The fundamentals of modern ground control management in Australian underground coal mines

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THE FUNDAMENTALS OF MODERN GROUND CONTROL MANAGEMENT IN AUSTRALIAN UNDERGROUND COAL MINES

Jason Emery¹, Iset Canbulat¹ and Chengguo Zhang¹

ABSTRACT: Underground coal mining is inherently hazardous, with uncontrolled ground failure regarded as one of only several critical risks for multiple fatality events. Development, implementation and management of overarching systems and procedures for maintaining strata control is an important step in mitigating the impact of ground failure hazards at a mine site operational level. This paper summarises the typical Proactive Ground Control Management System (PGCMS) implemented in various Australian underground coal mines. Australia produces approximately 100 million tonnes a year of metallurgical and thermal coal from approximately 30 of the world’s safest longwall mines operating in New South Wales and Queensland. The increased longwall productivity required to achieve both high levels of safety and profitability, places significant emphasis on the reliability of proactive ground control management for longwall mining operations. Increased depths, adverse geological conditions, elevated variable stress regimes and weaker ground conditions, coupled with an industry wide need for increased development rates continue to make ground control management challenging. Ground control management is not only about ground support and pillar design though but is also a structured process that requires a coordinated effort from all levels of the workforce to both minimise the occurrence of adverse geotechnical events and mitigate the potential risks when they do occur. The PGCMS presented in this paper is proven to provide both a safer and more productive mine environment through minimisation of unplanned delays. The critical elements of the method are presented in detail and demonstrate the utility and value of a ground control management system that has potential for implementation in underground coal mining globally.

INTRODUCTION

Coal has been the main source of energy for producing electricity in Australia for over 200 years and in more recent times a top five export commodity in terms of revenue. The Department of Industry, Innovation and Science estimates that saleable black coal production in Australia was over 440 million tonnes in 2014–15, which is more than 50 per cent higher than a decade ago and over 150 per cent higher than 1990–91 (Department of Industry, Innovation and Science, 2016). Open-cut coal mining accounts for approximately 77 per cent of coal production in Australia. Currently, approximately 100 million tonnes a year of coal is produced from 30 longwall mines operating in New South Wales and Queensland. The geological and geotechnical conditions vary significantly both between and within these operations and successfully managing such variability requires an integrated, Pro-active Ground Control Management Strategy (PGCMS).

Australia’s coal mining safety record outperforms that of the US, China and other major coal mining countries (Harris, et al., 2014), with the fatal risks associated with strata failure typically well managed. Large ground control failures resulting in unplanned delays to production and lost revenue do still occur relatively frequently but are often only reported on internally within organisations for commercial reasons. Over the years, many mines have developed various ground control strategies to minimise or eliminate uncontrolled strata failures as the loss of control poses significant safety and financial risks. Since the decline of coal prices from 2012 (Minerals Council of Australia, 2015), a typical internal ground control strategy has evolved utilising in-house geotechnical engineering groups within the company and/or mine site technical services departments. This has resulted in most geotechnical designs being conducted by mine site geotechnical engineers whereas in times gone by this was often provided by an independent third party, or consultant engineers. Although this new approach is sound practice and acceptable if completed by suitable competent persons, it should still incorporate some form of peer and/or external third-party review. But rather than rely on the third party, the PGCMS has evolved from a desire for mining companies to continue to manage the risks on a daily basis throughout the life cycle of an operation to ensure it operates as safely and productively as possible.

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The PGCMS involves many critical elements. It is not only an understanding of the impacts of the
gеotехнического окружения on likely ground behaviour to allow the mines to extract underground
reserves safely and economically, but also how to predict, communicate and escalate the expected
conditions in a timely manner to the appropriate audience so its impact is suitably mitigated. This
paper provides an overview of the foremost PGCMS in Australia, describes the critical elements and
main features of the system, and offers guidelines for all coal mine operators to consider incorporating
into a ground control management plan.

**CRITICAL ELEMENTS OF A PRO-ACTIVE GROUND CONTROL MANAGEMENT STRATEGY**

A PGCMS is a practical stepwise, systematic process that has evolved within the Australian coal
mining industry to ensure that no person is exposed to an unacceptable level of risk from an
uncontrolled strata failure. This approach is based on a standard Plan–Do–Check–Act (PDCA)
methodology (or similar) originally developed as a tool to control and continuously improve processes
in manufacturing, otherwise known as the Deming Wheel (Demming, 1950).

![PDCA Model (after Demming, 1950)](Figure 1: PDCA Model (after Demming, 1950))

The following principles form the PDCA model in an iterative manner:

- **Plan** – planning and documentation of objectives, expected outcomes, systems, processes and
  activities
- **Do** – acceptance and implementation of the plan
- **Check** – measurement and analysis that is understood and accepted
- **Act** – review and management follow-up, enact a response to changing conditions and
  implementation of improvement initiatives that are sustainable.

For implementation of a successful PGCMS, it is vital to ensure that all relevant stakeholders are
involved in its formulation, and once formulated, the process is integrated into the mine’s “Safety and
Health Management System” (SHMS). It is equally important that the PGCMS is communicated and
made available to the entire workforce. An underlying requisite is that the process is owned not only by
mine management (usually the Site Senior Executive), but the entire workforce. In many cases,
implementation of a ground control management plan may be less than optimal as personnel fail to
complete their roles defined within the plan. This may not be due to negligence but maybe the strategy
itself is flawed, the person was unaware of their requirements in the plan or several other valid
reasons not involving disregard. Involving people at all levels of the organisation in the process as
required by a PGCMS, creates ownership at all levels. Hence the first point is worth iterating again; the
relevant persons at the mine should all be involved in the development of the PGCMS so that they
have ownership of the final document, understand its components and why they were included.

The elements of a typical ground control plan used in Australian underground coal mines can be
grouped into four main categories: a) procedures and standards, b) data collection and design, c)
implementation and monitoring and d) review and investigation. The following critical elements are
included in those four categories:
• strata control principal hazard management plan  
• ground control standards  
• geotechnical design manuals and programs (software and calculators)  
• geotechnical design reports  
• geotechnical data and associated calculations  
• geological and geotechnical mapping and hazard plans  
• investigation of incidents and hazard reports  
• trigger action response plans specific to various stages of mining  
• monitoring regime (observation, extensometry, powered roof support monitoring etc.)  
• risk management and risk assessments  
• permit to mine process (also commonly referred to as Authority to Mine Process)  
• periodic geotechnical testing and sampling maintained in an accessible database  
• periodic third-party audits of high-risk zones ("critical areas")  
• ground support product standard specifications, evaluation and testing procedures  
• weekly reporting system  
• training for employees and geotechnical engineers  
• definition and appointment of suitably qualified geotechnical engineers  
• audits and reviews of ground control management process

The above list is not exhaustive; there are other processes that Australian mines may use, and some listed that are not used. It is up to the individual mine operator to determine what is most suitable for their operation, often via a risk assessment process. While some mining companies develop the above elements as standalone processes, others combine them into an overall “ground control management plan” or into the “principal hazard management plan” in a hierarchical structure with subordinate documentation referenced in the overarching plan. The following sections present a practical guideline for the combination of those elements.

**Procedures and standards**

*Strata control principal hazard management plan*

The Principal Hazard Management Plans (PHMP), also commonly referred to as principal mining hazard management plans or ground control management plans are required by legislation in Australia as part of each mine’s safety and health management system. The PHMP must provide for the following basic elements so far as is reasonably practicable:

• risk identification and assessment  
• hazard analysis  
• hazard management and control  
• reporting and recording relevant safety and health information and;  
• recording of data and any calculations made.

It is a common practice that each principal hazard is individually risk assessed before the commencement of mining and that the principal hazard management plans are developed in accordance with that assessment to mitigate the risks identified. As discussed previously PHMPs are unique to each operating mine, involve a comprehensive and systematic investigation and analysis of all aspects of risk to health and safety associated with the principal hazard. Following commencement of mining the underlying risk assessments are reviewed periodically prior to the PHMP being reviewed, based on several criteria typically documented within the PHMP (including when a major loss of control event occurs at the mine).

The PHMP must address hazard identification, control selection, control management, review, audit and corrective action to manage risk associated with the principal hazard to within acceptable limits. In general, principal hazard management plans include:

• legislative requirements  
• background information about the mine including history of any significant loss of control events  
• major strata control risks to the operation  
• underlying risk assessments  
• geotechnical design guidelines  
• review requirements for the principal hazard management plan or equivalent  
• geotechnical characterisation (domains, zones, districts etc.)
roles and responsibilities in accordance with the mines organisational structure
all relevant Standard Operating Procedures and Standard Work Procedures
the site's critical controls process including methods of assessing and recording the quality of implementation.

**Ground control standards**

The aim of ground control standards is to ensure that the ground control processes at the mines are carried out to a minimum acceptable standard to ensure safe and economic extraction of reserves and to provide a set of consistent and auditable outputs.

These standards also provide a framework for compliance with the relevant government statutory bodies and internal corporate regulations of the operator (such as Anglo American Fatal Risk Standards, 2008; BHP Billiton Fatal Risk Control Protocols, 2003). Regular audits are conducted at the mines to check that as a minimum these standards are met, and appropriate controls are in place. In general, the requirements of fatal risk standards, which form part of the ground control standards, are summarised in the following risk areas: a) plant and equipment requirements, b) system and procedural requirements and c) people requirements, which are regularly audited six-monthly or annually (Anglo American Fatal Risk Standards, 2008; BHP Billiton Fatal Risk Control Protocols, 2003).

**Geotechnical design manuals, software and calculators**

Since the decline of coal prices, most coal companies in Australia employ geotechnical engineers within their technical services departments to conduct detailed geotechnical designs. These designs are often complex and require specialist skills only attained from specific training and experience. It is an important requirement of these designs that a standard process is followed, and all assumptions and calculations are transparent and auditable, as required by legislation in both New South Wales and Queensland. The internal design manuals and programs must be aligned with these requirements as the minimum unless otherwise determined by risk assessment.

Over the years, numerous pillar and roof support design methodologies have been developed in Australia and elsewhere. These methodologies are based on empirical, analytical and/or numerical methods. As the underlying principles and the databases used in the development of these methodologies vary, their applicability to geotechnical environments also vary, often requiring engineering judgement to determine their suitability. Geotechnical manuals summarise the recommended design methodologies and make recommendations on the applicability of them and the minimum design process maps as well as the acceptable standards that need to be used at mines by all personnel, both employees and contractors. In addition, design manuals make recommendations for monitoring, mapping and hazard plans to ensure that the design can be analysed, reviewed and adjusted if required in a timely manner.

A premise of having a design manual is that a standard design process is followed which is auditable and repeatable. An example of such a design and evaluation process is presented in Figure 2. The design manuals typically contain the following sections:

- overall geotechnical design process (i.e. flow chart)
- roof support design – recommendations on the input data, serviceability requirements, roof support design strategy in standard and in critical areas, e.g. longwall install and recovery roadways, design criteria, implementation and communication (i.e. support plans), review process and data storage
- pillar design – design process, pillar types and serviceability requirements geological and geotechnical data, design methodologies, design criteria (i.e., factor of safety and probability of failure), implementation and communication, review process and storage of data
- monitoring – ground deformation monitoring, roof support performance monitoring, stress measurements, critical area audits, surface subsidence monitoring, longwall powered support monitoring, implementation and communication, and monitoring data collection and analysis
- mapping and hazard plans – methodology, data requirements and mapping, currency of data, hazard plan presentation and communication.
In terms of ground support, there are no universally accepted roof and rib support design methodologies in Australia. Therefore, many mines tend to use a “combined support design methodology” which considers several methods and/or uses one method for the design and then one or more methods to back analyse and check the design. The following methods are generally used:

- analytical methods for buckling, shear and dead-weight loading
- field testing and monitoring (including underground observation)
- numerical modelling
- rock mass classification and empirical analysis.

For pillar design, there is more uniformity amongst the geotechnical fraternity, who rely on the following methods to design coal pillars based on loading and serviceability requirements:

- UNSW pillar design methodology (Salamon et al., 1996)
- Analysis of Longwall Pillar Stability (Mark, 1990)
- Analysis of Longwall Tailgate Serviceability (Colwell, 1998)
- 2D and 3D numerical modelling using both Finite Element Method and Distinct Element Method.

Worthy of special mention is the ALTS design methodology, which was initially provided to the Australian coal industry in early 1999 (Colwell, 1998) and over a ten year period was continually refined and updated such that the latest version, ALTS 2009 (Colwell et al, 1999 and Colwell, 2010) and associated software package, has grown to be the prevalent technique for chain pillar and gateroad ground (roof and rib) support design at most operating longwall mines in Australia.
This is largely because the outputs from ALTS 2009 most accurately reflect the design requirements to provide serviceable gateroads associated with longwall extraction. In addition, ALTS 2009 is relatively quick and straightforward to use allowing typically time poor mine site geotechnical engineers to conduct in house design work with high levels of accuracy, improving both safety and productivity at those mine sites. However, like all design methodologies the geotechnical environment needs to be properly characterised so that data input parameters (such as the Coal Mine Roof Rating - CMRR and in situ stress levels) and their potential variation across the area under design consideration is well understood and therefore data input can be selected using appropriate/prudent judgement.

**Geological and geotechnical mapping and hazard plans**

Mapping and hazard plans are integral parts of an effective ground control management strategy requiring a consistent and standardised process integrated with the daily operations of a mine. The mapping and geotechnical hazard plan standards are usually linked to the operational and planning cycle of the mine assisting in reducing uncertainty around the nature of the rock mass and its impact upon the mine schedule.

In development sections, the geological mapping is conducted regularly immediately behind the development face, typically on a weekly basis. The longwall mapping is more variable depending on the difficulty of the seam, with some mines only mapping the gateroad before the panel starts while other mines map the longwall face after every shear is taken. Development mapping can be a good indicator for areas of increased risk due to geological and mining induced features but is heavily dependent on its quality and consistency. Best practice requires a second underground inspection by a geotechnical engineer to verify mapping and check for ongoing signs of deterioration prior to utilising the data for design purposes.

Development hazard plans typically use data from mapping, borehole cores, borehole geophysics and remote sensing such as surface seismic reflection surveying and aeromagnetic surveying. In general, development hazard plans consider the following information:

- thickness of the seam and seam split
- stress environment
- depth of cover,
- roof competency: uniaxial comprehensive strength and coal mine roof rating
- floor competency: uniaxial comprehensive strength and slake durability
- presence, persistence and magnitude of discontinuities (faults, joints, shears)
- presence and nature of igneous intrusions
- interaction between geological structures
- overlying competent rock thickness and strength (e.g. sandstone or basalt channels)
- dip of the seam
- water or water bearing strata

Hazard plans for secondary extraction refer to:

- geological structures (reverse or thrust faults, mid-angled structures, structures aligned at a shallow angle to the roadway and areas where two or more geological structures intersect)
- direction of minor and major geological structures
- presence and nature of igneous intrusions
- roof competency: uniaxial comprehensive strength and coal mine roof rating
- floor competency: uniaxial comprehensive strength and slake durability
- roadway size
- roof slabbings, falls and guttering
- roof displacements following the development
- horizontal stress direction, magnitude and notch
- mine site-specific hazards (i.e., depth of cover, in-seam and multi-seam interactions, installed densities of support, rib spall, changes in seam dip and sandstone or conglomerate channels)
- installed support densities
- off-line cut areas
- installed support
It is imperative that all available data (historical and recent) is presented on mapping and hazard plans, which are provided prior to the start of any underground development and any secondary extraction. For pre-feasibility and feasibility studies hazard plans are also provided to the project teams. It is also imperative that hazard plans are routinely updated with the most recent information.

**Risk management and risk assessments**

In the context of this paper, risk management refers to co-ordinated activities to direct and control an organisation with respect to risk; and risk assessment is the overall process of risk identification, risk analysis and risk evaluation (Standards Australia, 2009).

The overall risk management strategy of coal mines is outlined in the mines’ health and risk management plans i.e. PHMP. Risk assessments are an important part of this plan and are used extensively throughout the Australian mining industry to underpin the strategy. There are many
publicly available publications on risk management and assessment procedures and standards. This paper explains how risk assessments are used in coal mining ground control.

Risk assessments in ground control are conducted in the following stages of mining:

- during pre-development studies, e.g., pre-feasibility, feasibility, pre-development design studies
- when preparing long term mine plans
- prior to the development of gateroads or mains sections
- prior to the extraction of longwall panels
- in all other circumstances when a specific assessment is warranted, for example prior to mining through a structurally disturbed zone or following a major change in mining circumstances since a previous risk assessment.

The aim of the risk assessment is to identify all potential hazards, to rank them and implement the appropriate controls to reduce their impact on safety and productivity. The risk assessments conducted prior to the start of development and the longwall consider the following information:

- geology and geotechnical – all potential structures, for example faults, dykes, seam thinning and thickening, seam rolls, competent layers in overburden, change in roof and floor competency, dip of seam and potential stress environment
- ventilation
- gas
- spontaneous combustion
- surface infrastructure, cultural heritage, surface vegetation, water bearing structures (e.g., dams)
- ground water and underground water hazards
- previous workings
- hazards associated with operating the mining equipment
- other hazards as deemed appropriate.

Many of these hazards are not identified with confidence prior to the start of development. However, many are observable before the commencement of secondary extraction (i.e., longwall retreat) and should be included in the new risk assessment.

Trigger action response plan

A Trigger Action Response Plan (TARP) is an essential element of any PGCMS. A TARP is designed and implemented for a specific geotechnical area or domain to deliver a simple set of rules to provide guidance on support requirements, and other actions required as a response to specific visual and/or monitoring ground behaviour. TARPs typically categorise the geological and geotechnical conditions in a “traffic light” system to indicate different risk levels. In addition, TARPs refer to the, required responses and responsibilities of all relevant people such as the deputy, mine manager, miner, geotechnical engineer, geologist etc. This may also include the appropriate level of support to be installed. An example of a longwall strata control TARP is presented in Figure 3, which shows the conditions and trigger levels in different geological and geotechnical conditions for the longwall face and the gateroads.

Australian coal mines use ground control TARPs for development, outbye areas, longwall face, longwall gateroads, installation roadways and longwall recovery. To be an effective trigger action response plans should define:

- different levels of ground behaviour (triggers), based on key parameters
- responses to triggers (changes in monitored parameters and associated actions)
- individual responsibilities.

The TARP should be as short and simple as possible and ideally not longer than one page. The number of relevant parameters should be distilled to the minimum required to reflect the range of ground behaviour experienced locally. Ultimately, production personnel must have significant input to the documentation and the system, so that common ownership exists.

Data collection

Routine geotechnical testing and sampling

Australian mines rely on extensive geological and geotechnical data for geotechnical designs and for overall ground control management. To ensure that the required data is provided adequately and in a
timely manner, mining companies developed guidelines for geotechnical testing and sampling for underground and open cut operations.

<table>
<thead>
<tr>
<th>Level</th>
<th>GEOLOGY</th>
<th>ROOF</th>
<th>Gate Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>EW FACE</td>
<td>• Minor faulting in face &lt; 0.3m</td>
<td>• Solid roof and floor</td>
<td>• Minor faulting of roof rib corner</td>
</tr>
<tr>
<td></td>
<td>• No visible tensile cracking in roof</td>
<td>• Break line stress of shields</td>
<td>• No additional gutting</td>
</tr>
<tr>
<td></td>
<td>• Face spill &lt; 0.5m</td>
<td></td>
<td>• No signals of additional loading on support.</td>
</tr>
<tr>
<td></td>
<td>• Minor spill ahead of lead drum</td>
<td></td>
<td>• No roof sink</td>
</tr>
<tr>
<td>CHOCKS</td>
<td>• No signs of check yield</td>
<td>• Tip to face &lt; 0.5m</td>
<td>• Minor additional rib spill &lt; 0.5m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Clearance spill plate to canopy &lt; 1m</td>
<td>• Installed rib support controlling rib conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Creep ≤ 500mm off centre</td>
<td>TELLTALES (&gt; 10m from face)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level</th>
<th>GEOLOGY</th>
<th>ROOF</th>
<th>Gate Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow - Level 2</td>
<td>• Faulting in face &gt; 0.3m but &lt; 0.7m</td>
<td>• Major Cracking in roof</td>
<td>• Major strata failure causing stoppage of production</td>
</tr>
<tr>
<td></td>
<td>• Fault planes converging</td>
<td>• Break line near face</td>
<td>• Major additional rib spill &gt; 20mm</td>
</tr>
<tr>
<td></td>
<td>• Cracking in roof</td>
<td>• Cavity affecting check setting (eg &lt; 0.5m for length of 10 checks)</td>
<td>OB Face</td>
</tr>
<tr>
<td></td>
<td>• Face spill &lt; 0.5m but &lt; 1m for length of more than 10 checks</td>
<td></td>
<td>OB Face</td>
</tr>
<tr>
<td></td>
<td>• Spill &lt; 10 checks ahead of lead drum</td>
<td></td>
<td>OB Face</td>
</tr>
<tr>
<td>CHOCKS</td>
<td>• Area of checks yielding</td>
<td>• Tip to face &gt; 1m but &lt; 1m</td>
<td>OB Face</td>
</tr>
<tr>
<td></td>
<td>• Clearance spill plate to canopy &lt; 1m</td>
<td>• Clearance spill plate to canopy &lt; 1m</td>
<td>OB Face</td>
</tr>
<tr>
<td></td>
<td>• Creep ≤ 500mm off centre</td>
<td>• Creep ≤ 500mm off centre</td>
<td>OB Face</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level</th>
<th>GEOLOGY</th>
<th>ROOF</th>
<th>Gate Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orange Level 3</td>
<td>• Faulting in face &gt; 0.7m</td>
<td>• Fresh fracturing evident</td>
<td>• Roof bolts and plates deforming Tendons</td>
</tr>
<tr>
<td></td>
<td>• Additional faulting of rib/rib corner &gt; 20mm OB Face</td>
<td></td>
<td>Buckling and/or heavily deformed plates</td>
</tr>
<tr>
<td></td>
<td>• Additional gutting &gt; 200-300mm &lt; 5m OB Face</td>
<td></td>
<td>Numerous broken bolts &quot;standing support</td>
</tr>
<tr>
<td></td>
<td>on one side only</td>
<td></td>
<td>showing significant loading</td>
</tr>
<tr>
<td></td>
<td>• Relatively infrequent roof rock</td>
<td></td>
<td>Roof buck</td>
</tr>
<tr>
<td>CHOCKS</td>
<td>• Additional rib spill &gt; 70-750mm (&gt;10m but &lt;20m OB Face)</td>
<td>• Additional gutting &gt; 100mm &gt; 1m OB Face on one or both sides of roadway</td>
<td>• Additional rib spill &gt; 150mm (&gt;20m OB Face)</td>
</tr>
<tr>
<td></td>
<td>• Rib bolt plates beginning to buckle or break</td>
<td></td>
<td>• Rib bolt plate buckled and breaking</td>
</tr>
<tr>
<td></td>
<td>• TELLTALES (&gt; 10m from face)</td>
<td></td>
<td>Area more than 1m long (&gt;10m OB Face)</td>
</tr>
<tr>
<td></td>
<td>• Additional movement &gt; 14mm but &lt; 40mm since stable conditions</td>
<td></td>
<td>with more than half the rib bolts broken or majorly exposed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level</th>
<th>GEOLOGY</th>
<th>ROOF</th>
<th>Gate Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Level 4</td>
<td>• Faulting in face &gt; 0.7m</td>
<td>• Fresh fracturing evident</td>
<td>• Fall of roof ahead of face in either gate</td>
</tr>
<tr>
<td></td>
<td>• Major Cracking in roof</td>
<td>• Additional fracturing of rib/rib corner &gt; 20mm OB Face</td>
<td>• Fall of rib greater than rib bolt length</td>
</tr>
<tr>
<td></td>
<td>• Break line near face</td>
<td>• Rib bolts and plates deforming Tendons</td>
<td>and further than 5m OB face</td>
</tr>
<tr>
<td></td>
<td>• Cavity affecting check setting (eg &lt; 0.5m for length of 10 checks)</td>
<td></td>
<td>• Stand support showing significant loading</td>
</tr>
<tr>
<td></td>
<td>• Face spill &gt; 1m for more than 10 checks</td>
<td>• Roof bolts and plates deforming Tendons</td>
<td>• Roof buck</td>
</tr>
<tr>
<td></td>
<td>• Spill &gt; 10 checks ahead of lead drum</td>
<td>Buckling and/or heavily deformed plates</td>
<td></td>
</tr>
<tr>
<td>CHOCKS</td>
<td>• Chocks on constant yield across face</td>
<td>Numerous broken bolts &quot;standing support</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Tip to face &gt; 1m but &lt; 1.5m</td>
<td>showing significant loading</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Clearance spill plate to canopy &gt; 1m</td>
<td>Roof buck</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Creep ≤ 500mm off centre</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5: An example of a longwall Trigger Action Response Plan. Note: the responses and the roles and responsibilities of relevant people are not included in this example.

These guidelines provide a framework for collecting geotechnical data during drilling in exploration programs to ensure that geotechnical data are measured and recorded systematically to a common standard. This ensures the data can be used reliably for the assessment of rock mass and the evaluation of mine design parameters. The frequency of geotechnical testing is also specified in the guidelines.

The guidelines are usually used in conjunction with mandatory guidelines for core logging to ensure that:

- Samples will provide adequate representation for the area of interest and/or over the entire lease.
- Samples are taken from within the correct/target horizons and lithology.
• The correct tests are undertaken on the samples, to allow for analysis of the conditions likely to be encountered during mining.
• The correct number of tests is conducted.
• All other data is recorded to allow for the assessment of the materials, and later calculation of rock mass rating systems, such as coal mine roof rating.
• Standard, reliable testing procedures are used in testing and data collection so that minimal uncertainties are introduced into the design during these processes.
• Data storage is adequate.

It is well-accepted by the Australian coal mining industry that collecting adequate geological and geotechnical data through monitoring, instrumentation, drilling from the surface or underground and through 2D and 3D seismic surveys is necessary to minimise the potential for an uncontrolled fall of ground. Further the consensus is that the cost of the data acquisition, although high, is paid for many times over by improvements to productivity from reduction in uncertainty. Therefore, coal mines usually collect substantial amounts of geological and geotechnical data throughout the life of the mine operations.

Roof bolt and accessories – standard specifications, evaluation and testing procedures

The Australian mining industry has access to a variety of ground support products. A concern with many support products is that the mines must make sure that the products supplied meet the minimum specifications outlined in ground support selection and testing standards. Therefore, in recent years, there has been an increasing emphasis on quality assurance and quality control testing.

Ground support selection and testing standards specify the dimensional, material and testing requirements for roof bolts, cables and accessories used at mines, including the steel bars, cables, nuts, plates, resin and mesh for use in a complete assembly. These standards also specify the requirement for the suppliers to conduct routine tests to ensure that the roof support components comply with the minimum standards.

There are several factors that contribute to the under-performance of installed ground support elements. These factors should be controlled to specified tolerances by regular, systematic quality control procedures. The factors that can affect the performance of a roof bolt support system can be classified into two areas: indirect controllables and direct controllables.

The indirect controls are related to suppliers’ quality control procedures, such as metallurgical properties of roof bolts, deformation pattern of roof bolts, and chemicals used in the manufacturing process of resin capsules and the consistency of these properties. The standards require that the suppliers’ quality control procedures are audited routinely and that the manufacturer’s quality control procedures should comply with the relevant ISO and/or Australian Standards. All quality assurance and quality control test results are also provided to the site geotechnical engineers for random checking and record keeping.

The direct controllables can be divided into three distinct groups: ground support and accessories; compliance with the design; and quality of installation.

The minimum specifications of the standards include:
• roof bolts and cables – chemical composition, length, profile, straightness, finish, colour coding, colour coding, nut break out, mechanical performance, plates (washers), nuts, drill bits, rods and spanners
• resin – capsule size, shelf life, gel and setting time, bond strength and system stiffness, colour coding, packaging, uniaxial compressive strength, elastic modulus, creep, shear strength, push test, capsule diameter, capsule length, freedom from leakage
• mesh and straps – compliance with relevant Australian standards, grade, fire resistance, profile, dimensions, yield strength and storage.

For the above specifications, regular testing and audit requirements are also prescribed in the standards. These standards are also used in supply contracts to ensure that the standards are obligatory. All required tests are usually conducted by the suppliers.

Many mines may also require on site quality assurance and quality control testing conducted by independent companies to ensure that all support products comply with the minimum standards.
Monitoring

Regular Monitoring

Monitoring is probably the most important element of a PGCMS to prevent uncontrolled falls of ground. Therefore, not surprisingly, ground deformation and support effectiveness monitoring are also a requirement of the Australian legislation. In Australian coal mines, strata monitoring consists of both observation (qualitative) and measurement (quantitative). Both methods are required primarily for design verification but also for identifying areas of non-conformance (such as unpredicted anomalies) so that remedial measures can be applied in a timely manner.

Monitoring provides different qualities of data to different users (i.e. operators for decision making and geotechnical engineers for design purposes). Ground monitoring is undertaken to (Galvin, 2016):

- aid in exploration
- establish benchmark data for environmental approval and licensing purposes
- determine properties for input into mine design
- validate mine design
- validate the quality of ground support hardware
- validate the quality of ground support installations
- research the unknown
- provide timely warning of deviation from predicted ground conditions and design performance, both in the short and long term
- identify, quantify and verify mining effects, impacts and consequences.

Australian mines conduct extensive mining monitoring to understand the ground behaviour and to measure all parameters that can result in strata problems. These include:

- pre-mining stresses
- stress changes
- displacements of roof, ribs, floor and pillars
- reinforcement installation procedures
- permeability of strata
- longwall shield loading
- performance or condition of pillars
- installed support.

Ideally, monitoring systems need to be designed and implemented to provide timely, fail-safe warning of the development of critical ground conditions so that personnel and equipment are not exposed to burial, entrapment, windblast, dust, and noxious and flammable atmospheres. Gaps in knowledge and technology currently prevent these monitoring goals from being fully achieved (Galvin, 2016). The use of real time strata control displacement monitoring (extensometers) is continuing to grow in popularity as the technology develops, however it is still not common or accepted practice.

Permit to mine process

A Permit to Mine (also known as Authority to Mine or PTM) is a site-based process that identifies the principal mining hazards and controls for each new mining area. This typically includes expected ground conditions, ground support requirements, gas drainage and ventilation compliance requirements, inrush potential, surface structures and restrictions. A Permit to Mine is developed before mining takes place in any area. The process originated as a tool to assist in controlling the risk of outburst but has since evolved to cover all principal hazards.

All relevant information is listed, reviewed and authorised by all parties (i.e., mine gas and ventilation engineer, geotechnical engineer, geologist, surveyor, development and/or longwall crews and mine manager) to indicate that the identified risks are considered and controlled. This allows the mine manager to make a well-informed decision on the expected hazards and ensure the appropriate controls are in place prior to approving mining to commence. If used appropriately, this system is powerful in identifying and mitigating risks before any mining takes place, hence it is universally adopted and covers all technical risk factors including ground control.
Regular geotechnical critical area inspection

Historically, strata control failures in mine access roadways that cease production are not uncommon, and often may have been preventable with earlier identification and intervention. Regular geotechnical critical area reviews ensure that certain critical areas of the mine are regularly inspected so that the ground support in those areas is in line with the mine’s minimum support requirements and any ongoing deterioration is recognised. A critical area is defined as areas of the mine where strata deterioration or failure may cause process delays or expose people or equipment to potential harm.

![Diagram of a Two-Anchor Remote Reading Tell Tale Schematic](image)

**Figure 6: A Two-Anchor Remote Reading Tell Tale Schematic (Buddery, et al., 2018)**

For active panels, there are routine processes in place, as stipulated in principal hazard management plans and mine inspection regimes, to manage the hazards associated with ground control. Therefore, the critical area inspections are specifically for outbye areas of the mine where inspection is less frequent.

Critical area inspections involve simple visual observations of ground conditions and identification of deteriorating ground conditions so that those areas are included in the mine’s maintenance scheme e.g. replacing corroded or damaged support elements. The inspections are usually performed by an independent third party who are not familiar with the area so that an objective and unbiased inspection of the ground conditions is conducted and recorded.

Weekly reporting system

Weekly reporting systems are another valuable tool in ground control management to ensure that all development and secondary extraction panels are inspected by geologists and/or geotechnical engineers and a standard inspection sheet is filled in. Following the inspections, a standard weekly report is produced and distributed to all relevant parties (i.e., development crews, longwall crews and management) to indicate the areas of non-compliance with ground support designs given in trigger action response plans. The frequency of response plan triggers and installed support are also mapped to ensure that the trigger levels in the response plans are appropriate for the conditions in the panel.

The geological mapping of the panel is also conducted during these inspections and a mine plan with geological structures, installed support and general geotechnical conditions in the panel are included in weekly reports.

Training

Ground control management in Australian mines involves many critical steps and requirements. To ensure that these steps are well-understood, and the requirements are met internal and external training programs are provided to geotechnical engineers as well as the workforce. A training scheme is also a requirement of Australian legislation.
All Australian mines have a system in place to ensure that all personnel working underground are competent, trained and authorised to perform the geotechnical tasks assigned to them. There is also an on-the-job training and assessment process for mine workers. All employees are also trained by a geotechnical engineer in the following areas:

- support design principles
- principal hazard management plan requirements
- identification of geological anomalies which contribute to weaker ground conditions
- trigger action response plans.

Geotechnical engineers are usually responsible for ensuring that refresher training courses are provided regularly to all employees. The training of junior geotechnical engineers involves in-house training sessions and external courses. In-house training sessions involve training in ground control management strategy and the geotechnical design processes. External courses are usually structured around new developments in geotechnical engineering. Registered professional engineers are required to complete and demonstrate Continual Professional Development (CPD) to a level determined by the governing body to remain registered and audited regularly.

Critical controls

As risk management has evolved over time so have the checks and balances used to assess the health of the system. One aspect that is now elementary to a PGCMS is the implementation of a critical controls monitoring or critical control verification process. A Critical Control (CC) is defined as a risk control that is either crucial to preventing an event from occurring or mitigating the consequences of an event (ICMM, 2015). Each mining company has its own slight variation on the CC process however it will typically consist of a series of verification activities to be performed periodically on the identified CCs. This verification will be completed by the risk owner within the site management team and compliance reported through to corporate. Where there are deficiencies identified action plans must be developed and assigned to relevant persons to ensure the deficiency is rectified. An example for ground control is the critical controls associated with geotechnical design. A universal critical control for geotechnical design is that each design is completed and peer reviewed by a competent person in accordance with the PHMP and ground control design guidelines. Evidence of this process must be available for each design currently being implemented at the mine (typically a peer review sign off form). Another universal CC is the monitoring of underground excavations according to a scheduled inspection regime. Documentation must be supplied as evidence that both the monitoring, and the appropriate responses to this monitoring, are being carried out in accordance with the relevant documentation.

Figure 7: Typical Critical Controls Process Flow Chart (ICMM, 2015)
Review and investigation

Investigation of accidents and incidents

In ground control management, accidents and incidents are related to fall of ground which is defined as an unplanned movement of ground that results in a failure within the ground control system with the potential to affect safety and production or has a business cost.

Investigations of accidents and incidents are required by Australian legislation. Queensland Coal Mining Safety and Health Regulation (2013) states that a coal mine’s safety and health management system must provide the following:

a. the procedure for investigating accidents and incidents at the mine
b. making the investigation findings available to the mine’s workers
c. implementing corrective action for accidents and incidents.

Many accident and incident investigations involve using the Incident Cause Analysis Method, which provides logic towards incident and accident causation and supports the notion that most incidents and accidents are rarely caused by a single act or condition, but rather by a number of factors working together (Mining Industry Resource Management, MIRMgate).

Audits and review of ground control management process

A PGCMS has many elements and it is a live process. The implementation of this strategy is not a simple task; it requires resources and time. To ensure that all operations are at comparable levels in implementation of the strategy, regular internal and external audits are conducted by mining companies.

Every element of a ground control strategy is also reviewed regularly to ensure each element is still effective and applicable to the environment the mine is operating in. In an event of a major failure (such as fall of ground), reviews of the complete process are also conducted, and this requirement is included within the ground control management plan.

Strata Defect Hazard Register

Although the risk of ground control failure is highest when within a certain distance of the active mining face, the deterioration of ground support over time has also become a key element of a PGCMS. With large-scale modern mines in operation for many decades the deterioration of ground support and the associated conditions increases with time due to weathering of the ground, weathering of support elements and damage due to impact from mobile equipment. Due to this deterioration over time and an absence of response there have been several large failures generally in outbye areas of mines that incurred significant business losses and unacceptable levels of exposure to coal mine workers. Many operations now utilise a system that includes the regular reporting, inspection and remediation tracking for identified defective strata support in outbye areas of the mines. These strata defects are also tracked in global information system (GIS) enabled maps so that the defects may be identified prior to planning tasks being undertaken in certain areas.

Figure 8: Example Strata Defect Hazard Map
CONCLUSIONS

Ground failures pose a high-level risk to both individuals and production in underground coal mines. Therefore, Australian mines have developed over time what is considered the best practice pro-active ground control management strategy globally, to provide work areas both safe for employees and to minimise unplanned delays to production.

This paper summarised the typical best practice pro-active ground control management strategy used in Australian underground coal mines and detailed the critical elements. A pro-active ground control management strategy is not only about roof support and pillar designs. It involves many critical steps. Applications of these steps vary significantly by both the size of a mine and the size of a mining company. Yet all ground control strategies are required to comply with and demonstrate compliance with the relevant Australian legislation. Although not all Australian coal mines apply all the elements outlined above, most of the mines do have similar systems that they utilise in daily ground control management. This requires a high level of onsite geotechnical knowledge and skills with most companies now employing several geotechnical engineers and geologists at each mine site to ensure the PGCMS is implemented effectively.

As research into ground control continues to improve, so does the application of ground control strategy and its elements with emphasis on roof and rib support designs, and technology for instrumentation and monitoring. The material presented in this paper gives guidance to mining engineers in other countries for achieving safe and productive coal extraction similar to that being achieved in Australia through a PGCMS.

REFERENCES