Mine Wide Risk Assessment – What is the State of your Arteries

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Abstract

A geotechnical mine wide risk management approach is presented for the systematic inspection, description, assessment and presentation of geotechnical hazards identified in all access and egress routes at George Fisher Mine. This systematic approach assesses arterial routes and using a risk matrix ranks segments according to ground condition, installed support, potential mode of failure and travel frequency by mine personnel. This risk ranking approach is used to prioritise the required rehabilitation and upgrading to current ground support standards for life of mine excavations to ensure a safe and sustainable production environment.

Introduction

> "*There are risks and costs to a program of action. But they are far less than the long-range risks and costs of comfortable inaction." (John F. Kennedy)*

The condition of main access and egress routes of an underground mine are comparable in importance as the human cardiovascular system is for a healthy, functioning and prolonged life style. If the arteries become blocked or congested in either environment the person or mining operation suffers until it can no longer function properly and efficiently.

As the human body requires a healthy life style in order to reduce or prevent the risk of heart disease, an underground mine requires regular assessment, review and remedial actions to ensure that it's main travelling ways remain fit for purpose for as long as required.

Presented are the experiences and proposed developments of a mine wide geotechnical risk assessment undertaken at George Fisher Zinc-Lead operations through assessing ground conditions and associated ground control risks in the main access and egress routes.

Locality

George Fisher Mine is located 24 km north of Mt Isa in northwest Queensland (Figure 1). The operation extracts ore through sub-level open stoping and benching methods. The ore at George Fisher lies in the central part of the Lower Proterozoic Urquhart Shale. However, the mineralised section is only one-third the thickness of the Mount Isa ore zone, extending from 300m to 1000m depth for 6.5km. It is more folded and more interrupted by faults and dykes. Ore zones are from 3m to 25m thick. 11 ore bodies have been assessed to contain 45Mt, providing a fifteen-year mine life at a production rate of 3Mt/y.

Figure 1: Locality Map.

George Fisher Mine (GFM) consists of distinct mining areas, namely George Fisher North (GFN) and George Fisher South (GFS). The main access and egress routes are the P49 Shaft from surface and a surface decline to GFS with a decline connecting 10 Level GFS and 12 Level GFN. A second connection between GFN and GFS exists via 15C Sub Level truck haulage (Figure 2).

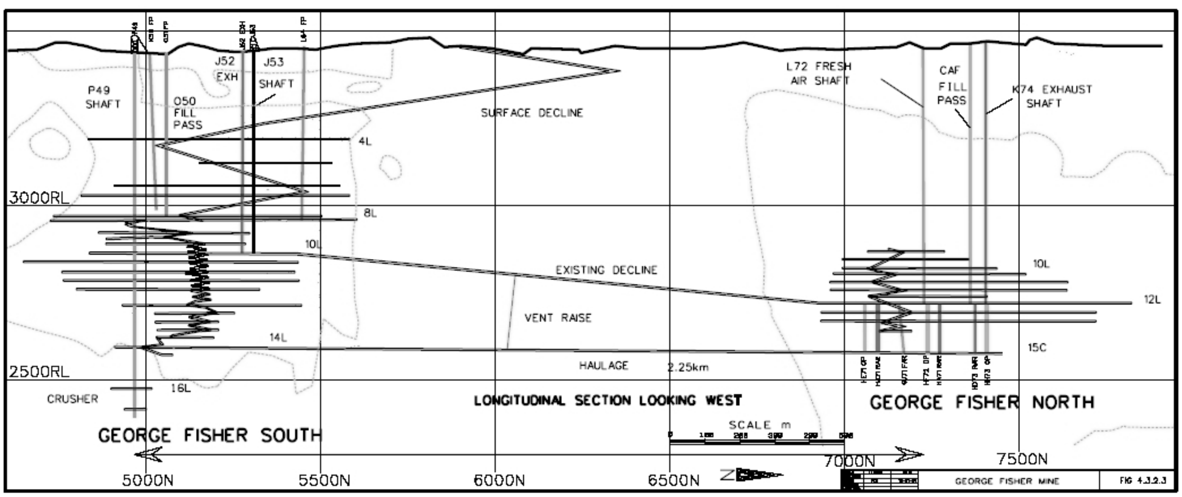

Figure 2: Longitudinal section of George Fisher Mine.

Access to the ore bodies is gained through internal decline/incline systems connecting to levels and sub levels spaced at regular 30m vertical intervals. Combinations of crosscuts and ore drives or footwall drives are used to extract the orebody using benching or transverse stoping methods. The mine wide risk assessment focuses on the shaft, decline/incline and primary development on all levels and sub levels.

Ground Support History

Modern ground support standards have been in existence at GFM since late 2001. A range of analysis tools have been used to validate the ground control standards by Robinson (2003). The purpose of ground support is to ensure a stable excavation, which will prevent injury to personnel and protect equipment from damage by the correct design and installation of ground support, ensuring that production targets are maintained and dilution levels are kept to a minimum.

Prior to the introduction of the ground support standards, the ground support was engineered on a site-by-site basis, this process was time consuming and in recent times mine safety has a higher profile and hence standards are required to manage the potential risk.

The change in ground support strategy where all mine personnel are to work under supported ground at all times has placed older areas of the mine in the sub-standard ground support category. The mine wide risk assessment approach provides management with a tool to prioritise ground support rehabilitation based on exposure to the identified rock related hazards.

Ground Support Strategy

Currently at GFM, ground support falls into two categories namely primary and secondary support. Ground support is defined as surface support and tendon reinforcement applied to the rock surface to ensure ground control is achieved for the required life of the excavation.

Primary ground support consists of surface support, mesh or fibrecrete and tendon reinforcement in the form of friction or resin bolts. This applies to all drive profiles within GFM. Where the factor of safety of the excavation (FoS) is deemed unacceptable, deep reinforcement secondary ground support is required in the form of fully encapsulated cable bolts.

Various drive profiles currently exist in the GFM. The size and profile of the drives vary depending on mining requirements such as trucking, mine services, ventilation and orientation with respect to the ore bodies for example parallel or perpendicular to bedding and relative proximity to the orebody for instance either an ore or footwall drive.

Each drive profile has a specific ground support standard which is designed to meet the minimum ground support requirements. Additional support may be required and is designed to meet site specific requirements. These standards have been determined and are continually revised using a combination of the analysis methods outlined below:

1) Empirical Design

Generally the first step to defining any ground support requirements is to classify the rock mass. Empirical rock mass classifications have been determined at GFM using discontinuity mapping data, historic rock mass property reports, and other observations made underground in the GFN and GFS ore bodies.

Accepted empirical design rules have been applied to determine guides for selection of bolt length and ring spacing requirements. The use of empirical design systems such as RMR, MRMR and Q system have been used widely at GFM.

2) Rock Support Interaction

Ongoing tests and monitoring are conducted to determine the rock mass and support response to various types of ground support in various rock mass conditions.

Rock bolts, cables, friction bolts and resin bolts are all mechanically pull tested to ensure correct installation and compliance with support requirements. Unfortunately this is not always possible in older areas as these types of bolts are not generally equipped for pull testing.

It's also important to consider the significance of providing adequate and satisfactory surface support to the excavation skin as well as tendon reinforcement. Mesh is the most commonly used type of surface support. In most areas underground the loose rock developed in the mesh rarely exceeds the capacity of the mesh. Fibrecrete is another type of surface support used when a stiff support system is required. Fibrecrete testing is performed regularly to determine the strength of the product.

Limiting equilibrium analysis has been incorporated to determine the likelihood of potential wedge failures using discontinuity data. Various failure block geometries are analysed and a FoS for each failure mechanism is determined using the existing ground control standard. This method is useful for determining where secondary support may be required to ensure a stable excavation.

3) Dynamic Loading

Blast induced and seismic related dynamic failures are also considered in defining the ground support standards.

Studies have shown that there is the potential for a rock fall to occur within 4m of the face where the FoS is less than 3 (if the ground control system is loaded to its static capacity).

Few failures of this kind have occurred at GFM as the support system is rarely loaded to its capacity when a dynamic load is applied. Micro-seismicity is not presently known to exist in the mine to the point where it would have an effect on ground support requirements.

4) Rockfall Data – Back Analysis

Rockfalls generally greater than 1 tonne in size are continually analysed. Factors that are analysed include but are not limited to: location, tonnages, drive classification, origin of the fall with respect to development for example did the fall originate from back, hangingwall or footwall, ground support installed, ground support failure and key contributing factors for instance corrosion, rock mass condition, stress change. This assists with flagging potential problematic areas which may require additional support or even a revision of the ground support standard for the specific area. This fall of ground information is considered during the mine wide risk assessment process and prioritisation of the required ground support rehabilitation.

Description of Assessment Process

The initial phase in the geotechnical mine wide risk assessment process is to identify the main access and egress routes to the mine and separate these routes into individually identifiable sections. Each section relates to either a portion of the shaft, decline, access drive or intersection and numbered for reference purposes. During the underground walkthrough the following information is recorded for each section being assessed:

A rehabilitation index is assigned to the section. The index consists of four categories:

- *R0 = No Rehab Required*
- *R1 = Low Priority – No obvious problems with the ground, but ground support is faulty. The drive or intersection can remain open but should be rehabilitated at some stage.*
- *R2 = Medium Priority – Drive can remain open but must be inspected and barred down when necessary, some loose rock but nothing obviously dangerous or life threatening.*
- *R3 = High Priority – Obvious loose blocks/wedges. Drive should be closed immediately.*

The distance of the required rehabilitation if any is included in the assessment and entered in the assessment database.

The installed ground support is accessed for the section and the type of ground support is recorded. Each type of ground support has its own code assigned which is used to calculate the risk rating for that section. For example:

- *G3 = Split sets*
- *G9 = Cable Bolts*
- *G10 = Shotcrete*

The ground conditions in the section are assessed and assigned one of following three ratings:

- *C1 = Generally Good – Back is flat and stable, very few scats and no loose blocks.*
- *C2 = Average – Some scats held in mesh, low corrosion apparent and minimal risk.*
- *C3 = Mostly Bad – Barricade and rehabilitate.*

The contributing factors or event causes, which would most likely result in ground control issues, are determined. The assessment sheet provides nine different event causes as identified at GFM and each have there own code which is then entered in to the assessment database. For example:

- *E9 = No Support*
- *E6 = Active Water Flow*
- *E5 = Insufficient Support*
- *E1 = No apparent Problem*

The combination of exposure to the potential ground control hazard or travel frequency and the rehabilitation index for an area has a significant impact on the final risk rating and prioritisation of rehabilitation resources at the mine.

The five travel frequencies that can be assigned to each section are:

- *T1 = Continuous Use* - >50% of the shift (> 6 Man Hours)
- *T2 = Major Travel Way* – 20% - 50% of the shift (2.5 -6 Man Hours)
- *T3 = Intermediate* - 5% - 20% of the shift (30mins – 2.5 Man Hours)
- *T4 = Rarely Used* – 0.1% - 5% of the shift (1min – 30mins)
- *T5 = Barricaded* - <0.1% of the shift (<1min)

The consequence of an event occurring in the area is determined using the five levels of consequence described in Table 1.

Table 1: A Summary of Consequence Category Descriptions.

CONSEQUENCES

Level	Descriptor	Example Detail Description		
		People	Business Impact	Environment
5	Catastrophe	Fatality/Fatalities	=>$10M	Catastrophe – long term, significant legal implications and potential to effect community
4	Major	Permanent Disability	=>$1M-<10M	Major Impact – harm or breach of license conditions or obligations, discharges off site
3	Moderate	Disability/Lost Time Incident (LTI)	=>$100k-<1M	Moderate Impact – external to local area, generally contained on site
2	Minor	Medical	=>$10-<100k	Minor Impact – minimal impact outside the local area
1	Insignificant	Minor	<$10k	Minor Non-Conformance – no impact, minor breach in procedure

Once all the data has been collected underground for each section it is inputted into a database which allows for likelihood, consequence and risk rating to be assigned to each section. This risk rating is what is used to prioritise areas for remedial action and ground support rehabilitation.

Risk Ratings

The underground data is summarised in a database using codes assigned to each relevant area. The risk rating is calculated based on the consequence and likelihood of an event occurring using a matrix based approach.

Table 2 uses the exposure time of mine personnel or equipment against the likelihood of a rockfall occurring which is based on the event cause and ground condition observed underground to determine the likelihood of an event occurring.

Table 2: Likelihood of Rockfall Risk Matrix.

			Almost Certain	Likely	Occassional	Unlikely	Rare
			A	B	C	D	E
Exposure	continuous use	1	1	2	3	4	5
	major travelway	2	2	3	4	5	5
	intermediate	3	3	4	5	5	5
	rarely used	4	4	5	5	5	5
	barricaded	5	5	5	5	5	5

Table 3 describes the categories used by the assessor to assign levels of likelihood of a rockfall event occurring in the section being assessed.

Table 3: A Summary of Likelihood Category Descriptions.

LIKELIHOOD

Level	Descriptor	Description	Quantification
A	Almost Certain	The event is expected to occur in most circumstances	Employees are exposed to the event occurring to its final outcome daily
B	Likely	The event will probably occur in most circumstances	Employees are exposed to the event occurring to its final outcome greater than once per week but no more than 4 times a month
C	Occasional	The event should occur at some time	Employees are exposed to the event occurring to its final outcome greater than once per month but no more than 12 times per year
D	Unlikely	The event could occur at some time	Employees are exposed to the event occurring to its final outcome greater than once per year but no more than 5 times in 5 years
E	Rare	The event may only occur in exceptional circumstances	Employees are exposed to the event occurring to its final outcome greater than once in 5 years

The factors that determine the consequence to be used against the likelihood of a rockfall event occurring have been determined as described during the last stage of the underground assessment process.

The second matrix uses the likelihood determined in the first matrix and rates that against the consequences determined during the underground inspection.

A rating of 1 – 5 is assigned using Table 4 to determine the final risk rating for the section.

Table 4: Risk Matrix.

			insignificant	minor	moderate	major	catastrophic
			1	2	3	4	5
Likelihood	almost certain	A	2	2	3	4	4
	likely	B	1	2	2	3	4
	moderate	C	1	1	2	3	3
	unlikely	D	1	1	2	2	3
	rare	E	1	1	1	2	2

The risk ratings are categorised into four risk levels ranging from low to extreme. This risk rating is used to highlight sections which need immediate attention with risk ratings 3-4 described as follows:

- *1 = Low*
- *2 = Moderate*
- *3 = High*
- *4 = Extreme*

Prioritising Rehabilitation Areas

Once a risk rating for each section is assigned, prioritising of the required rehabilitation or management strategy to manage the risk can be formulated. Sections that have a risk rating of 3 or 4 require immediate attention while the remaining sections with a rating of 1 or 2 require long term management plans to be implemented to ensure a sustainable safe working environment.

When it comes to prioritising high to extreme risk rated areas, exposure to personnel is used as the deciding factor.

Outputs

From the mine wide risk assessment process a report is compiled summarising the process and rehabilitation priorities to be addressed in the required time frames. The appropriate resources can be allocated to the rehabilitation program as required to ensure safe sustainable mining operations.

Future Work

Recent developments have led to the possibility of the mine wide risk assessment information being incorporated into the 3D mine planning software packaged currently being used at GFM. This will make available the latest geotechnical information regarding ground conditions, ground support installed and risk ratings to the mine planning engineers via the design database. Any mine designs involving high risk areas will be flagged for further investigation.

Conclusions

Risk management plays a major role in the day to day mining operations at GFM and recalls to mind a quote with which I strongly agree. This has been called the First Principle of Risk Assessment, "Before you can MANAGE something, you must first be able to MEASURE it." As a risk assessor, you have to be able to measure the risks and provide that information to mine management. If you cannot measure something, how will you even know if you are actually managing anything?

In summary, evidence suggests that declines in death rates for coronary heart disease and stroke have been influenced by changes in some risk factors and in clinical intervention such as lifestyle advice and counselling, drug use, emergency care, medical and surgical treatment, rehabilitation and follow-up care. This leads back to the question, so what is the state of your arteries?

References

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