one ChaSM plot, these distributions are not adequate to model the many permutations of possible block dimensions that could occur. In order to overcome this problem, Monte Carlo sampling from the block face area and height distributions was used. From this process, distributions of the overall block volumes were obtained. The output from this exercise took the form of a cumulative distribution of undercut back fragmentation.

Determination of Initial Block Cave Production Tonnage

Once the block and wedge volumes have been ascertained, the initial production tonnage can be calculated from the multiplication of the number of unstable blocks by the unstable block volume and the relevant ore density (Fig. 1, Step 5). It is important to note that the calculated tonnage is only the initial production tonnage that reports to cave drawpoints once the undercut blast swell has been extracted. The simulation cannot model secondary fragmentation. In essence, all tonnage estimations can be considered to be conservative, and it is assumed that all unstable blocks will fall within a 24 hour period. However, since the aim of the method is to determine, to scoping study level, whether a block cave is viable, this conservatism was considered to be acceptable.

Assessment of Cavability

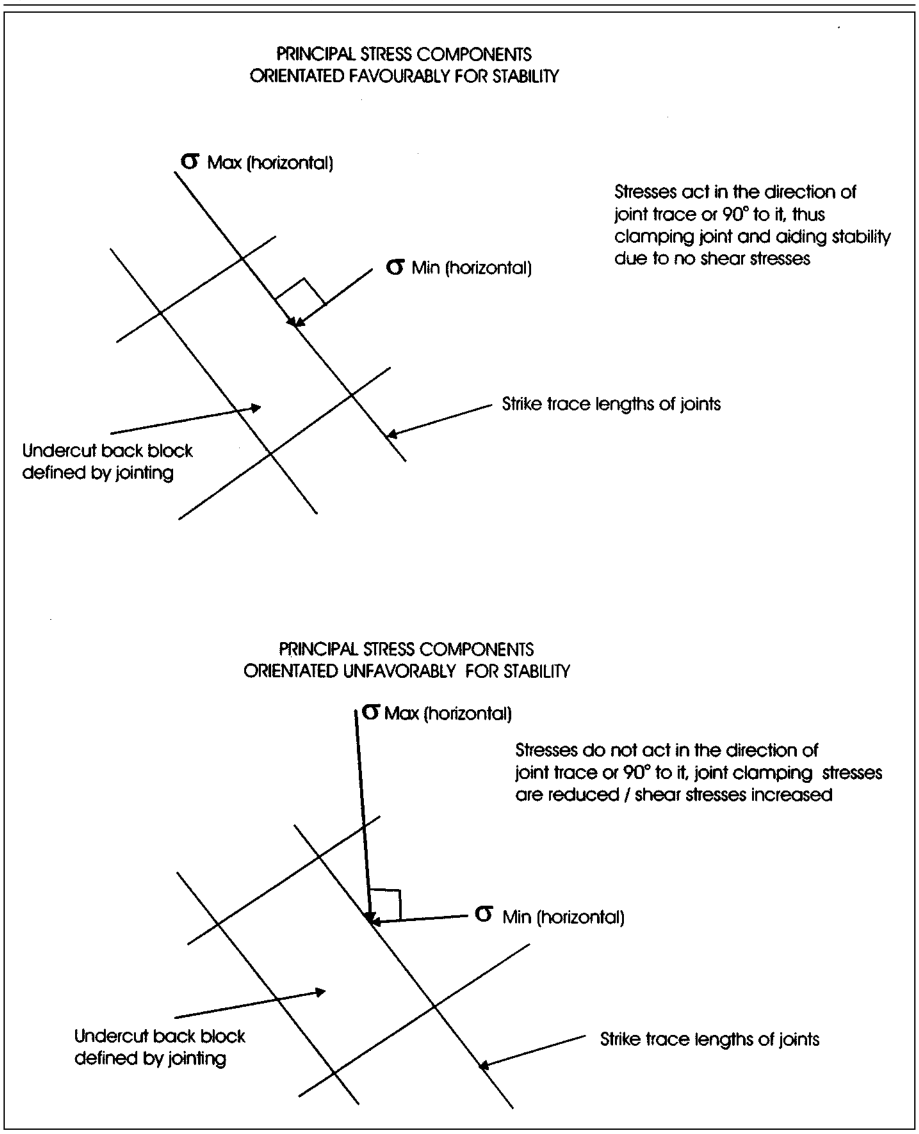
In the use of this method to predict cavability of a block cave (Fig. 1), it is important to recognize that all rock masses will cave and that what has to be determined is the extent of the undercut required to induce caving. It must be further recognized that the process of caving is not instantaneous. In this respect, caving has two distinct processes: the initiation of rock mass caving; and the propagation of the rock mass caving (mass mobilization).

Only blocks that are not clamped by the principal stresses will fall during the caving process. The practical implication of the above is that not all blocks will fall from the back once the caving process begins. Some kinematically unstable blocks will fall only once the caving process begins and back ravelling increases due to the reduction in confining stresses in the back. It is therefore evident that, in assessing the extent of the undercut required for caving, it is important to define the quantum of blocks required to initiate caving. If it is possible to determine the initial tonnage from the block cave, then it is possible to determine the total face area of blocks per undercut area as a percentage. This percentage can then be compared with the percentage value obtained from an actual case of a block cave (base case) where cavability was achieved. Thus, by comparison, cavability of a new deposit can be assessed. It is therefore evident that the base case back analysis study is an important part in the ChaSM method.

Back Analysis Study

To determine the accuracy of the method, a back analysis study was undertaken using data from a block cave in which the actual behaviour is known. A description of the mine and the data used is given.

Fig. 3. Criteria for undercut block stability/instability.



General Description of the Base Case Block Cave

The base case cave is extracting a class 4 orebody (MRMR rating).

Base Case Geotechnical Input Data

Two main geotechnical units are encountered on the cave extraction level — the country rock and the ore. The geotechnical characteristics of these units are summarized in Tables 1 and 2.

The characteristics of the joints in the orebody are summarized in Table 3. These data show that the rock mass is characterized by closely spaced joints with short trace lengths. Table 4 shows the major principal stress orientation only. There was no information on the orientations of the other principal stress components.

Cavability and Initial Production History

The block undercut dimension was determined using Laubscher's stability graph method (Fig. 8). In this respect, it was predicted that this orebody required a hydraulic radius of 17 m to initiate caving. The orebody did cave at this predicted dimension. In the initial stages, production records showed that the block produced a maximum of 980 tons/day.

Results of Base Case Study

Using the modelling method (as depicted in Figure 1) above, the following results were obtained.

1. Back block dimensions for cave initiation — 227 unstable back blocks were identified from the ChaSM plots and the dimensions of these blocks were used as input data. Figures 5 and 6 give statistical distributions of generated block width and block height. In Figure 7, the primary fragmentation distribution generated from the ChaSM block volumes is compared

Fig. 4. Back block stability/instability stress rosette.

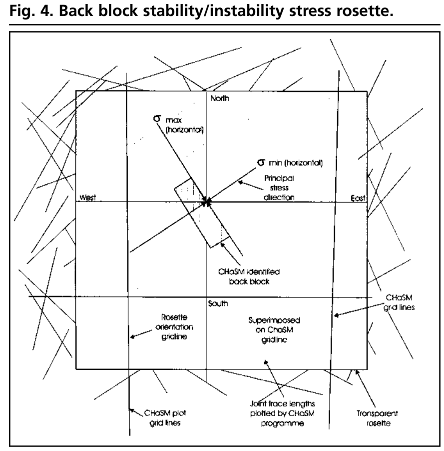


Table 1. Country rock geotechnical properties

Unit	Uniaxial compressive strength (MPa)	Young's modulus E (GPa)	Poisson's ratio (ν)	RQD (%)	FF*	MRMR	Class
Country rock	174	75	0.2	90	2	58	3a (fair)

* Fracture frequency in fractures per metre

Table 2. Ore geotechnical properties

Unit	Uniaxial compressive strength (MPa)	Young's modulus E (GPa)	Poisson's ratio (ν)	RQD (%)	FF*	MRMR	Class
Ore	35 to 87	18	0.2	75	1	31	4b (poor)

Table 3. Ore structural characteristics

		Dip angle (°)	Dip direction (°)	Strike length (m)	Dip length (m)	Joint spacing (m)
Set 1	Mean	49.0	174.0	1.6	1.0	0.4
	Standard deviation	7.4	4.7	1.2	0.1	0.2
Set 2	Mean	88.5	89.0	1.0	1.8	0.4
	Standard deviation	0.7	5.7	1.0	1.1	0.0
Set 3	Mean	84.3	170.5	0.9	1.9	0.5
	Standard deviation	6.5	14.0	0.8	0.9	0.1

Table 4. Missing stress regime

Stress component	Dip direction (degrees)
σ_1	264

with primary fragmentation data from Premier mine (Esterhuizen et al., 1996) in the form of a cumulative distribution (Premier mine also has a class 4 orebody).

2. Initial block tonnage — Using the data from the previous sections in the manner described in the modelling method and depicted in Figures 5 and 6, the initial block tonnage was calculated as 1190 tons by the ChaSM process. This is in reasonable agreement with the actual initial block tonnage.

3. Assessment of cavability — From the calculation of the production tonnage, it was possible to calculate the total face area of unstable blocks involved in the initiation of caving. This was calculated as 735 m^2, which corresponds approximately with 15% of the required area to initiate free caving according to Laubscher's stability graph (determined caving hydraulic radius). This value is plotted as point A on the Laubscher stability graph (Fig. 8). It should be recognized that this value plots near the cave initiation point on the stability graph.

Assessment of Base Case Study Results

The following can be ascertained from the ChaSM base case (back analysis) study:

1. The fragmentation distribution obtained shows a close correlation with another class 4 block cave's fragmentation (Premier mine). This indicates that the block selection process was sufficiently accurate.

2. The ChaSM exercise predicted that the initial block cave tonnage would be 1190 tons/day. The actual recorded tonnage was 980 tons/day. The ChaSM and actual recorded tonnages agree to 82%. Since the purpose of the exercise was to determine tonnages to scoping/conceptual study accuracy level, which is a 50% accuracy (Anon., 1993), it can be concluded that the study has been conducted to the required levels of accuracy.

3. A major input into the tonnage calculation was the total face area of unstable blocks occurring in the back. This has been calculated at 15% of the undercut area, the undercut area being determined by the caving hydraulic radius (as given by Laubscher's stability diagram). It can be concluded that 15% of the undercut back area must consist of unstable blocks to initiate caving. Further observations from the Chasm plots indicated that 80% of the back must be made up of unstable back blocks to continue the process of caving and cause propagation.

Application of the Method to a Hard Rock Orebody

The results of the back analysis study showed that the method can be applied to a block caving scenario to give scoping study levels of accuracy. The method was then applied to a hard rock orebody where block caving was being considered. In terms of block caving, a hard rock orebody is defined as one where the MRMR exceeds 45. In order to check the accuracy of results, a comparison was made with the tonnages and fragmentation from the Palabora block cave study (Kear et al., 1996).

General Description of the Hard Rock Orebody

The orebody occurs at depth greater than 500 m with a footprint in excess 15 000 m^2. The deposit is hosted in a granite.

Geotechnical Environment

The country rock and orebody are competent, with the mineralized areas being slightly stronger than the areas outside the footprint.

Fig. 5. Statistical distribution of block widths generated from base case ChaSM data.

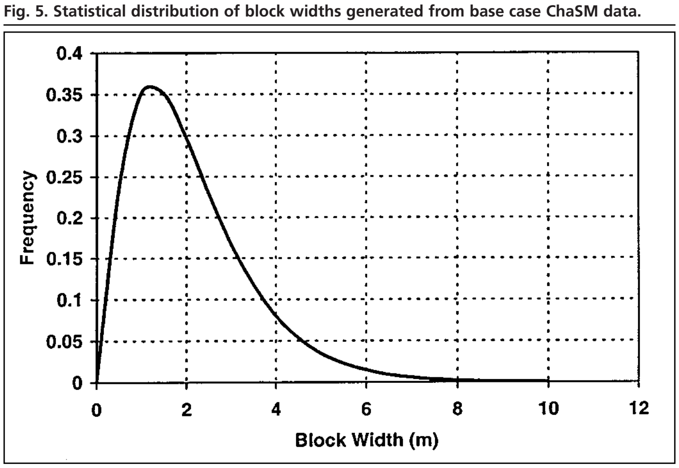


Fig. 6. Statistical distribution of block heights generated from base case ChaSM data.

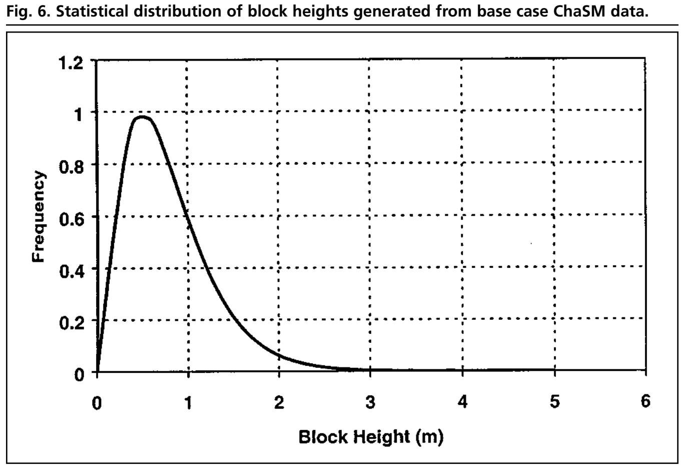


Table 5. Country rock and ore geotechnical properties

Unit	Uniaxial compressive strength (MPa)	Young's modulus E (GPa)	Poisson's ratio (ν)	RQD (%)	FF*	MRMR	Class
Country rock/ore	+184	75	0.2	70 to 90	2 to 6	54	3b (fair)

Table 6. Ore structural characteristics

		Dip angle (°)	Dip direction (°)	Strike length (m)	Dip length (m)	Joint spacing (m)
Set 1	Mean	67.0	8.8	3.1	2.6	1.5
	Standard Deviation	10.0	16.4	2.9	2.6	0.4
Set 2	Mean	63.1	278.5	3.3	2.0	2.3
	Standard Deviation	8.8	15.1	3.3	2.8	0.4
Set 3	Mean	77.3	65.0	3.4	1.3	1.5
	Standard Deviation	11.1	8.6	3.6	2.2	1.0

Limited geotechnical investigation work has been carried out on the orebody, as a result of which a full geotechnical description is not possible. Both country rock and ore can be considered to be the same geotechnical unit. A summary of the geotechnical characteristics of the county rock/ore rock is given in Table 5. The ore rock mass structural characteristics are summarized in Table 6. The competency of the orebody is indicated by the larger joint spacing.

Table 7. Hard rock orebody principal stress orientation

Stress component	Direction
σ_1	100° to 120°

Mining Stress Regime

The orientation of the maximum principal stress is given in Table 7.

Production History and Fragmentation

Block caving or sublevel caving has never been used on the mine. Open stopes with back dimensions of 30 m by 65 m have been used in the mine with no recorded regional instability being recorded, but stope sloughs of up to 100 m^3 have occurred.

Laubscher's stability diagram (Fig. 8) indicates that the orebody requires a hydraulic radius of 29 m to initiate caving should a block caving method be used.

Results of the Hard Rock Orebody Study

Using the method described previously, the following results were obtained from an analysis of block dimension data taken from the hard rock orebody ChaSM plans and sections.

1. Back block dimensions for cave initiation — Figures 9 and 10 give statistical distributions of generated block widths and block heights. Figure 11 gives the block volume as a cumulative distribution.
2. Calculation of initial block tonnage — Using the statistical results given above, the initial production tonnage was calculated as 7980 tons/day (taking the ore density as 2.7 ton/m^3).
3. Assessment of cavability — From the block face dimensions, it was possible to calculate the total face area of unstable blocks to initiate caving. This was calculated at 2605 m, which corresponds approximately with 20% of the area required as the undercut dimension (to

Fig 7. Comparison of Premier fragmentation distribution with base case study fragmentation distribution.

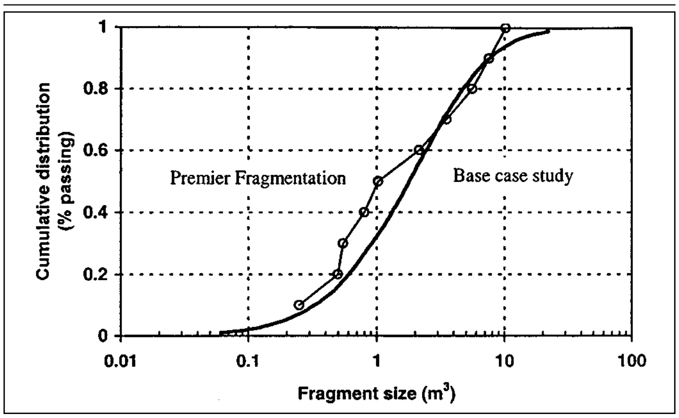


Fig. 9. Hard rock orebody statistical distribution of block widths generated from ChaSM data.

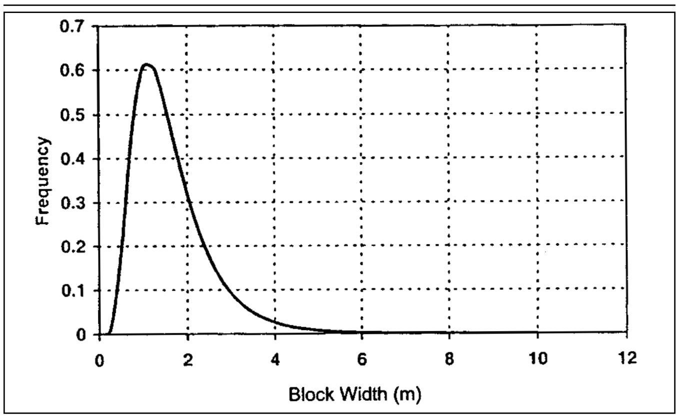


Fig. 8. Laubscher stability graph showing cavability assessment for both the base case study and hard rock orebody.

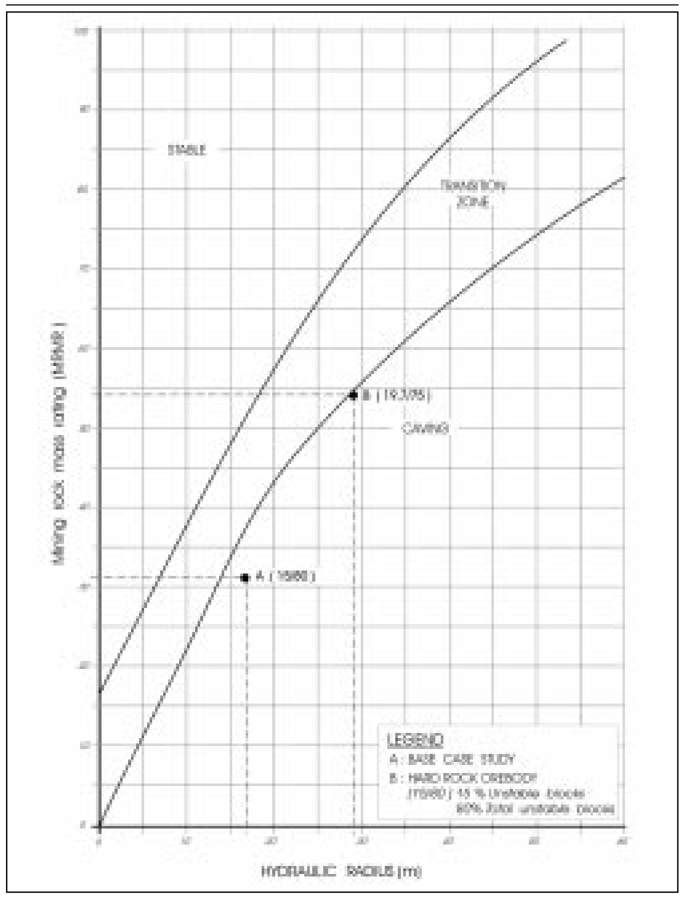


Fig. 10. Hard rock orebody statistical distribution of block heights generated from ChaSM data.

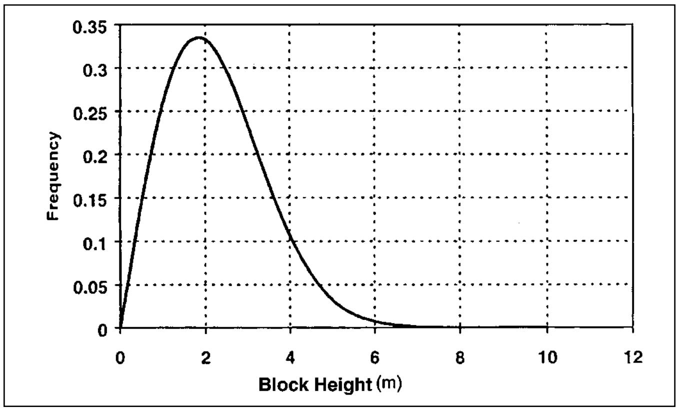
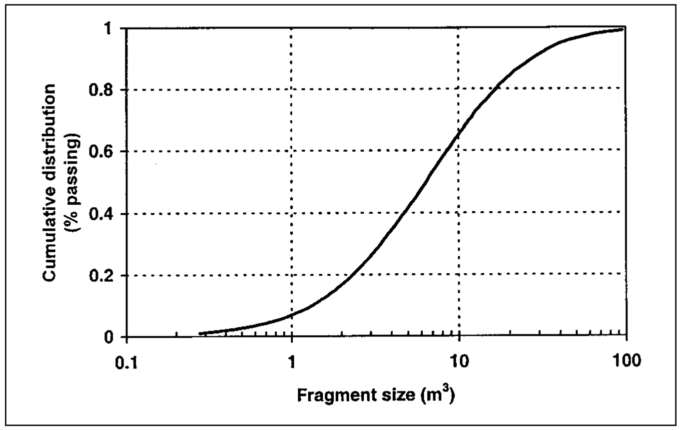


Fig. 11. Fragmentation size distribution for hard rock orebody.



induce free cave), determined according to Laubscher's stability diagram. It should be further recognized that again the results plot on the cave initiation zone.

Analysis of Hard Rock Orebody (Block Caving Study Results)

The following can be ascertained from the ChaSM cavability assessment of the hard rock orebody.

As expected, the fragmentation from the hard rock orebody is much larger than the base case study. 7% of the base case study fragmentation is greater than 10 m^3, compared with the hard rock orebody in which 30% of the fragmentation is greater than 10 m^3. In relation to other hard rock block caves, this fragmentation is large. At North Parkes, 50% of the fragmentation is greater than 2 m^3 (Chen, 1995), compared with the hard rock orebody, where 83% will be greater than 2 m^3.

The study predicts that 7980 tons/day will be produced initially from the modelled orebody. Kear et al. (1996) state that the Palabora block cave will have an initial production capacity in the region of 5000 to 10 000 tons/day after the first year of operation (after undercutting). Since the MRMR values of Palabora's carbonatite ore are similar to the hard rock ore, the ChaSM determined tonnages for hard rock orebody appear to be realistic. The results show another similarity to the Palabora block cave — a high daily tonnage capacity, but fragmentation reporting to the drawpoints would be extremely large. In essence, the block cave's high tonnage capacity is due to the large size of fragments falling from the back. It therefore becomes evident that, for hard rock block caving to be considered viable, an important consideration must be how quickly and cheaply large ore fragments can be removed from the cave muck pile. This is in contrast with soft rock block caves, where project economics are based on the quantity of ore fragments that report to drawpoints.

Using the base case study results (which show that for cave initiation to occur, at least 15% of the undercut back must be comprised of unstable blocks), the hard rock orebody will cave, as 19% of the back is comprised of unstable blocks (Fig. 8). From the ChaSM plans it was determined that 75% of the back is comprised of blocks that would fail after cave initiation. This figure is slightly below that which was determined in the base case study for cave propagation. From this it could be interpreted that a slower rate of caving will be experienced, with failure of the non-jointed areas being due to stress caving as the back arches. The slow rate of cave propagation could also indicate the potential for air blast due to cave back collapse. This could occur if draw rates are not matched to caving rates (resulting in an air gap between the cave back and muck pile).

Conclusions

The method described has been designed to be used with scoping study level input data. In this respect, it is expected that results must be accurate to within 50%. The primary aim of the method is to provide results that can be placed into an economic model to determine more quantitatively whether block caving is viable, without this decision being made on the basis of engineering judgement only.

The results of the ChaSM base case study show that there is a close correlation between the predicted and observed results in terms of fragmentation, and production tonnage determination. The level of accuracy is within the scoping study requirements.

The study showed that the ChaSM system can be successfully applied to hard rock orebodies. The tonnage determined from this study appears to be realistic when compared with that determined for the Palabora cave.

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