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Guidelines for orepass design in a sublevel cave mine

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Abstract

Underground mines commonly use orepass systems as a safe and economic method to transport broken rock between levels. Although these systems are an integral part of such operations, design methodologies are generally limited to empirical methods, rules of thumb and limited case studies. This paper details orepass design issues in an operating sublevel cave (SLC) mine and the method used to determine suitable design parameters for future orepasses at the mine. The guidelines, as well as the system used to determine the parameters, can be used as a design methodology applicable to any other mine at a planning or operational stage.

Operational issues during early orepass operation included hang-ups due to cohesive arching and ore compaction, and higher than forecasted wear rates. The operational and financial implications of these issues have necessitated the need to develop site based guidelines for orepass design and layout. Laboratory testing and statistical analysis were conducted in conjunction with empirical methods to determine optimum orepass diameter, inclination angle, pass length and tipping methodology. Wear rates have been measured for different tipping methods and used to provide an estimate for orepass longevity. Forecast wear rates for planned throughput have then been analysed to calculate maximum stable pass dimensions. Numerical modelling was utilised to determine suitable stand-off distances between other orepasses, development and the SLC footprint. Regular monitoring was used to calibrate theoretical wear rates with actual measurements.

This paper outlines how orepass design guidelines have been developed for the Ernest Henry SLC. Empirical methods and numerical analyse have been undertaken to determine guidelines which have been progressively calibrated using monitoring data and field observations.

1 Introduction

Ernest Henry Mining (EHM) is situated 38 km northeast of Cloncurry in the Eastern Fold Belt of the Mount Isa Inlier of North West Queensland. The copper-gold orebody is overlain by 50 m of cover sequence consisting of sand, gravel, shale and clay, and hosted by strong Proterozoic rocks (mainly comprising intermediate and felsic volcanics). The orebody dips south at 45° and is near-cylindrical in shape.

The EHM operation comprises of both an open pit and an underground SLC. Operation of the open pit spanned from 1996 to late 2011 and its final dimensions are 1.5 × 1.3 km, with a depth of 530 m. Development for the underground SLC commenced in 2008 and the first extraction of ore occurred in 2011. The SLC targets ore which extends 425 m vertically or 670 m down dip from the overlying open pit, with a total depth approaching 1 km. Dimensions of the planned cave footprint on the upper production levels is approximately 220 × 220 m and reduces at the lowest levels to 220 × 150 m. Initially ore production was trucked via the open pit, building up to a rate of 3 Mtpa in 2013. Shaft hoisting commenced in 2014, increasing production to 6 Mtpa. A conceptual layout of the underground mine with respect to the open pit is shown in Figure 1.

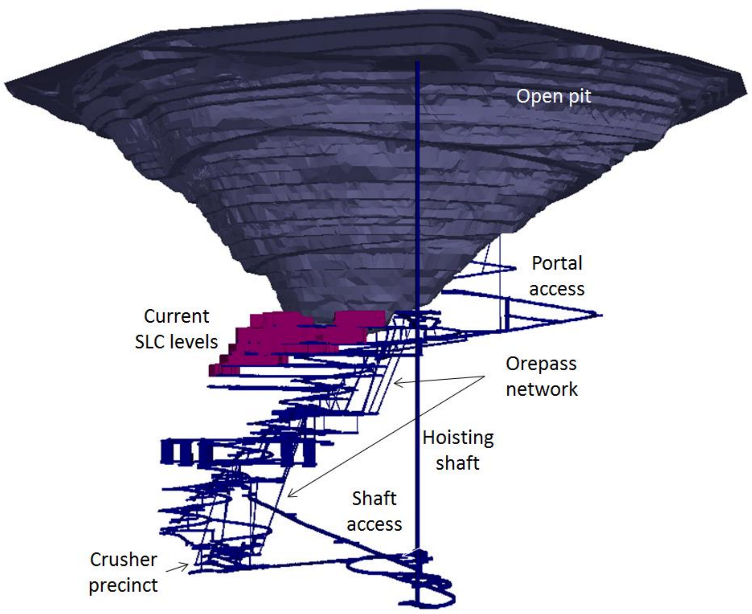


Figure 1 Oblique view of the open pit and underground mine at EHM looking west

The orepass system at EHM is required to transfer ore from various SLC production levels to the crusher precinct. The orepass network comprises of both the east and west orepass systems which run in parallel (Figure 2). Each side of the pass system has stages that service the production levels as well as the transfer levels on 1600, 1475, 1325 RL and the crusher at 1175 RL.

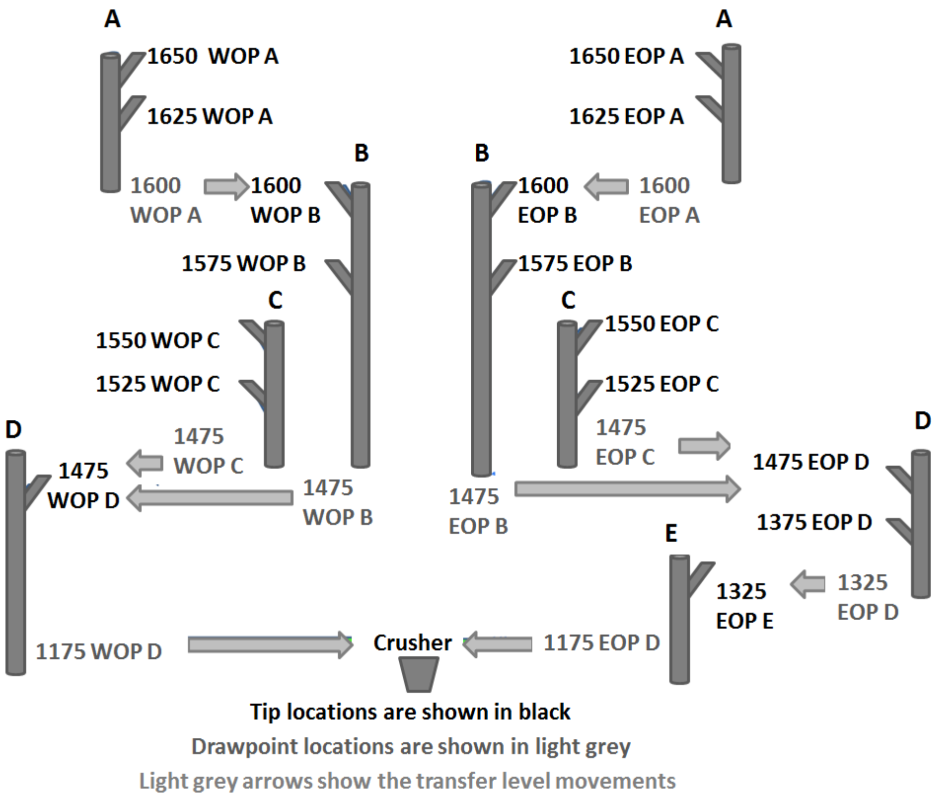


Figure 2 Schematic of EHM orepass system

Throughout 2014, two significant events occurred that lead to an investigation of overall design and placement of the orepasses. The first event occurred in the west orepass, leg D (WOP D), which is situated between 1475 and 1175 RL (Figure 2) and was raise bored at 70° at a diameter of 2.8 m. A total of 5 Mt was planned to be drawn from this orepass; however, at approximately 0.65 Mt, significant overbreak required the orepass to be abandoned and an alternate orepass to be developed. The significant shortfall in throughput (87%) was due to heavy bombing from frequent hang-ups in the orepass. The hang-ups were caused by a combination of factors including generation of fines due to large free fall distances (i.e. the broken material in the pass was not filled to capacity) and excess water contained in ore being tipped in the pass. Although the amount of water entering the pass was relatively low, the moisture content of the fines material was sufficient to result in cohesive arch formation. These hang-ups were particularly difficult to remove, requiring frequent bombing. Bombing resulted in accelerated damage of the orepass, resulting in the pass diameter increasing to 6.4 m in places. Frequent blockages and inadequate orepass management practices forced the early closure of the pass. The pass closure further reduced production rates for two months and increased production pressure on the eastern orepass system. This incident prompted a review of the minimum orepass diameter and tipping methodology.

The second major event occurred in EOP D (Figure 2), which was initially designed to mirror WOP D and transfer ore from 1475 to 1175 RL. However, upon completion of raisebore drilling of the orepass, an excessive amount of inflow of ground water (4.5L/s) was found to be entering the orepass at 1225 RL, where a major fault intersected the orepass. Due to the potential for inrush or mudrush occurring, this orepass was abandoned without ever being used. A replacement pass was required in a short period of time to prevent any further impact on mine production. The solution was to use an existing return air raise between 1325 and 1175 RL. A review of the orepass layout was then conducted due to the presence of water in proximity of the future passes in the eastern ore transfer network. Due to the limited area available to place new orepasses, potential interaction and stability issues with mine excavations and the negative impact of long tramming distances, a geotechnical assessment for orepass stability and stand-off distances was conducted.

Following the review of orepass design, a set of guidelines was developed for all future orepasses at the EHM SLC. This design methodology is outlined in this paper and includes:

- Laboratory testing guidelines and EHM test results.
- Orepass diameter to reduce the likelihood of cohesive arching and block hang-ups.
- Tipping practices to prevent the generation of fines.
- The effects of water ingress and moisture content.
- Wall stability assessment.
- Orepass layout and stand-off distances.
- Forecast and actual orepass wear vs pass throughput.

2 Laboratory testing and material properties

In order to ascertain why specific hang-ups occur in orepasses, it is first necessary to investigate the characteristics of the rock being tipped down these passes. Three main characteristics that have generally clear associations with hang-ups are the fragmentation of the material, the presence of water in the material and the shear strength parameters of the material.

2.1 Fragmentation

Fines material has the ability to consolidate when combined with water, causing cohesive arch type blockages. Research in long orepasses for Japanese limestone quarries indicated that fines material that contributes to arching can be up to 20 mm in diameter (Mogi et al. 1995). Blockages can also occur from the interlocking of large blocks tipped into the pass or from wall failure within the pass.

Inspections of all producing drawpoints were conducted and fragmentation was recorded as a percentage and divided into four categories:

- % < 50 mm.
- % between 50 and 500 mm.
- % between 500 and 1,000 mm.
- % > 1,000 mm.

These inspections showed that the dominant fragmentation size was between 50 and 500 mm (Figure 3).

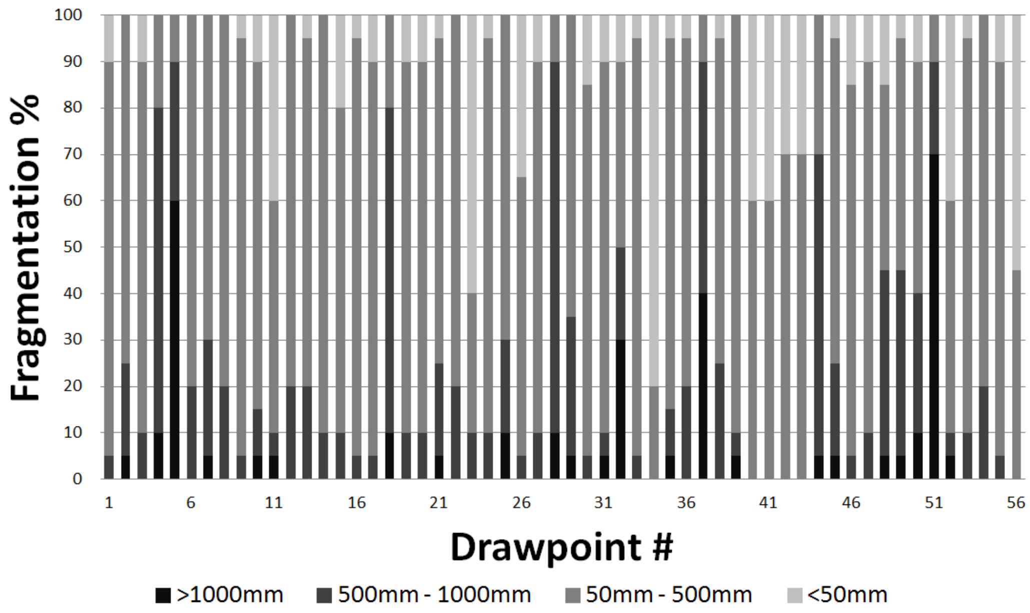
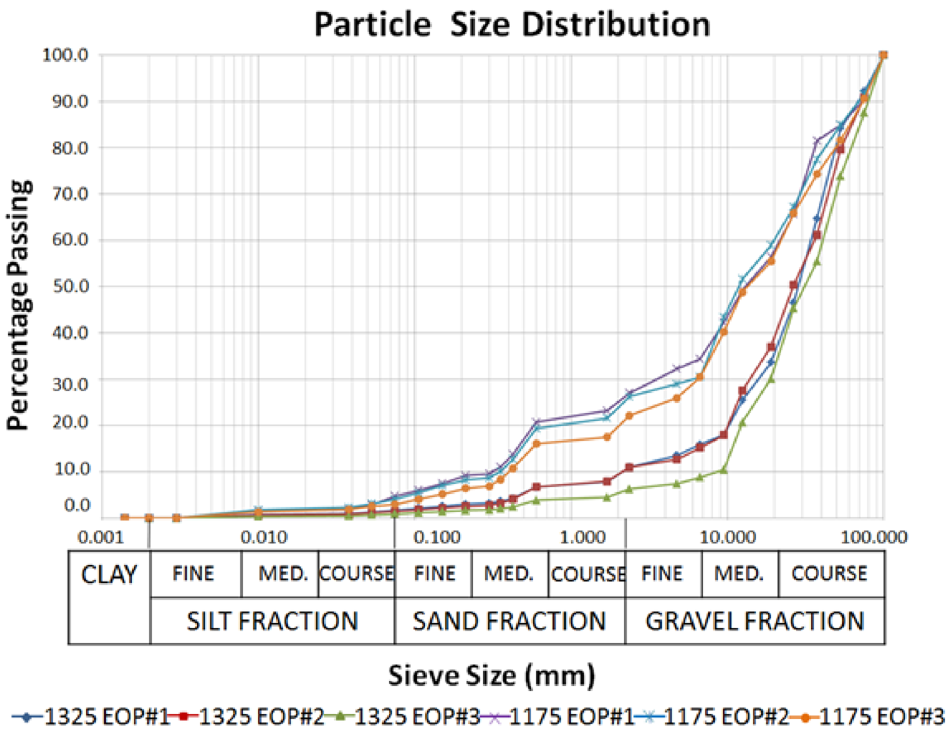


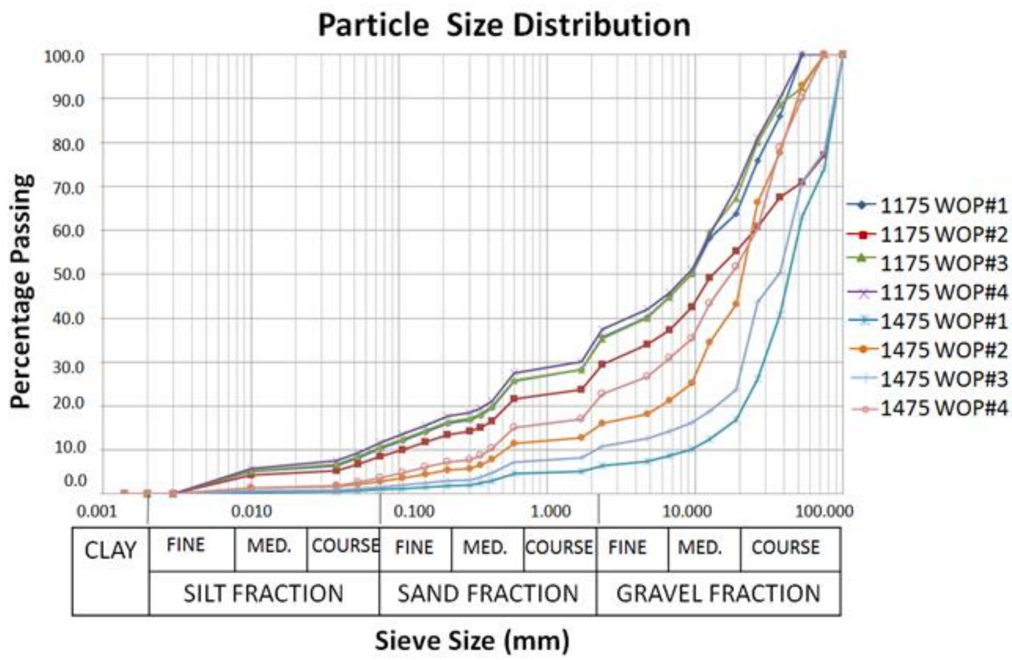
Figure 3 Distribution of fragmentation with EHM drawpoints

Particle size testing was also conducted for the material being tipped down 1475 WOP D and 1325 EOP E and again at 1175 WOP D and EOP E drawpoints (Figure 4). Samples were taken for material less than 200 mm in size with the potential to have cohesive properties. Testing found that there was a relatively even size distribution at 1475 and 1325, but at 1175, fragmentation reduced significantly with 48% of fragments from WOP D and 53% from EOP E being less than 12.5 mm in size. These results were attributed to a combination of the length that the material had to travel through the orepasses and the compaction occurring in the orepasses.

Material samples were collected from the drawpoints at 1475 WOPC, 1325 EOP D, 1175 EOP E and 1175 WOP D and their moisture contents were assessed. On average, the samples recorded moisture content levels of just below 2.5%.



(a)



(b)

Figure 4 Particle size testing results at orepass drawpoints: (a) EOP E; and (b) WOP D

2.2 Moisture content

The presence of water in orepass material has the potential to increase the cohesive properties of the material. When the material becomes increasingly cohesive, the flow of rock is affected and there is an increased potential for hang-ups and risk of mud-rush.

An internal audit within all active drawpoints as well as in the vicinity of tipping areas was conducted. Out of 39 drawpoints available, 29 had water pooling at the rill, which was due to a combination of water trickling in from the cave and from sprays being left on at the drawpoints. Two of the 29 drawpoints had pooling water in excess of 300 mm deep. WOP D and EOP E tipping areas were damp, but no water in-flow was visible and the conditions were reported at both these drawpoints.

Material samples were collected from the drawpoints at 1475 WOPC, 1325 EOP D, 1175 EOP E and 1175 WOP D and their moisture content was assessed. On average, the samples recorded moisture content levels of just below 2.5%.

2.3 Cohesion and friction angle testing

The understanding of a material's shear strength parameters is important in determining the behaviour of material when flowing through an orepass. Nine triaxial tests were undertaken to determine these parameters, summarised in Table 1. These tests indicated a high degree of variability with respect to shear strength and sample density. Upon further investigation, it was found that the coarser fractions (up to 70 mm in diameter) had not been removed from the sample prior to testing in 200 mm diameter cylinders and may explain the variability in sample density, shear strength and high peak strength frictions angles (O'Toole 2014).

Table 1 Triaxial test results with best fit values of cohesion and friction angle (Russell 2014)

Test no.	Principal stresses at peak conditions		Best fit total strength parameters at peak conditions		Principal stresses at softened conditions		Best fit total strength parameters at softened conditions	
	σ_1 (kPa)	σ_3 (kPa)	c (kPa)	Ø (°)	σ_1 (kPa)	σ_3 (kPa)	c (kPa)	Ø (°)
1	243.9	7.7	26.9	57.4	48.0	7.6	0	47.6
2	841.4	50.0	26.9	57.4	324.3	49.9	0	47.6
3	1,316.4	99.6	26.9	57.4	667.4	99.7	0	47.6
4	172.6	12.9	7.0	55.0	74.0	7.1	9.4	46.1
5	555.3	50.4	7.0	55.0	393.7	50.3	9.4	46.1
6	1,060.2	100.9	7.0	55.0	649.8	100.9	9.4	46.1
7	190.2	7.0	19.2	56.8	49.3	7.8	0	50.9
8	725.1	50.1	19.2	56.8	345.8	50.1	0	50.9
9	1,247.8	101.2	19.2	56.8	821.6	100.4	0	50.9

Values of cohesion in the order of 10 to 20 kPa are within the range expected, from experience, when testing ore fines from other operations (O'Toole 2014). The UNSW values for friction angle (Ø) are considerably higher than expected. Hambley et al. (1983) suggest that the practical range of friction angle is between 25 and 55°.

To supplement the laboratory triaxial testing, samples of ore were collected and sieved to less than 10 mm to remove coarser material. A number of simple angle of repose tests were conducted on a sample of ore fines to further investigate the concerns regarding the friction angle (O'Toole 2014). These tests were conducted in accordance with procedures outlined in Iverson and Jung (2005). The results of these tests (Table 2) appear to confirm the concerns regarding the high friction angle values obtained from the triaxial testing.

Table 2 Angle of repose measurement observations

Method	Observed angle of repose
One scoop	34°
Multi-scoop formed pile	35°
Pipe formed pile	37°

3 Determination of orepass diameter

Calculating an appropriate minimum orepass diameter was conducted for both interlocking arch and cohesive arching type hang-up mechanisms. The calculations were conducted for the maximum grizzly aperture of 1.2 m and the particle size distribution and material properties from laboratory testing.

3.1 Interlocking arches

The risk of hang-ups due to rock arching is a function of the size of the pass with respect to the size of the rock blocks being passed (Stacey & Erasmus 2005). Hambley et al. (1983) summarise the potential of interlocking arches forming as a ratio between pass diameter and maximum block size (Table 3).

Table 3 Guidelines for preventing interlocking arches in orepasses (Hambley et al. 1983)

Ratio of orepass dimension (D) to particle dimension (d)	Relative frequency of interlocking	Flow probability
D/d > 5	Very low	Almost certain
5 > D/d > 3	Often	Variable
D/d < 3	Very high	Almost certain not to flow

The grizzly design at EHM has three apertures at 0.9 m situated closest to the apron and three 1.2 m apertures positioned behind. The maximum allowable block size could be considered equal to these. With pass diameters of 2.8 and 3.5 m respectively, the potential for hang-ups in the 2.8 m diameter WOP D are very high while for the 3.5 m diameter EOP E, the rating is often.

It should be noted that using the grizzly aperture dimensions for these calculations can often result in overly conservative outcomes as the maximum particle size may often be smaller than the grizzly aperture. This can be the case for WOP D and EOP E as the fragment size samples were well below the size of the apertures. In this case, a risk-based approach was applied to provide a practical guide for evaluating the risk of interlocking arches. Consideration was given to the percentage of ore likely to pass the apertures, the percentage greater than the 0.9 and 1.2 m apertures requiring secondary breakage, and the estimated percentage capable of passing the apertures, having at least one dimension equal to or larger than the grizzly aperture. Laser scanning and fragmentation analysis of drawpoint material tipped into the passes showed that fragmentation was generally smaller than 0.9 m and material flowed freely without the need of secondary breakage. Therefore, the risk of interlocking arches was deemed low in both cases.

3.2 Cohesive arching

When a well graded material (similar percentage of different size ranges) flows through an orepass, the large particles tend to move with their mass while the material shears across the fines. Therefore, the shear strength of the mass in the pass is dependent on the composition of the fines present. Provided that the orepass has suitable characteristics to avoid block interlocking, the coarse particles should be free flowing. However, these coarse particles can cause compaction of the fines when interaction occurs while travelling through the orepass. Cohesive fines display an increase in shear strength with compaction, and have a higher potential to cause hang-ups (O'Toole 2014).

For material consisting of a range of particle sizes, the smaller particles pack in the spaces remaining between the larger particles. Therefore, the potential for compaction and arching is more prevalent in well graded material as opposed to uniformly graded material (O'Toole 2014). Material samples taken from the primary orepasses indicated that EHM material was well graded.

Stacey and Erasmus (2005) provide a guideline based on a relationship between pass size and cohesion to determine the risk of hang-ups where 'sticky' material is present (Figure 5). In respect to cohesion alone, EHM would require orepasses with a diameter in the order of 3.8 m.

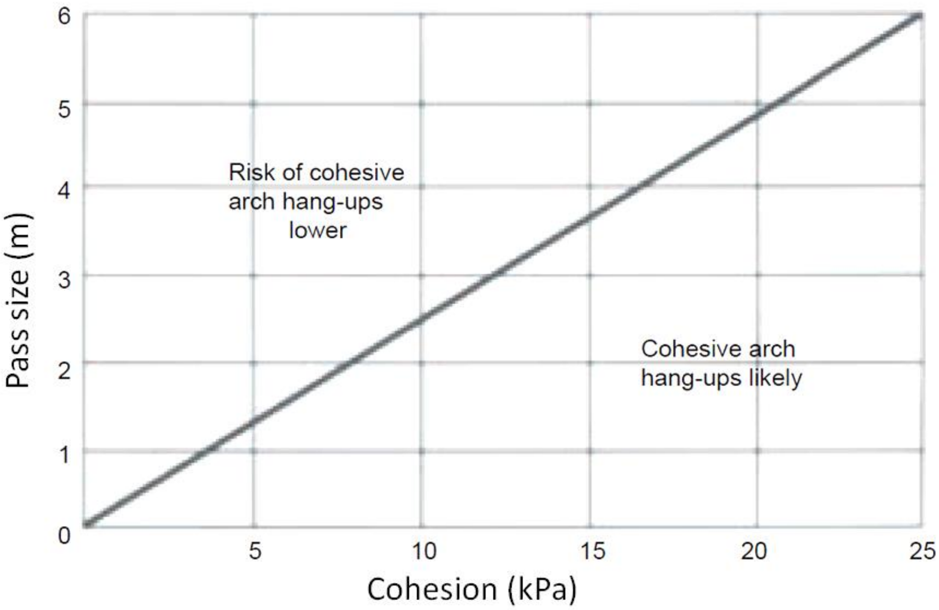


Figure 5 Guideline for determining pass size with respect to 'sticky' material (Stacey & Erasmus 2005)

In order to minimise the risk of cohesive arch formation, the orepass diameter is required to be sufficiently large such that the shear strength of the compacted fines is less than the effective load applied by the larger fragments of ore (O'Toole 2014). Hambley (1987) proposed a relationship between the shear strength of fines and orepass diameter in order to avoid the formation of cohesive arches. For circular orepasses used at EHM, this took the form of:

$$D > (4c/y)(1+\sin\emptyset) \tag{1}$$

where:

- D = minimum diameter (m).
- c = cohesion (kPa).
- y = density (kN/m^3).
- Ø = friction angle.

A Monte Carlo simulation was conducted to investigate orepass diameter by varying the shear strength parameters. Triaxial and simple angle of repose testing results had an average friction angle of 41° with a standard deviation of five. Cohesion averaged 15 kPa with a standard deviation of three. The inputs for the analysis are shown in Figure 6.

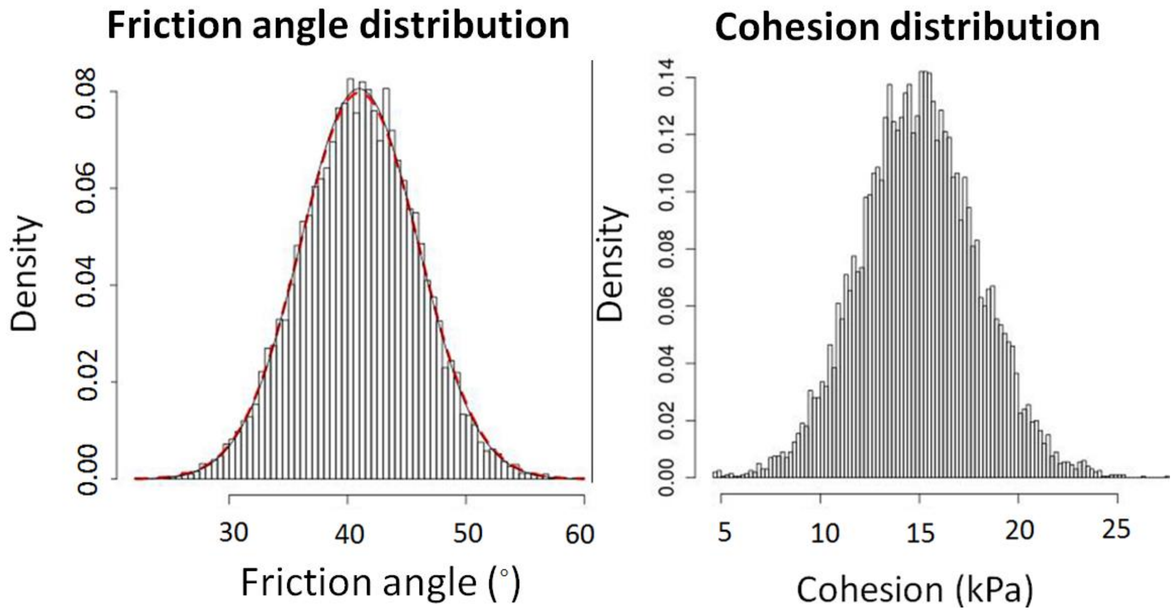
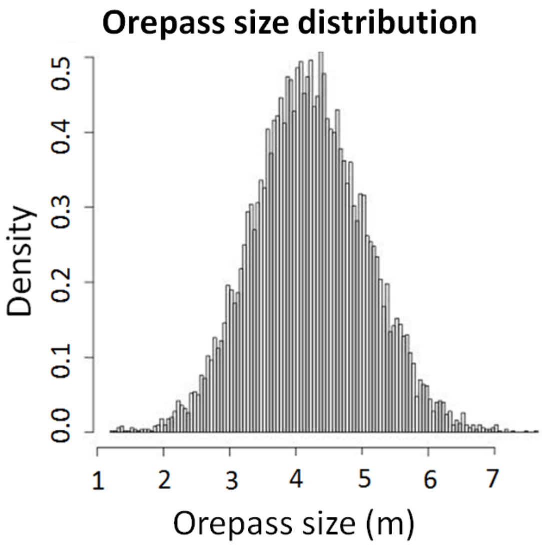


Figure 6 **Broken rock material properties for Monte Carlo analysis of orepass diameters to avoid cohesive arching (O'Toole 2014)**

A Monte Carlo parametric analysis was undertaken to determine the minimum orepass diameter calculated using the Hambley equation. A minimum orepass diameter of 4.2 m was determined using the average of the Monte Carlo simulation. The results of the analysis are shown in Figure 7.



1st quartile size (m)	Median size (m)	Mean size (m)	3rd quartile size (m)
3.6	4.2	4.2	4.8

Figure 7 **Results of Monte Carlo analysis of orepass diameters to avoid hang-ups caused by cohesive arching (O'Toole 2014)**

A minimum orepass diameter of 4.0 m was adopted for all future orepasses. It is also important to note that the presence of water also influences the behaviour of ore fines. In dry conditions, cohesion is not likely to develop, and a smaller diameter pass is suitable. At low moisture contents cohesion and arching have increased probabilities of developing (Figure 8). With increased moisture content, the cohesion decreases and the ore changes from a loose solid to a plastic liquid, flowing slowly and sticking to the wall of the pass. At high moisture contents, the ore behaves as a quasi-liquid (liquefaction) and will flow rather than form stable arches (O'Toole 2014). From these findings, it was concluded that drainage be provided to avoid pooling of water in the vicinity of drawpoints and orepasses. Water ingress to the orepasses, including excessively wet ore from drawpoint sprays, should be avoided. Another criterion to avoid generation of fine material and arch formation was to limit the freefall distance of ore tipped in the pass. Once these two recommendations were implemented, the frequency of hang-ups reduced significantly.

Figure 8 Material sticking to side of WOP D

4 Inclination of orepass

The inclination of an orepass influences how material will flow. Steep inclinations force the material through at a higher velocity, potentially causing compaction. Shallow passes reduce flow and increase the chances of blockage, especially where a high portion of fines is present (Stacey & Erasmus 2005).

In general, most mines prefer near-vertical orepasses which are typically operated choke-fed, while orepasses of a shallower nature (less than 70°) are run empty. All EHM orepasses are designed at 70° or greater. Running orepasses empty increases the potential for scouring to occur along the footwall of the pass, whereas a more even wear profile is associated with near-vertical orepasses run choke-fed. Due to the issues frequently faced with hang-ups at WOP D, it was decided that this orepass be run empty. Conversely, EOP E was being run choke-fed with no significant hang-ups.

5 Prediction of orepass longevity

It is difficult to define when an orepass is considered to have failed. Hadjigeorgiou et al. (2005) suggested that an orepass section has failed if it has increased to twice its original design geometry. EHM engineers were more interested in the amount of wear that could be sustained before the orepass became unstable and would collapse.

The Canadian Mining Industry Research Organization (CAMIRO) orepass longevity chart (Brummer 1998) indicates that it is possible to transfer large quantities of ore with a stress/strength ratio of 0.5, despite the first signs of rock failure beginning at a ratio of 0.3 (Figure 9). Once the stress/strength ratio reaches 0.6, it becomes difficult to predict behaviour and longevity is reduced. The chart also does not take into account large scale structures or the impact of bombing for hang-ups. Current numerical modelling and rock mass characteristics for the areas surrounding the lower level EHM orepasses suggest that the stress/strength ratio begins at 0.5 for the upper sections and exceeds 0.6 in the lower sections. The chart therefore indicates that the total material passing through both WOP D and EOP E should not exceed 2.5 Mt if designed to remain stable. As can be seen in Figure 9, WOP D had significantly less throughput than predicted due to frequent bombing and the manner in which the orepass was operated (bucket in, bucket out). On the border of the approximate failure boundary, EOP E has started showing signs of stress damage.

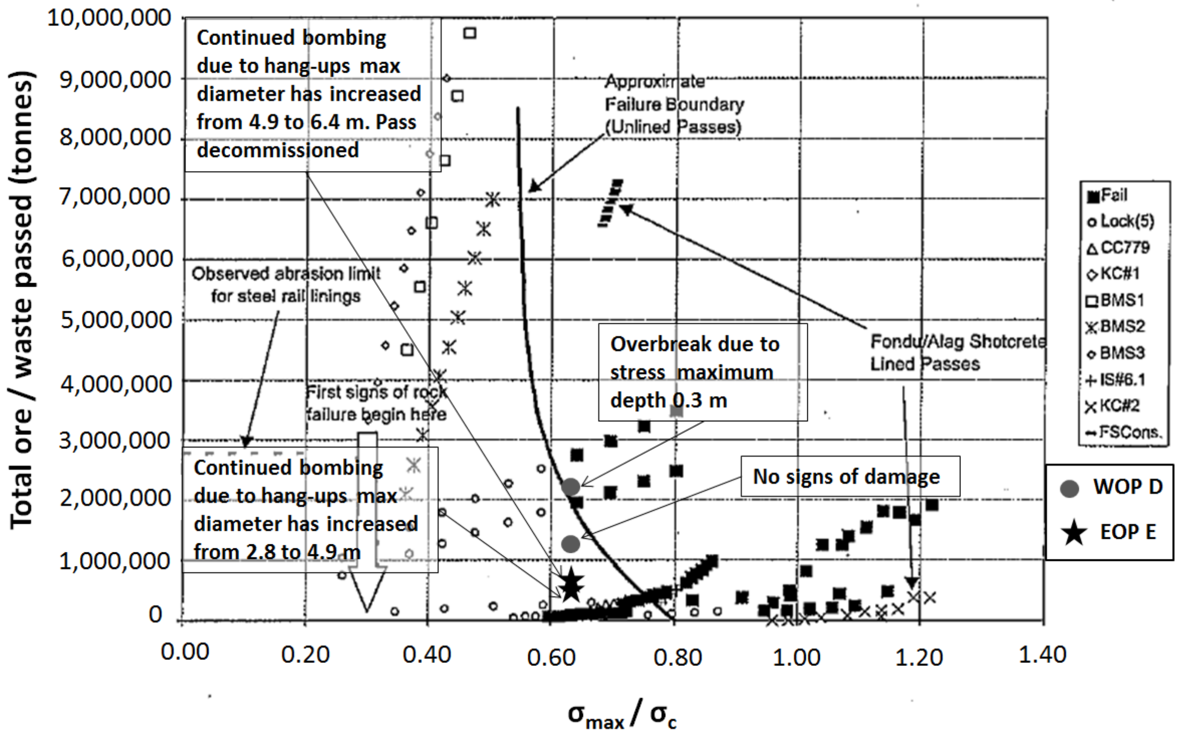


Figure 9 CAMIRO orepass longevity chart (Brummer 1998)

As geotechnical conditions will also have a signifciant impact on the longevity of an orepass at a given location, the Hadjigeorgiou and Mercier-Langevin model (2008) was also used to provide an additional estimate empirically for orepass longevity at EHM. WOP D and EOP E generally hold the same characteristics of fault intersection and general ground conditions and the results for both are provided in Table 4.

Table 4 WOP D and EOP E orepass longevity assessment using the Hadjigeorgiou and Mercier-Langevin (2008) model

Orepass scenario	Indicated longevity
Choke-fed	4.7 Mt
Free-fall	2.4 Mt
Frequent firing to free hang-ups (choke-fed)	3.7 Mt
Frequent firing to free hang-ups (free-fall)	1.8 Mt
Supported and lined with greater than 150 mm thick liner	10 Mt

As can be seen from Table 4, orepass longevity increases when choke-fed as opposed to being operated free-fall, but a far greater increase in longevity is estimated with the implementation of support and lining. The financial implications and practicality of orepass lining were reviewed and deemed unfeasible for the scenario at EHM. From the testing and analysis completed, a maximum design throughput of 5 Mt for each orepass was planned before an additional pass would be required.

5.1 Orepass wear

Very little information has been published regarding wear rates in large scale orepasses. As such, in order to gain a better understanding of wear rates at EHM, a monitoring regime for each of the orepasses was developed to determine orepass wear with respect to ore throughput, and to calibrate the Hadjigeorgiou and Mercier-Langevin (2008) model. The regime encompasses camera surveys and cavity auto-scanning laser system (C-ALS) scans (where practical) to be completed for every 1 Mt throughput. Once significant overbreak is identified or frequent hang-ups are observed, the frequency of orepass surveying is increased to every 0.5 Mt throughput. Whilst this regime is in its early stages, information gathered so far for both WOP D and EOP E is provided in Figure 10.

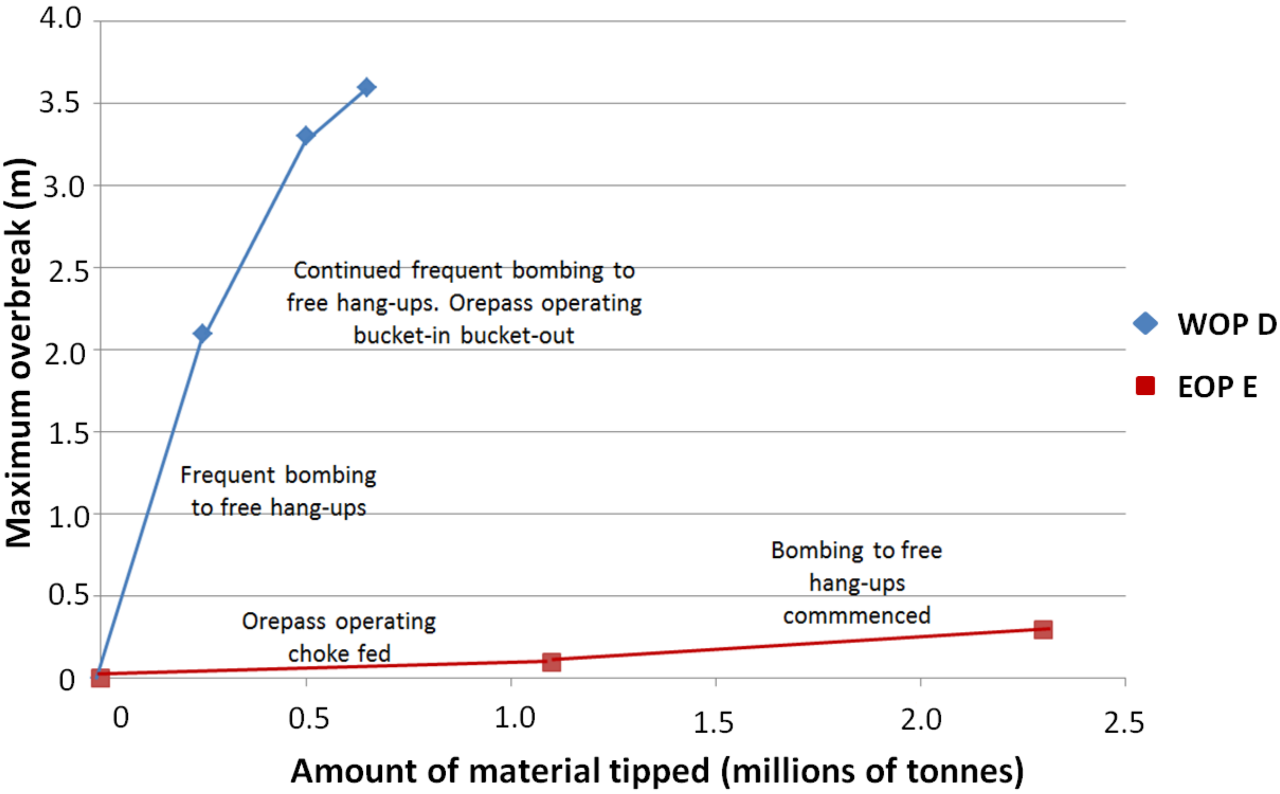


Figure 10 Orepass tonnes throughput versus maximum overbreak

The wear rate of WOP D was 5.5 m/Mt and EOP E was 0.13 m/Mt throughput. As can be seen from Figures 10 and 11, it is evident that frequent bombing (weekly) has had a significant impact on damage, and subsequent overbreak within WOP D in particular.

(a) (b)

Figure 11 WOP D prior to tipping (a) and following 0.65 Mt tipped (b)

6 Operation of orepass

When analysing the most probable mechanism of hang-ups for EHM orepasses it is evident that greater focus should be placed on operating the orepasses to reduce the risk of fines compaction and thus the risk of cohesive arching.

Stacey and Erasmus (2005) summarise the advantages and disadvantages of operating an orepass choke-fed versus free-fall (empty), highlighting that while operating an orepass choke-fed is likely to increase the risk of hang-ups due to block and cohesive arching, the risk of impact compaction, impact wear and scaling is reduced. Due to production requirements, it is not feasible to operate orepasses in a free-fall manner at EHM. In order to overcome the risk of cohesive arching, the orepasses were recommended to be drawn regularly to avoid material consolidation.

7 Orepass layout parameters

Orepass networks in SLC mines are generally located in close proximity to the orebody to minimise tramming distance. This can lead to stability issues that need to be considered during the design stage. These considerations include:

- Maximum stable pass diameter or span before the pass becomes unstable.
- The minimum separation distance between orepasses to ensure the in situ rock between the passes remains stable. This distance must consider the maximum orepass dimensions.
- The minimum separation distance between orepasses and mine development, particularly in zones of high wear and above the hanging wall of the pass.
- The distance from the SLC and influence of mining induced stress on the pass stability.
- Monitoring methods and access requirements.

Due to the manner in which the life-of-mine orepass system and additional vertical raises have been designed, there is potential for a number of small pillars to develop. In order to better understand the minimum stand-off distances required to prevent vertical raise interaction, numerical modelling and empirical analysis was conducted for EOP D between 1475 and 1175 RL prior to its intended implementation. The process is intended to be utilised with any deviation to the vertical raise structure at EHM prior to any development being undertaken.

7.1 Orepass wall stability

The McCracken and Stacey (1989) raise stability assessment was used to identify the probability of failure within faulted and non-faulted ground conditions at EHM, and EOP D was used as the initial benchmark. The McCracken and Stacey (1989) assessment uses a modified Q-system known as the raise rock quality (Q_r) to assess raisebore stability (Table 5). It should be noted that Q_r does not take into account time dependant deterioration, e.g. scouring of the sidewalls due to continued orepass tipping. Therefore, these results were considered non-conservative and, in reality, orepass overbreak was anticipated to be much more severe.

Table 5 Q_r values at certain depths of EOP D

Depth	Characteristic	Result
0-225 m	Non-faulted ground	Q_r ~10
230-265 m	Fault zone	Q_r <1
270-330 m	Non-faulted ground	Q_r ~10

This data was then used to understand the probability of raise failure within different ground conditions and raise diameters (Table 6).

Table 6 Probability of failure with respect to orepass diameter and ground conditions

Orepass diameter	Non-faulted ground	Faulted ground
2.8 m	1% probability of failure	22% probability of failure
15 m	25% probability of failure	>50% probability of failure

Based on the information gathered, the theoretical 'critical' orepass diameter is 15 m. When critical dimensions have been reached, there is a higher potential for large scale failure of the orepass.

7.2 Separation distance

For design guidelines, it was recommended that a minimum stand-off of 10 m exists between an operating orepass and lateral development and a minimum stand-off distance in the order of 30 m exists between functioning orepasses.

Boundary element numerical stress modelling using Map3D was conducted to evaluate stress interaction between orepasses with varying amounts of wear. Four orepass diameters were modelled including the design diameter and three orepass overbreak diameters. The results of this numerical modelling are shown in Figure 12 and Table 7. It must be noted that for ease of modelling, the orepasses have been simplified to have uniform diameters throughout the entire length. The results produced by Map3D may also be considered best case scenarios as they are modelled in an elastic, homogeneous rock mass.

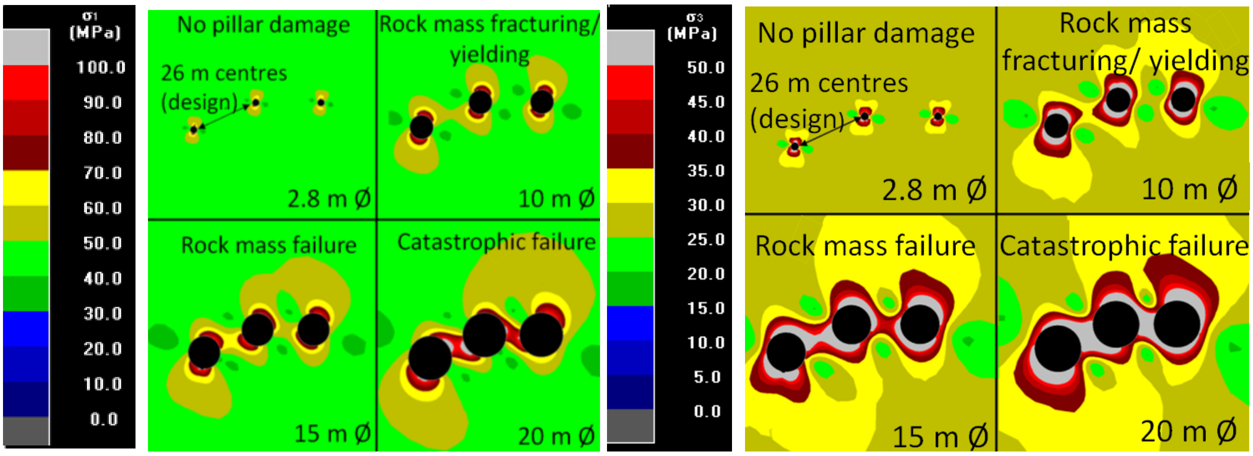


Figure 12 Vertical raise interaction, sigma 1 (left) and deviatoric (right) stress results at 1300 RL

Table 7 Numerical modelling results based on orepass diameter

Orepass diameter	Pillar thickness between passes	Model results
2.8 m (design)	23 m	Minimal stress interaction.
10 m	19 m	Moderate stress interaction. Rock mass fracturing/yielding.
15 m	14 m	Significant interactions are observed. Onset of rock mass failure.
20 m	9 m	No distinction between orepasses. Potential for major failure, i.e. orepasses are acting as one combined void.

Numerical modelling was also conducted to determine minimum stand-off distances for orepasses and mine development. Model results found that once the pillar between an orepass and development heading reached 10 m, stress interaction began to occur with potential for rock mass damage. At less than 10 m excavation interaction becomes significant with an increasing risk of rock mass failure with progressive orepass wear/overbreak.

Orepasses located within 50 m of the SLC were also affected by the mining induced stress changes surrounding mined out levels. McCracken and Stacey (1989) analysis found that the stress influence inside the 50 m boundary increased the potential for wall instability.

8 Conclusion

This paper illustrates the process undertaken to determine basic guidelines for orepass design and operation. This was necessitated by some issues encountered with pre-existing designs and operational practices. The design methodology is applicable to any mine with an orepass system. Ongoing monitoring of the EHM orepass system has been designed to ensure that orepass wear rates are determined for varying geotechnical conditions, operating methods and bombing considerations.

Guidelines developed at the Ernest Henry SLC for orepass design and operation can be summarised as follows:

- Minimum pass diameter of 4.0 m to prevent cohesive arch formation.
- Orepass inclination of 70 to 80°.
- Choke feeding of passes and ore levels maintained to within 25 m of the lower tipping point.
- Minimising of the moisture content of ore tipped into the pass through brow spray improvements and removal of pooled water at drawpoints.
- Maximum orepass span of 15 m before planned closure.
- Planned throughput of 5 Mt per orepass. This corresponds to an average wear rate of approximately 2.0 m (1.0 m from opposing walls) for every million tonnes throughput.
- Separation distance between orepasses of 30 m.
- 10 m deportation distance between development drives and the maximum orepass size (i.e. 15 m).
- Separation distance of 50 m between an orepass and the final SLC position.

Overall, a variety of tools has been used to assist in determining these guidelines and these will continue to be reviewed and updated as information becomes available.

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