

## Improvements to void hazard management for an active open pit mining through an old underground mine

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### ABSTRACT

*McArthur River Mine (MRM) in the Northern Territory, Australia is one of the largest Zn-Pb deposits in the world. The ore body was initially mined with an expansive underground network of room and pillar and stopes, many of which remain open. The operation transitioned to open pit mining in 2006. Due to the extent and location of underground workings under the pit floor, void hazard interaction and management is an important part of the day-to-day pit operations.*

*The Void Management Procedure and Plans provide a framework to manage the risks to personnel and equipment from interaction with underground workings. More specifically, Void Management Plans provide a review and operational management plan for a particular void hazard area, considering the cost, timing and equipment access prior to works commencing. Due to variation in ground conditions and void geometry, management solutions are often not a straightforward problem. Prioritisation of safe management options may cause delays or changes to mine schedule.*

*This paper presents an overview of the operational strategies as well as recent improvements to void management, which involve a focus on a more rigorous and robust review of ground and void conditions. These improvements include a grid based Catastrophic Failure Analysis (CFA) check, which was developed to provide a rapid assessment of areas that require targeted investigation. The development of specific Q values to refine Scaled Span Analysis (SSA) results are also presented. The paper also presents an updated probe and monitor approach for stope management.*

**Keywords:** underground, void, interaction, open pit, operations, geotechnical.

### 1 INTRODUCTION

McArthur River Mine (MRM) in the Northern Territory, Australia is one of the largest stratiform sediment hosted Zn-Pb deposits in the world. The eastward dipping orebody was initially mined with an expansive underground network of room and pillar and stopes, many of which remain open (Figure 1). Typical development drives are 5 m high by 8 m wide. Stopes are much larger, up to 40 m wide, 100 m long and 30 m high. The operation transitioned to open pit mining in 2006, with staged cutbacks progressing towards the east. The underground workings (referred to as “voids” at MRM) constitute an area of approximately 1.0 km by 1.5 km and will largely be mined out by the final life of mine (LOM) open pit. Due to the extent and location of voids under the pit floor, void hazard interaction and management is an important part of the day-to-day pit operations and will continue to be so throughout the life of the open pit.

This paper first presents a brief overview of the operational management plans for underground void interaction at MRM. Void interaction is managed through two primary documents: (1) the Void Management Procedure (Procedure) and (2) Void Management Plans (VMPs). The Procedure documents the general site guidelines for void hazard classification and management strategies (Smith and Bertuzzi, 2021). In contrast, the VMPs provide a detailed review and analysis of a specific void hazard and the operational management strategy for that area. VMPs typically include: a desktop study to assess current ground and void conditions, field investigation including probe drilling, analysis including Catastrophic Failure Analysis (CFA) and Scaled Span Analysis (SSA) and finally, the formulation of a management plan including delineation of specific voids to target for collapse or filling and addition/removal of void hazard exclusion zones. This paper presents recent improvements to the void analysis process, which provide a more rigorous and robust review of ground and void conditions.

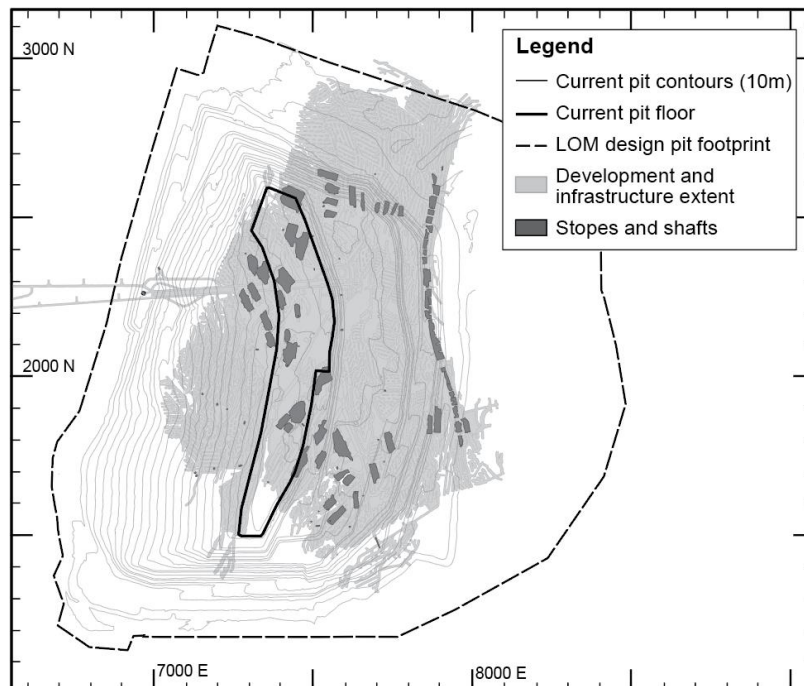


Figure 1: Extent of underground workings under the McArthur River Mine open pit.

Catastrophic Failure Analyses (CFA) are undertaken to assess the required crown thickness to safely operate over a void of a given height (Smith and Bertuzzi, 2021). The CFA equation is:

$$V = x (1 + 1/SF) \quad (1)$$

The analysis calculates the maximum possible vertical caving extent ( $V$ ) of a void of given height ( $x$ ) assuming that the caved material expands by a bulking factor ( $SF$ ) and chokes the void such that no further caving can occur. This paper presents a grid-based CFA method that was developed to provide a rapid assessment of areas that require targeted investigation and reduce the time-consuming process of initial void analysis during the desktop study.

Scaled Span Analysis (SSA) is an empirical assessment of crown pillar stability against a series of case studies to determine the probability of failure (PoF) (Carter, 2014). It is routinely undertaken at MRM to compare against CFA results. The SSA considers the crown pillar rock mass quality ( $Q$ ) and the void geometry, plotting results graphically.  $Q$  is calculated using the following formula:

$$Q = RQD/J_n \times J_r/J_a \times J_w/SRF \quad (2)$$

Where  $RQD$  is the rock quality designation,  $J_n$  is the number of defect sets,  $J_r$  is the defect roughness,  $J_a$  is the defect alteration,  $J_w$  is the defect water reduction factor and  $SRF$  is the strength reduction factor. This paper presents the site-specific  $Q$  values that were developed to refine Scaled Span Analysis (SSA). Lastly, this paper presents a proposed probe and monitor approach for stope interaction management.

## 2 VOID MANAGEMENT PLANS

Two common forms of VMPs at MRM are (1) Blast Master VMPs, which address all voids for the upcoming mining floor elevation and (2) Stope VMPs, which focus on specific voids with an elevated hazard, such as stopes or vertical shafts. The following sections detail the VMP process for both forms.

### 2.1 Blast Master Void Management Plans

Due to the extensive distribution of voids at MRM, Blast Master VMPs consider development drives for a given mining floor elevation. The workflow for a typical Blast Master VMP is as follows:

1. Assess current ground and void conditions, including:
  - a. Overview of underground workings present in area under review
  - b. Review of all previous probing drilling to determine caving extent

- c. Review of production blast patterns to delineate areas of broken ground vs intact and collapsed voids
  - d. Preliminary void analysis including CFA and SSA
  - e. Development of field investigation program to address data gaps.
2. Field investigation including probing and 3D scanning.
3. Analysis of field investigation results including CFA and SSA.
4. Formulation of void management plan including:
  - a. Targeting specific voids or areas for collapse or filling
  - b. Create draft void hazard exclusion zones for both post-blast and post-excavation to the next pit floor elevation to assist with mine planning
  - c. Any other area specific recommendations.
5. Review and implementation of management plan.

VMPs need to consider the potential cost, timing and equipment access for different management options. Due to the extent and complexity of underground workings at MRM, safe management options may cause delays or changes to mine schedule. Examples of this include where changes to blast pattern extents are required to collapse certain voids, where void hazard exclusion zones are extensive in a certain area requiring cranes for personnel to load blast patterns and where access for LVs and personnel is blocked to certain areas of the pit due to void hazard zones.

## 2.2 Slope Void Management Plans

Approximately 44 bulk stopes and 35 bench stopes were mined utilising a mine and retreat method which leaves the stopes open. Interaction of the open pit with the bench stopes is not anticipated for another 10 years. For the bulk stopes, 22 have been historically managed through a combination of filling and collapse. Many of the remaining bulk stopes require management in upcoming pit cutbacks. Due to the large stope void height (typically 30 m) the stopes require management from higher pit floor elevations than typical development drives. The workflow for a typical Stope VMP is as follows:

1. Analysis of the surveyed stope geometry, using CFA and SSA to determine the maximum possible caving extents
2. Development and implementation of probe investigation program
3. 3D scanning of open stope geometry to determine caving extent
4. Development and implementation of filling program
5. Further scanning and probing to determine the success of the filling program and resultant void hazard classification (generally a reduction in exclusion extent).

Due to the large void height, CFA results often mean that a void hazard exclusion zone would be implemented before site drill rigs were able to reach the stope crown for filling. This poses a substantial operational problem due to the required size of the exclusion zone and the locations of stopes, often under major haul road routes. Recent strategies to manage this issue are discussed in Section 3.3.

## 3 RECENT IMPROVEMENTS TO VOID ANALYSIS AND MANAGEMENT PRACTICES

### 3.1 Grid-Based Catastrophic Failure Analysis

CFA is typically utilised in void hazard assessments by spot checking areas of concern or relevance to upcoming operational works. Spot checks are undertaken by site engineers, and input into a spreadsheet, using equation (1). This form of the assessment relies on the diligence of the site engineer to identify areas that require analysis and can be very time consuming considering the number of voids present at MRM.

To streamline part of the analysis process, a grid-based CFA check was developed, allowing for a rapid assessment of broad areas. 3 x 3 m grids were created for the top and bottom of each development using "Vulcan", a 3D mine visualisation and modelling software developed by Maptek. The grid nodes were imported into a spreadsheet and the CFA calculated for corresponding top and bottom nodes for different pit floor elevations. The results were then imported back into Vulcan for visualisation. By progressively loading in CFA grid layers corresponding to different floor elevations, the engineer can rapidly assess large areas visually, with the CFA grids highlighting areas that fail CFA as the pit floor progresses downwards (Figure 2).

The grid-based approach provides an extremely useful tool for rapid, broad void hazard assessment. It has also substantially improved the robustness of the assessment in terms of detection. It is noted

however that the CFA assumes solid ground in the crown above the top of the development. In some cases, this does not represent the actual ground conditions, particularly where overlying developments have already been collapsed by blasting. The grid-based CFA assessment is therefore useful for assessments such as in the initial desktop study stages of void management plan development. However, it does not replace the need for detailed review of the ground conditions and void hazard prior to operations commencing in an area of risk.

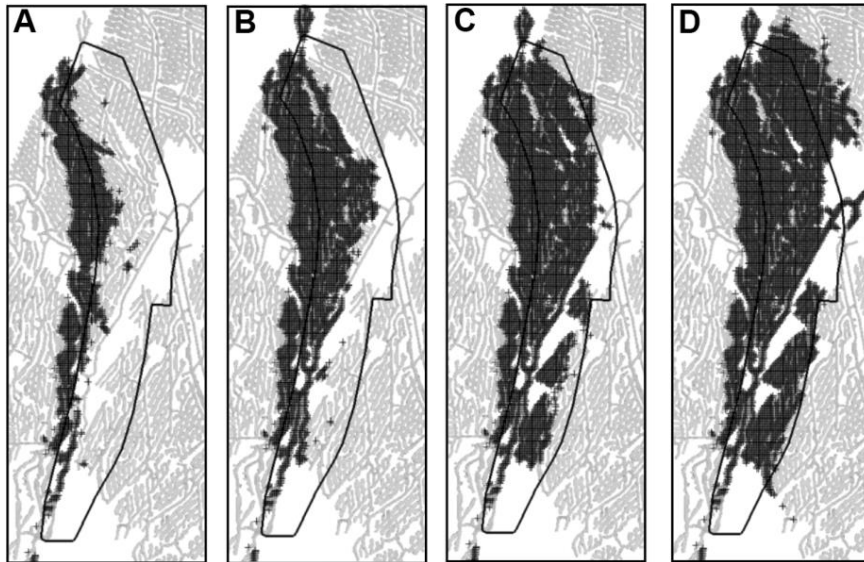


Figure 2: Example of grid-based CFA assessment for 2 Orebody Development (light grey). Dark Grey developments are areas that fail CFA for pit floor elevations A) 9840RL, B) 9816RL, C) 9800RL, D) 9784RL. The current pit floor extent is shown as a black polygon for reference.

### 3.2 Q Value Assessment for Scaled Span Analysis

An assessment of ground conditions was undertaken to develop site specific Q values for use in SSA. Previous analyses had assumed a Q value of 4.5, which was potentially conservative in typical rock mass conditions and unconservative where unfavourably oriented faults were present in the crown pillar.

Three rock mass/ structural domains were defined for the Q value assessment: (1) typical, (2) folded and (3) faulted. The 'typical' domain is the most common at MRM, characterised by uniform, moderately dipping bedding with two orthogonal joint sets. The 'folded' domain is where large to small-scale folds are present in the crown pillar. The 'folded' rock mass is likely to have a slightly reduced quality when compared to the 'typical' domain. The 'faulted' domain is applicable where a major or minor fault is modelled in the crown pillar and its orientation would promote chimneying and a higher degree of caving. The 'faulted' domain has significantly lower quality rock mass compared with the other two domains.

The equation (2) inputs to calculate a Q value for each domain are listed in Table 1. Most parameters were assessed based on mapping and available borehole data. The adopted  $J_w$  value considers that the underground workings have a significant dewatering impact on the pit. Consequently, the crown pillars for voids near the pit floor are likely to be largely dry, with only minor inflow during rain events. SFR was assessed by running a finite element (FE) analysis in the "RS2" software by Rocscience. The analysis section represents a typical distribution of development drives at MRM and parameters follow those used in previous site analysis. The results show that a SRF value of 0.5 – 2 is appropriate for the Q value assessment for typical and folded cases. A slightly higher SRF value of 5 was adopted for the faulted domains.

Table 1: Q Value Assessment Input

Domain	RQD	$J_n$	$J_r$	$J_a$	$J_w$	SRF
Typical	70 - 93	9 - 12	2 - 3	1	0.66 - 1	1
Folded	83 - 90	9 - 12	1 - 3	1	0.66 - 1	1
Faulted	65 - 83	9 - 12	1 - 1.5	15	0.66 - 1	5

Due to variability of conditions within the three domains, a range of input parameters were assessed. This resulted in a range of Q values for each domain as shown in Figure 3. The average Q value for each domain has been adopted for SSA.

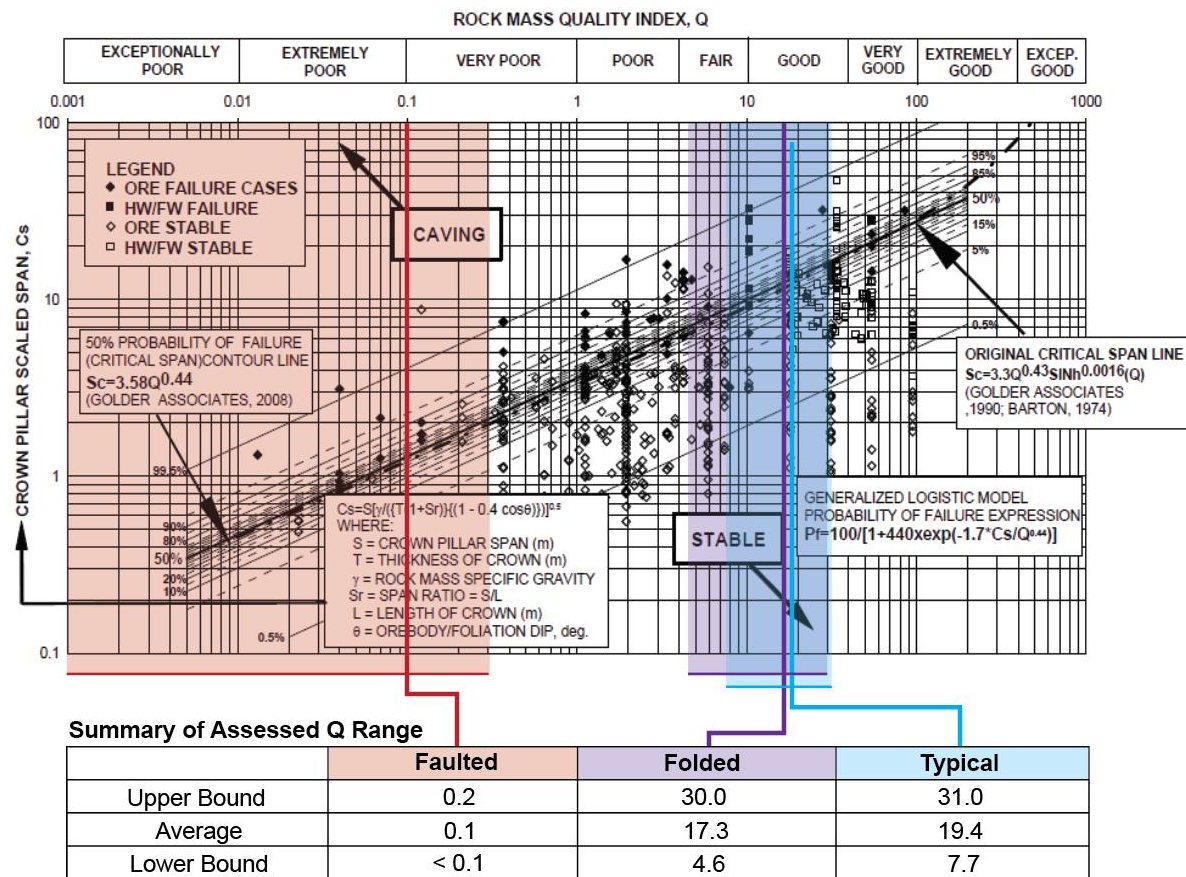


Figure 3: Summary of assessed Q values for MRM (modified from Carter, 2014).

### 3.3 Operational Stope Management

The upcoming open pit cutbacks are expected to intersect a number of large open stopes (Figure 1). SSA show that the stope crowns could be unstable as mining approaches and possibly experience caving conditions. CFA analysis for the surveyed stopes shows that current site drill rigs will be unable to intersect the stope crowns to fill and reduce the void height without operating below the CFA failure level. Consequently, a total exclusion zone would be triggered when the pit floor transitions below the CFA failure level of the open stope. The largest stopes are about 40 m wide by 100 m long. An exclusion zone of this size becomes unmanageable from an operational perspective, unable to be effectively blasted and excavated, and would potentially leave a large intact pillar as the rest of the pit floor progresses down. In addition to this, the stopes are sometimes located under major haul ramps, which would require major pit redesigns to maintain pit floor access.

An investigation was undertaken to assess different approaches and controls to manage the bulk stopes safely to reduce the impact to the operations and the mine schedule. Three main components were considered: (1) exclusion zones, (2) proving that the crown pillar is intact and (3) monitoring. In the absence of drilling capability to confirm the caving extent of the stopes and assuming that caving occurs progressively overtime as the open pit operations progress closer to the stope, a probe and monitor approach was proposed, as shown in Figure 4.

Several crown pillar monitoring options of varying complexity were assessed. Sub-surface monitoring options included resistance wire or rod extensometers, wireless crown monitoring systems typically used in block cave mining and geophones. Surface monitoring options would utilise the existing site slope stability radar and prism systems. Cost, timing, interaction and complexity were considered for

each option. Preference was given to less complex options leading to a simple manual extensometer being chosen.

The proposed updated process for operational stope management is as follows: Stage A) vertical probe holes drilled from above the CFA failure level to the maximum depth that site drill rigs can achieve (70 m). Once 70 m of intact crown pillar is confirmed, the floor is blasted to the next bench elevation, with an exclusion zone being triggered post blast as per the void management procedure guidelines. Stage B) Inclined probe hole(s) are drilled from outside of the exclusion zone to prove that the stope has not caved within ~60 m of the surface. Once this is confirmed, a vertical hole is drilled to 70 m depth and an extensometer installed. The extensometer extends above the hole collar with an easy to see, large displacement scale that corresponds to a Trigger Action Response Plan (TARP). Should the extensometer indicate that the displacement threshold has been reached, then a total exclusion zone is triggered pending further investigation. Stage B is repeated iteratively bench by bench until the stope crown is intersected by probe holes. Stage C) once the crown is intersected a fill plan can be implemented aiming to reduce the total open void height. Stage D) once the fill program has been completed, and filling success confirmed, a revised CFA level can be implemented with consideration to the reduced void height. Lastly, the void hazard exclusion zone can be removed.

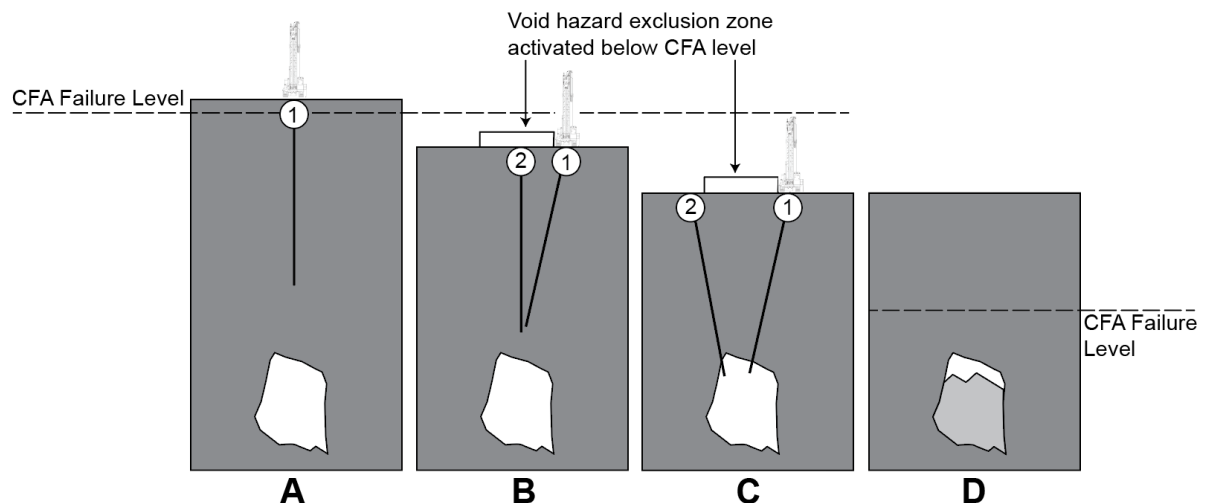


Figure 4: Schematic of updated management strategy for bulk stopes.

#### 4 CONCLUSIONS

This paper has presented several recent improvements to the void hazard management at McArthur River Mine. The development of a grid-based CFA check has drastically reduced the amount of time required and improved robustness for preliminary void hazard assessments on a broad-scale. The development of site-specific Q values has improved the application of the SSA. The improvements to void analysis will ensure that void hazards are safely managed while reducing delays and impacts to mine scheduling. Lastly, a new probe and monitor stope management approach was presented. This process aims to reduce impacts to mine operations while safely managing the void hazard presented by large open stopes.

#### 5 ACKNOWLEDGEMENTS

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