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Geotechnical risk in mining methods and practice: critical issues and pitfalls of risk management

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Abstract

This paper reviews the progressive growth of awareness, adoption and practices with respect to geotechnical risk in mining in Australia over the last four decades, with a particular focus on underground mining. Initial experience in the 1980s was drawn from other high-risk industries such as nuclear and petrochemical sectors, and whilst the mining industry recognised the issue of a changing hazard and risk environment, it did not change practices significantly. Subsequent growth in understanding of the evolving discipline of risk management, coupled with major changes in mining legislation to a more enabling legislative framework, have led to a far more risk-aware industry where risk assessment and risk management practices have become a fundamental component of the overall mining management systems.

In underground mining, geotechnical risk is at, or close to, the top of the risk priority list for proactive mine management today. The recognition of what are referred to as 'core risks' associated with particular mining methods was a further development in the maturity of the industry management systems, with implications for all levels of management, right from feasibility through to design, planning and operations.

One of the problems with the growth of risk-based management practices in Australia is that because we do so many risk assessments and develop so many hazard plans, we have, in some cases, become too blasé about them and do not give due recognition and priority to the ongoing management of important risks – with the potential for serious consequences through lack of attention to detail and lack of integration of risk management into the mine management system. In an effort to overcome this issue and place higher priority on the most critical risks facing a mining operation, the International Council of Mining and Metals (ICMM) Critical Control Management (CCM) system, for focusing on the most critical risks, and then directing more attention to the actual control practices required to manage them, has been a valuable trend in recent years.

In the Australian coal sector over the last 10 years, the industry-funded RISKGATE system has also been an extremely useful documentation of industry experience and a tool to assist operators either investigate incidents or plan risk assessments on new topics or areas. Geotechnical topics make up at least three of the 18 major topic areas covered by RISKGATE. This paper will briefly outline how RISKGATE operates and is applicable to the industry in the geotechnical space.

Keywords: *geotechnical risk, legislative frameworks, mining methods, hazards, risk assessment, risk management*

1 Introduction

Mining operations operate in a different risk environment to most other industries, not because the risks are unavoidable or unmanageable, as was once widely assumed, but because of the ever-changing environment in which the mine operates.

What is different? Compare mining to a manufacturing process where the manufacturing factory is fixed in space and a consistent feedstock is fed to it and processed. By contrast, in mining, the feedstock (the orebody) is fixed in space and the process (the mining operation) is continually moving through it, encountering a constantly changing environment, or feedstock. The mine is in a different location, working with different conditions every day. As a result of this ever-changing, dynamic 'feedstock' of mining conditions, the risk profile encountered will be constantly changing. It is also important to recognise that the mine environment and the implications posed by it not only changes in space but also in time, relative to available technologies, market pressures, etc. What is considered as a solution or risk control measure at project feasibility stage will inevitably be different to that encountered later in the project life. As such, it is important to consider this changing profile continuously from 'Day 1' through to mine closure.

Geotechnical risk sits high on the priority of risk categories faced by any mining operation, especially underground operations. Historically, the use of rock mechanics or more broadly, geotechnical engineering, in mining was as a technical 'fix' when problems arose. It was there for trouble-shooting, rather than a routine part of the mining operation. The next stage of acceptance of geotechnical engineering in mining came in about the 1970s and 1980s when it became a key component of most mine design, mining method selection and mine planning processes. It then further came of age from the 1980s and later, as the concept of mine management matured and it was recognised that all of these technical issues, such as the geotechnical factors, required management and so geotechnical engineering, or ground control management, became part of the multifaceted overall mine management system.

This paper reviews the development of geotechnical risk in the mining industry, focussing on both mining method selection and ongoing mining operations. It considers the evolution of risk management practices in the mining industry in Australia over the last several decades and focusses particularly on the importance of geotechnical risk management. This is largely a subjective overview of what has been a significant and changing landscape within the industry, with enormous benefits derived but also some major pitfalls.

2 The early days of risk management

The practice of risk management came into the Australian mining industry in about the 1980s, having been adopted from practices used elsewhere in high-risk industries such as the petrochemical and nuclear sectors, as well as aviation. In the coal sector, early prototype projects were funded by the industry to trial simple risk assessment and management models, under the leadership of people such as Dr Jim Joy who brought Canadian experience from these other industry sectors to Australia. The trials were well received and seen as offering a means of recognising the relative importance or significance of different types of mining hazards, including geotechnical hazards. As a result of this success, a joint venture company was formed between Dr Joy's Alara Group and ACIRL Ltd, being MineRisk Pty Ltd (MineRisk). MineRisk began to implement many of the early risk assessment models, including the very popular and applicable Workplace Risk Assessment and Control (WRAC) system.

However, even with a greater awareness of hazard identification and risk assessment techniques, the industry practices did not change significantly – restricted by very conventional legislative practices which had not adapted yet to these powerful and potentially more flexible and applicable risk management tools.

A simple example of such reluctance to change was in the area of ground support in underground coal mining. Legislation required that a mine have a set of 'minimum support rules' developed by the mine, signed off by the mine manager and approved by the local inspector. These were very often a single set of support rules for the whole mine, regardless of variable conditions or changing geotechnical domains. They always contained the caveat that stated words to the effect that *"nothing in these rules shall prevent persons (operators) from installing more support than prescribed by the rules".* However, no guidance was provided as to when or where such extra support might be considered or required, nor was there any significant provision of training or skills to the point where operators themselves could be expected to make informed design decisions as to what extent of extra support might be required. Placing such a responsibility on operators or even frontline supervisors who did not have the ability to make informed decisions was highly inappropriate and created a recipe for accidents and inappropriate blame.

2.1 Legislative environment

An important external consideration that provides the background to effective and comprehensive risk management is the prevailing legislative environment in any mining country, both for occupational health and safety (OHS) generally and mining legislation in particular. Whilst the mining-specific legislation will cover a number of specific mining industry technical requirements, the OHS framework is generally more about provisions for ensuring a safe place of work, safe systems of work, and various forms of management and operators' duty of care obligations.

In the Australian mining legislative environment, we have progressed from a very conventional prescriptive style of legislation (see explanation in following paragraph) in place up to the 1980s period, to one where risk management in the mining industry is now well advanced and widely accepted by all stakeholders. These improved legislative regimes have developed over the last two to three decades into what can be described as a largely enabling legislative framework, whereby the mine management has a controlling responsibility in terms of developing such things as mine plans and systems of work, provided they are also capable of demonstrating to authorities that there has been a rigorous hazard identification process and an implementation of appropriate risk management strategies and controls that deal with all the hazards involved. This does not mean that mine operators have a 'carte blanche' to do what they like. Quite the opposite, they have a very clear responsibility to develop and demonstrate a well-constructed set of mine plans and designs and associated procedures that recognise and take account of all the possible risks that might manifest themselves in the mining operation. Such a system allows for innovation and progressive ongoing development of practices, but under a very tightly controlled set of processes.

The alternative to such a legislative environment is the prescriptive approach where the regulator develops a set of rules and standards, and requires all mines to comply with such rules, at the risk of citations, fines and other forms of penalty and embargo on forward development, if non-compliance is detected. This form of legislation tends to stifle development and innovation and can lead to operations not taking full responsibility for their own safety management, but rather simply complying with the regulations – whether they are appropriate to the specific site conditions or not. A former senior Australian mine executive Mr Ken Foots, was quoted as saying: *"An emphasis on prescriptive regulation leads to mediocrity, … prescriptive operation and safety regulations lead to underperformance, with everyone, from the CEO down, abdicating their responsibilities"* (Kirsch et al. 2014a).

In reality, the Australian mining industry currently operates under a system that falls somewhere between these two extremes but is far closer to the purely enabling regime than to the prescriptive regime. Risk management and related risk assessment practices are a critical component of such management systems.

3 Risk management principles and practices

The first of the building blocks that make up sound risk management is the recognition that every workplace involves hazards, or potential hazards. A hazard is often described as any unwanted event or situation that can cause harm; or any loss of control of energy in a workplace. Hazards are ever-present and the starting point of good risk management is hazard identification, leading to the development of a hazard plan. In the context of geotechnical factors, the development of a comprehensive geotechnical hazard plan is absolutely fundamental to being able to maintain control of the ever-changing geotechnical environment. Changing geotechnical factors may include:

- Pre-mining stress magnitudes and/or directions.
- Changing lithology in either the orebody/deposit or host rock.
- Changing rock properties, even within the same rock type.
- Changing concentration or nature of defects impacting on the in situ rock mass properties.
- Presence and nature of major geological structural defects.
- Presence of aquifers, water and/or gas pressure etc.

The geotechnical hazard plan must capture all of these changes in a meaningful manner that can be interpreted and used effectively by mine planners and designers, who need to be able to use these hazard plans, for example, to develop appropriate mine and ground support layouts for a range of identified geotechnical domains across the mine lease. The hazard plans will also find later application and so, must be meaningful for use by frontline supervisors and operators in day to day management.

The second stage of the process is then risk assessment, where risk can be defined as a measure of the magnitude and significance of the consequence posed by the hazard, if it is to occur, and is often defined by the combination or a function of parameters of probability (or likelihood) of occurrence, and consequence or severity. The risk assessment process is a structured means of linking hazards to risks and consequences, and usually involves relative ranking of these risks. Risk assessment practices can be applied under any form of mine management or operational system, and there are many different forms of risk assessment tools available (from qualitative to semi-quantitative) such as WRAC analysis, fault tree analysis, bow-tie analysis and others.

The important point to recognise is that every workplace will always involve hazards that can pose risks to workers or to mining systems and these must be recognised and managed in some way. There is no such thing as a risk-free environment in a mining scenario or in any other aspect of daily life. Failure to recognise hazards and the risks they pose in the workplace is a recipe for accidents to happen or for management systems to fail.

The third key component that is part of or follows on from the conduct of a risk assessment, is the implementation of controls to either eliminate or mitigate the risk, if it is present at an unacceptable level (above what would be deemed an acceptable residual level of risk); or controls to mitigate the consequence posed by the hazard. The widely accepted hierarchy of risk control is:

- Eliminate.
- Mitigate.
- Tolerate.

If an unacceptably high level of risk posed can be eliminated by changes to the design, to procedures, or through additional controls, then this is the first-choice control approach. If elimination is not possible, then the second option is risk mitigation to reduce the risk to a lower, more acceptable level. Finally, if the risk level is deemed sufficiently low to be acceptable under prevailing, existing controls, then that is deemed to be sufficient and no further control measures are needed. The concept of ALARP (as low as reasonably practicable) is often used to describe tolerable or acceptable residual risk levels.

A further tool in the risk management approach in mining, and particularly in relation to the extremely variable and multiple-component set of geotechnical hazards present, is the role of what are referred to as trigger action response plans (TARPs). These are used for implementation of the controls for different hazards by reliably identifying a change in hazard level. Essential components in such an application of risk management to ground control are:

- Determination of the key variables involved and from them, definition of a discrete number of risk levels or geotechnical hazard levels likely to be encountered.
- Identification of practical and reliable 'triggers' to indicate an impending change in the risk or hazard level (both upward and downward change) (TARPs).
- Development of control strategies or 'responses' (support rules) for each of the chosen risk levels.
- Comprehensive documentation of the agreed management system and well-defined communication procedures.
- Training of all appropriate employees in the system.

3.1 Current best practice

A bow-tie analysis risk assessment approach is a powerful means of identifying a full range of causes and their preventive controls, as well as consequences and their mitigating controls. The bow-tie approach has been adopted in a comprehensive coal industry-funded project in Australia, known as RISKGATE (Kirsch et al. 2014b) which has assembled a suite of risk assessments based on industry best practice, and built these into an online interactive knowledge database, covering at least 18 main safety-related topic areas. Three of these 18 are of a geotechnical nature; strata control (for underground mines), ground control (for surface mines), and coal bursts. The RISKGATE website (www.riskgate.org) provides an overview of the project and also of the bow-tie method of analysis.

Extending RISKGATE beyond Australia, the Australian RISKGATE team, together with Virginia Tech, also received Alpha Foundation funding to build a prototype US version of RISKGATE (Jong et al. 2015; Restrepo et al. 2015).

The main difference and power of a bow-tie analysis, when compared to a simple matrix-based risk assessment, is the greater emphasis on controls, and the differentiation between preventive controls that respond to potential causes and can stop the unwanted or initiating event from occurring, and mitigating controls which focus on reducing the level of consequence, if the event were to occur.

Risk assessment methodologies and management practices are now widely used in a number of mining industries around the world, adopted primarily for safety-related issues, but also applied to mining system and equipment design, compatibility issues and similar applications. In countries that have actively pursued risk management as ‘a way of doing business’, such as in Australia or South Africa, the use of risk assessments and development of risk-based controls and procedures have led to risk-based management plans that cover all major hazard areas, such as ground control, spontaneous combustion, fire, inrush, etc.

4 Core risks of mining methods

A further development that has now become accepted, at least in Australia following the 1999 Northparkes air blast accident, is the concept of identifying (and hence managing) what are referred to as ‘core risks’ for any mining system, at the feasibility stage of a project (Hebblewhite 2003a, 2003b). The following definition was adopted for core risks:

> *“The term “core risk” is used to describe any risk associated with a major hazard or potential hazard, that is an inherent feature of a generic mining method. Almost by definition, core risks cannot be totally eliminated, and must therefore be controlled and managed during the life of the mining method or system of work.”*

It is critical that once these core risks are identified, specific risk management plans are developed for each core risk, and they must be continually implemented throughout the life of the mine, as part of the overall mine management system.

Putting this into the geotechnical context, selection and ongoing management of particular mining methods will inevitably include important geotechnical core risk considerations. Examples include:

- Assessment of the rock mass quality for both the orebody and the host rock, in order to select a mining system, in the context of underground mining, anything from open stoping or room and pillar at one extreme to block caving at the other extreme.
- Understanding the impact of geological defects (large and small scale) on the integrity of material that may form pillars or excavation boundaries such as roof or hanging walls.
- Selection of appropriate design methodologies for key elements of a mining system such as pillar dimensions, design and location of barrier, sill or crown pillars, prediction, and control of mine subsidence; etc.

Failure to recognise and then maintain appropriate control management systems for these core risks can lead to serious safety and/or economic consequences. In the case of a block caving operation, the core risks would include caving hang-up with dual consequences of either a stalled cave, or followed by potential for uncontrolled mass caving leading to possible air blast and regional instability; water or mud inrush; loss of caving control with dilution, and caving outside the orebody boundary.

It is therefore critical that once the core risks have been identified for the chosen mining method, they must be managed throughout the mine life, with assignment of responsibility to a particular position within the management team and regular reporting of control procedures and effectiveness. In many mining operations, over the life of a mine, the mining method may change or at least be varied significantly due to either economic, technological or simply mining condition factors. At such times, it is imperative that the management team formally re-assess the core risks involved and identify any new risks associated with the change in mining method.

5 Critical issues and pitfalls of a risk management approach

All of the preceding discussion has focussed on the strengths and benefits that a well-designed and implemented risk management approach can provide to a mining operator under an appropriate legislative regime. The Australian mining industry has seen such benefits and continues to embrace this approach as it maintains one of the best mine safety records in the world – in no small part attributable to a risk-based management approach.

However, it is important to identify some of the issues and pitfalls which can lead to problems of such a system. These are not just hypothetical or theoretical 'risk 101' examples or issues but are based on real experience within the Australian mining industry over recent years where risk assessments and related risk management systems have become a way of life.

5.1 Complacency

The Australian mining industry has embraced risk management to such an extent that risk assessments are being conducted at some larger mine sites almost every day or week. Whilst in theory this is a good thing, it brings with it the danger of people becoming complacent because of over-familiarity with the approach. Risk assessments in some cases are done almost by rote, without due consideration of all possible scenarios, and without giving due weighting to the more critical issues amongst a sea of lesser issues. With this problem of complacency also comes the problem of people following the due process, but then putting the completed risk assessment on the shelf and not giving it any further consideration or follow-up.

Risk assessment alone will not eliminate risks or deliver a safe mining environment. It is the correct use of the system and the complete follow-through that is vital. A case in point was the Northparkes Mine that experienced the tragic multiple fatality air blast accident in 1999 (Hebblewhite 2003b). Northparkes had a very forward-thinking management team at the time and were fully engaged with risk management approaches. Prior to the event occurring, over a period of less than three years, they had conducted no fewer than three comprehensive risk assessments, all of which had considered the risk of an air blast occurring. They had all identified the potential for this to have fatal consequences. However, for a range of reasons, the assessment processes were flawed, either in their conduct or in their follow-up implementation.

Conducting risk assessments will not save lives. It is all about the appropriateness of the risk assessment and the follow-through of actions and responsibilities.

5.2 Inappropriate team selection

It is a well-known principle of risk assessments that they cannot be conducted by an individual person, in isolation, but that they must be carried out by a well-chosen team that is representative of the topic area covered by the risk assessment scope, and this involves the broadest range of knowledge and experience in that scope area, ranging from on the ground operator experience, through technical and management experience and where necessary, the highest level of specialist expertise.

Failure to select the right team can lead to ill-conceived risk assessments and inappropriate control strategies. It is essential that a broad range of skills and experience is in the room throughout the risk assessment process and that everyone's voice is heard with equal weighting, regardless of their position within the organisation.

5.3 Poor documentation and implementation

A good test of any documented risk assessment is 'if someone who was not part of the risk assessment team were to read the documentation at least two years after it was prepared:

1. Would they understand what was meant by all of the text and the controls recorded?
2. Would the method of risk assessment be transparent so that they could follow the logic of why risks were ranked in a certain way?
3. Could they follow up the controls identified and find them embedded in the current mine management system or records with appropriate responsibilities assigned and actions closed off?'

Poor risk assessment documentation, often incomplete or quite cryptic, is unfortunately commonplace across our industry. There are also serious shortcomings evident at times in assignment of responsibility for control actions and lack of clear evidence as to when those actions are required and by whom. Such deficiencies may not negate all of the benefits of the risk assessment process but they can potentially lead to serious flaws in the process.

The actual nature of many identified controls is often weak or inadequate due to lack of consideration of all possible scenarios that could occur. The controls may be suitable for the more obvious outcomes but may be grossly ineffective for others.

6 The future

In consideration of the mining industry internationally, a short answer to any question on 'what of the future?', in regard to this topic may be 'more of the same'. However, there is a need to continually improve the rigour, the objectivity and the comprehensiveness of our risk-based management systems in order to continue to improve safety and to operate mines in a most productive and efficient manner under increasingly extreme or difficult conditions. It is therefore worth contemplating where the industry and the safety and risk management practices are heading.

What might the international mining industry future look like in 20-years' time, with respect to risk management and mine safety? It is difficult to answer, especially as it depends very much on external factors such as legislative environments, as discussed earlier. However, it is reasonable to hope that we might see a mining industry where mining companies around the world are operating under enabling forms of legislation, with risk-based management plans that address all major hazard and risk areas of their operations, especially in the geotechnical risk field. The key to the success of such a management strategy is that these management plans are fully integrated into the overall mine management systems, and that the various areas of responsibility and accountability are clearly linked to individual position descriptions of all key personnel throughout the mine management structure.

We do not have such a transparent and fully integrated system today, even in the best of our mines, but it is certainly achievable. The ultimate test, and expectation for the industry, is to focus on the safety outcomes and that means delivering a safe workplace for all, and a healthy and safe workforce for all personnel on or about the mine site.

How to achieve this future? At present, the international mining industry has the full range of legislative environments – from a totally prescriptive approach in some mining countries, to a largely enabling approach in others. This diverse legislative background will take many years to change, but it is hoped that gradual change will occur across most mining countries. Even without such change, there is scope and value for mining industries to adopt and benefit from risk-based approaches to safety, even under largely prescriptive legislative regimes.

It is also anticipated that a broader acceptance of the concept of core risks associated with mining methods will occur, with corresponding responses in terms of mining method decision-making and subsequent management systems.

The other major change that is already underway and is likely to have a major impact over the next 10 years or more, is the development and adoption of the concept of critical control management (CCM), as first identified by the London-based International Council of Mining and Metals (ICMM) in a guide published on health and safety critical control management (ICMM 2015).

In Australia, this concept has been supported by a recent research project by the Australian Coal Association Research Program led by The University of Queensland and Jim Joy Associates, titled ‘Effective and Efficient Implementation of Critical Control Management in the Australian Coal Industry by 2020’ (Hassall & Joy 2016). The project overview states:

> *“The ICMM guide provides a process for identifying, optimising and effectively managing the 'critical few' controls for the highest consequence potential unwanted events in mining and minerals processing, such as an underground explosion. Critical Control Management (CCM) is a progression in current risk management practices, not a revolutionary change. Current risk assessment methods are still useful but CCM adds aspects that help focus and more effectively manage. For the last decade the Australian coal mining industry has been recognising that acceptable risk is related to the adequacy and effectiveness of controls. CCM builds on that realisation. The objective of CCM is to focus the business and site on effective management of carefully selected Critical Controls for the highest priority unwanted events.”*

Progressive adoption of CCM across the international mining industries is considered to be a valuable, incremental and achievable improvement in risk management approaches for mine safety.

6.1 The future for geotechnical risk

There is no doubt that hazards presented in the geotechnical field are amongst the most numerous, diverse, and least well-defined of all fields affecting a mining operation. More often than not, they are also the types of hazards that can lead to risks with the highest or worst possible consequences, including multiple fatalities. For these reasons, all of the above discussion and commentary, whilst quite generic in nature, applies particularly to geotechnical risk. This means that we have to apply greater levels of diligence to our geotechnical risk assessment and management systems, commencing right from hazard identification. One of the areas where there is greatest scope for improvement is in better rock mass characterisation and subsequent geotechnical domain definition, as part of the initial geotechnical hazard mapping.

7 Conclusion

This paper has mapped the history of risk management in the Australian mining industry over recent decades. Whilst providing a broad, generic look at risk in mining, the findings are highly appropriate with respect to geotechnical risk, both because of the extensive and diverse nature of geotechnical hazards we have to deal with, and also the severity of the consequences posed by the risks associated with such hazards.

The Australian mining industry has embraced risk assessment and risk management principles to a large extent, and this has been achieved through related changes in the legislative environment within which we operate.

However, evidence suggests that we have maybe become so entrenched in conducting risk assessments that we have lost sight of the purpose or the importance of some of the assessments we conduct, resulting in a degree of complacency and inadequate follow-through of risk controls and actions.

There is a need for greater diligence moving to the future and use of more rigorous assessment techniques to provide even more effective and appropriate management controls, leading hopefully to continuing improvements in mine safety and mine operational performance.

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