GEOTECHNICAL CONSIDERATIONS IN UNDERGROUND MINES

GUIDELINE

MOSHAB Approved

December 1997

Document No: ZME723QT

Department of Industry and Resources

MOSHAB
Mines Occupational Safety and Health Advisory Board

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FOREWORD

This Department of Industry and Resources guideline has been issued to assist mine operators in the development of procedures relating to the application of **sound geotechnical engineering practice** in underground metalliferous mines.

It is emphasised that this guideline is not totally inclusive of all factors concerning the application of geotechnical engineering in an underground metalliferous mine. It may not be totally suited to the specific requirements of every mine.

Comments on and suggestions for improvements to the guidelines are encouraged. The guideline will be revised where appropriate to reflect legislative changes and to accommodate new information, improvements in technology and improvements deriving from operational experience.

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1.0 INTRODUCTION

The potentially hazardous nature of underground mining requires the application of **sound geotechnical engineering practice** to determine the ground conditions, the ground support and reinforcement requirements, as well as the size, shape and orientation of all the openings that can be safely and economically excavated in a particular rock mass.

The purpose of this guideline is to provide an outline of how Regulation 10.28 of the Mines Safety and Inspection Regulations 1995 may be complied with. This guideline seeks to encourage the **application** of **current** geotechnical knowledge, methodology, instrumentation and rock support and reinforcement hardware to the practical solution of geotechnical engineering issues in underground mining. When situations arise with geotechnical issues that are intractable with the current level of knowledge and/or technology, impetus is generated for further research and development work.

Regulation 10.28 may be described as a **performance based standard** that states the result to be achieved rather than a detailed prescriptive methodology. The general obligation is stated but it does not take the form of minimum standard to be achieved, thus potentially **limiting** the obligation. Hence, the regulation is not **self-limiting**, but remains current as our understanding of geotechnical issues improves.

It is recognised that **underground mining experience** and **professional judgement** are important aspects of geotechnical engineering that are not easily quantified, but which do have the potential to contribute significantly to the formulation of a variety of equally acceptable and potentially viable solutions to a particular situation. Management at each underground mining operation should recognise, identify and address the geotechnical issues that are unique to a particular mine, in an appropriate manner, using current geotechnical knowledge, methodology, software and hardware. It will be appreciated that **every mine does not necessarily have to apply all the techniques discussed in this guideline**. Conversely, **this guideline may not cover all the issues that need to be addressed**. However, sound management requires that the techniques appropriate to a given set of conditions should be selected and applied.

A selection of geotechnical and mining engineering references, that more fully explain the various aspects of current geotechnical engineering practice, is provided. The list of references is by no means complete.
This guideline has been compiled on the basis of wide spread auditing of industry practice, consultation and interaction between the Department and Industry.

2.0 LEGISLATIVE REQUIREMENTS (WESTERN AUSTRALIA)

The Mines Safety and Inspection Regulations 1995 contains regulations in Part 10, Division 2 - General, that apply to the geotechnical considerations that should be adequately considered during the design, operation and abandonment of an underground mine.

Geotechnical considerations

Regulation 10.28

(1) The principal employer at, and the manager of, an underground mine must ensure that geotechnical aspects are adequately considered in relation to the design, operation and abandonment of the mine.

Penalty: See regulation 17.1

(2) The principal employer at, and the manager of, an underground mine must ensure that the following things are done in relation to workplaces, travelways and installations underground in the mine-

- (a) Due consideration is given to local geological structure and its influence on rock stability;
- (b) Rock damage at the excavation perimeter due to blasting is minimized by careful drilling and charging;
- (c) Due consideration is given to the size and geometry of openings;
- (d) Appropriate equipment and procedures are used for scaling;
- (e) Appropriate measures are taken to ensure the proper design, installation and quality control of rock support and reinforcement; and
- (f) The installation of ground support is timed to take into account rock conditions.

Penalty: See regulation 17.1

(3) The principal employer at, and the manager of, an underground mine must ensure that the following things are done in relation to all development openings and stoping systems underground in the mine-

- (a) Geotechnical data (including monitoring of openings when appropriate) is systematically collected, analysed and interpreted;
- (b) Appropriate stope and pillar dimensions are determined;
- (c) Rationale for sequencing stope extraction and filling (if appropriate) is determined;
- (d) There is adequate design, control and monitoring of production blasts; and
- (e) Rock support and reinforcement are adequately designed and installed.

Penalty: See regulation 17.1

General penalty

Regulation 17.1

The penalty for contravention of a provision of these regulations that refers to this regulation is-

- (a) in the case of an individual, $5 000; and
- (b) in the case of a corporation, $25 000.

3.0 GEOTECHNICAL CONCEPTS

3.1 Introduction

Geotechnical engineering is a comparatively new engineering discipline that has developed rapidly during the past 30 or so years. The origins of geotechnical engineering can be traced to a series of surface and underground civil and mining engineering projects where a range of challenges had to be addressed in a practical and cost effective manner. Geotechnical engineering deals with the whole spectrum of natural geological materials. Geological and weathering processes have resulted in a wide range of natural materials ranging from low strength soils to high strength rocks. The inherent variability of naturally occurring materials is an important aspect that needs to be recognised and allowed for in geotechnical engineering. There are a number of significant challenges in geotechnical engineering that have not yet been fully resolved in the strict scientific sense. Nevertheless, the application of **sound geotechnical engineering practice** (including influence of planes of weakness, materials strength concepts, precedent based experience, empirical methods, instrumentation, monitoring, physical testing and numerical modelling), has enabled substantial and stable underground voids to be constructed in challenging rock mass conditions.

Regulation 10.28 and this guideline contain a number of important terms that need to be understood to appreciate what is required to comply with the regulation. A glossary of terms is provided in Appendix A.

3.2 Geotechnical aspects

This includes all aspects of **geotechnical engineering** including - engineering geology, hydrogeology, soil mechanics, rock mechanics and mining seismology. The term geomechanics could also be used, however it is a more narrowly defined term referring to the fields of soil mechanics and rock mechanics. The term geotechnical engineering is preferred as it includes the essential component of geology, together with the engineering aspects of natural materials, in the search for **practical solutions** to ground control issues.

Geotechnical engineering is one of the tools that the mining industry is encouraged to apply in the continuing endeavour to achieve safe, cost effective mines. The requirement to rehabilitate extensive areas of a mine, due primarily to a failure to address the prevailing geotechnical issues, exposes the workforce to potentially hazardous ground conditions. An on-going need for rehabilitation is symptomatic of inadequate mining practice which results in direct and indirect (opportunity) costs being incurred. **Responsible, safe and economic mining practice requires that mining work be carried out correctly the first time.**

3.3 Geological structure

In geotechnical engineering the term geological structure refers to all the natural planes of weakness in the rock mass that pre-date any mining activity and includes: joints, faults, shears, bedding planes, foliation and schistosity. Across these natural planes of weakness or discontinuities the rock mass has very little or no tensile strength. **A discontinuity is any significant mechanical break or fracture of negligible tensile strength in a rock**[1]. Planes of weakness divide the rock mass up to a collection of potential blocks the size, shape and orientation of which strongly influence rock stability conditions in underground mines. This assemblage of discontinuities is an important characteristic of any given rock mass.

- Geological structure can have a range of characteristics including:
- Orientation - usually specified by dip angle and dip direction;
- Spacing;
- Persistence or continuity;
- Roughness;
- Wall strength;
- Aperture;
- Filling;
- Seepage; and
- Number of sets.

The important role that geological structures have in ground control cannot be over-emphasised. Thorough investigation and analysis[1] of geological structure is vital to a good understanding of the major influence that geological structure exert in determining the ground conditions in underground mining.

3.4 Geotechnical domain

A geotechnical domain is a volume of rock with generally similar geotechnical rock mass properties. The geotechnical properties that should be considered when defining the geotechnical domains include:

- Similar geotechnical characteristics of the planes of weakness - particularly orientation, spacing, persistence and shear strength properties;
- Degree of weathering and/or alteration;
- Intact rock uniaxial compressive strength;
- Deformation modulus of the rock mass;
- Rock stress field (pre-mining and induced stress fields); and
- Permeability of the rock mass.

Rock mass classification methods[2] may be useful in determining the extent of geotechnical domains in a mine. The three main rock mass classification systems that have been used in geotechnical engineering are:

1. Rock Mass Rating system or RMR system[3];
2. Rock quality system or Q-system[4]; and
3. Mining Rock Mass Rating system or MRMR system[5].

These methods **do have limitations** including the "parameters" used in their calculation and the arbitrary class boundaries that have been selected for the various "parameters". **Rock mass classification methods may not be completely suited to all ground conditions and excavation geometries**. Additional geotechnical work may be required to **modify or adapt** these methods to make them more sensitive to variations in the fundamental geotechnical properties listed above.

3.5 Ground

Ground refers to rock in all the possible forms that it may take from a fresh, high strength material to an extremely weathered, very low strength, essentially soil like material. This term also includes all fill materials, both cemented in any way, or uncemented.

A very wide variety of ore body geometries, mining systems and size of mining operations is characteristic of the underground mining environment. This diversity, combined with the high level of uncertainty that exists in the state of knowledge of the rock mass geotechnical conditions, **should be recognised** as a major challenge facing mine management. There needs to be clear recognition that there are a number of **fundamental uncertainties** in our knowledge of the rock mass geotechnical conditions including:

- The rock mass is not a continuum but is comprised of a large number of potential discontinuity bound potential blocks the size, shape, orientation, location and number of which are largely unknown;
- The forces or stresses acting in large volumes of the rock mass are generally unknown and are subject to variation (possibly as a result of block interactions or rock anisotropy), however "point" measurements of the rock stress field are possible;
- The strength of the rock mass is not well known and is difficult to measure in large volumes of rock; and large scale rock testing is difficult and expensive to conduct (however, it may be estimated by back analysis);
- The time dependent behaviour of the rock mass is not well known; and
- Blast damage to the rock mass, particularly from large scale blasting operations, is an additional factor that has generally not been well quantified.

In view of the above uncertainties it is not surprising that even the most carefully planned and designed underground mines have to deal with the unexpected. Consequently, it would be wrong to suggest that there are rules of thumb or specific guidelines that are universally applicable in every situation, at any mine, in perpetuity.

3.6 Ground control

Ground control may be described as the ability to predict and influence the behaviour of rock in a mining environment, having due regard for the safety of the workforce and the required serviceability and design life of the openings. Successful ground control is an integral part of any well managed underground mining operation and is primarily concerned with rock stability and instability issues that result from mine development and the economic extraction of ore. The geotechnical conditions that exist in the rock mass, together with the influence of mining activity, should be well understood in order to be able to predict or assess the ground conditions with any degree of reliability. The ability to influence ground behaviour may vary greatly depending on available access and the volume of potentially unstable rock. Hence, the ability to control or prevent ground movement can be very limited in some situations. In dealing with the complex range of issues in geotechnical engineering it is useful to consider two types of ground control:

1. Micro scale ground control; and
2. Macro scale ground control.

A variety of terms can be used equally well to describe the scale or size of the issues to be addressed. The following terms may be used interchangeably, depending on individual preference.

- Local-scale, micro scale, tactical or workplace ground control involves those factors to which the workforce are exposed and over which they have some control during their day to day mining activities. Ultimately, however, these matters are the responsibility of the principal employer and mine management.
- Large-scale, macro scale, strategic or regional ground control involves those factors that affect the stability of the whole mine, or large sections of the mine, and may typically include one or more stopes, pillars, abutments and development openings. These matters are usually beyond the capacity of the individual miner or general workforce to deal with and are entirely the responsibility of the principal employer and mine management.

The terms **local-scale ground control** and **large-scale ground control**, as described above, will be used in the remainder of the guideline. There are no clear cut boundaries between local-scale and large-scale ground control issues as the two obviously grade into each other. Consequently some of the statements that are made later for one particular area of ground control may apply equally to the other, depending on the mining method, the depth of mining and/or the scale of mining operations.

Ground control may be considered to be made up of three main components:

- Ground conditions;
- Mine planning and design; and
- Ground support and reinforcement.

Put simply:

Ground Control = Ground Conditions + Mine Planning and Design + Ground Support and Reinforcement

It cannot be over-emphasised that a well managed and systematic approach to ground control necessarily requires a good understanding of the ground conditions. Mine planning and design aspects will be discussed in various parts of section 4. Ground support and reinforcement will be discussed in sub-sections 3.13, 4.3 and 4.4.

3.7 Ground conditions

Ground conditions may be thought of as those fundamental geotechnical properties of the rock mass. The influence of mining activity, in a given set of ground conditions, may produce a potentially unstable situation at or near the perimeter of an opening. The main factors that may combine to produce a given set of ground conditions include:

- Geological structure;
- Rock stress;
- Rock strength;
- Groundwater;
- Blast damage; and
- Size, number, shape, type and orientation of openings and their interaction with the five factors listed above.

The first four are naturally occurring geotechnical features of the rock mass, while the fifth and sixth are determined by mining activity. The first factor, geological structure, was discussed previously. Each of the remaining five factors will be briefly discussed following a summary of the types of ground conditions.

It is imperative that the **diverse range of ground conditions**, that may be encountered in Western Australian (WA) underground mines, are recognised and understood as a challenge to achieving cost effective ground control. The range of ground conditions that may be encountered includes:

- Low strength, jointed or sheared, plastic rock in a low stress environment (soft rock conditions);
- High strength, well jointed, elastic rock in a low stress environment (hard rock conditions); and
- High strength, brittle, sparsely jointed, elastic rock in a moderate to high rock stress environment that is prone to mining induced seismicity (seismic rock conditions).

3.7.1 Soft rock conditions

The recognition of soft rock conditions is a very important geotechnical issue that overlaps the boundary between the usually separate geomechanics disciplines of soil mechanics and rock mechanics. Soft rock ground conditions may be identified as those where the intact rock has a uniaxial compressive strength that can range from approximately 0.5 to 25 MPa. There is a need for the combined application of both soil mechanics and rock mechanics methods for the analysis of soft rock materials. The importance of high pore water pressures in soft rock geomechanics needs to be recognised and addressed. The dissipation of excess pore water pressures is controlled by the permeability of the rock mass.

The dissipation of excess pore water pressures in the soft rock mass, with time, may lead to movement of the rock mass into the excavation resulting in gradual closure of the excavation. This apparent **time dependent behaviour** of the rock mass should be expected in a soft rock mining environment, and has important implications for the design and installation of rock support and reinforcement and the time available for use of the excavation. Such ground behaviour can be observed at comparatively shallow depths where the rock stress levels may be a substantial percentage of the intact rock uniaxial compressive strength.

3.7.2 Hard rock conditions

Hard rock conditions are generally the most common ground conditions encountered in underground mines in Western Australia. In this environment rock failure is primarily controlled by the presence of geological structure and the influence of gravity. The size and shape of the potentially unstable rock blocks depends primarily on the orientation, continuity and spacing of the planes of weakness in the rock mass plus the size, shape and orientation of the mining excavations. In hard rock mining conditions the strength of the intact rock is usually considerably greater than 25 MPa.

The combination of wide excavation spans and the presence of flat dipping continuous planes of weakness in the backs is particularly adverse for rock stability.

3.7.3 Seismic rock conditions

Seismic rock conditions, at the other end of the ground conditions spectrum, and mining seismicity generally has been the subject of considerable international research and analysis for many years. Seismicity associated with underground mining operations is primarily caused by the progressive build up of high stress levels in the rock mass remaining around an excavation as it is enlarged by mining. The progressive removal of rock from a stope causes the stress originally carried by that rock to be transferred to nearby abutments and/or pillars. The induced rock stress can eventually reach a sufficiently high level to cause one of the following things to happen:

- sudden movement or slip occurs on pre-existing planes of weakness in the rock mass; and/or
- failure through the intact rock mass creating a new plane or planes of weakness on which movement can occur.

Movement of the rock mass allows the partial dissipation of high rock stress levels. In seismic rock conditions rock failure is primarily caused by high stress levels resulting in fracturing of the rock mass, with gravity playing a secondary role. These movements of the rock mass can result in a wide variety of consequences including:

- Rock noise;
- Small rock falls;
- Rock ejected into excavations at high velocity;
- Large scale collapse or crushing of excavations; and
- Bursting of pillars or faces in development headings or stopes.

There is always potential for the workforce to be exposed to hazards associated with seismically active ground conditions where high rock stress levels exist. The use of appropriate mining practices when seismic rock conditions are encountered is an important issue that management should recognise and address.

The design and installation of ground support and reinforcement systems that are capable of withstanding dynamic loading caused by seismic rock conditions is a significant challenge for the mining industry.

3.8 Rock stress

The rock stress field has both magnitude and orientation and can be considered to consist of two parts:

1. Pre-mining stress field; and
2. Disturbance effects due to excavation.

Rock stress around an excavation	**=**	**Pre-mining stress field**	**+**	**Disturbance effects**

The pre-mining stress field primarily consists of two components:

1. Forces exerted by the weight of overlying rock mass; and
2. Large horizontal forces (tectonic forces) in the Earth's crust.

The importance of rock stress and its influence on underground mining activity should be recognised and understood. The rock stress field around an excavation provides the driving forces that can cause rock instability of considerable violence. There are two types of stress measurements that can be undertaken:

1. Absolute rock stress measurements; and
2. Stress change measurements.

There are several methods are can be used to estimate the magnitude and orientation of the rock stress field[6,7], in terms of absolute stress levels or stress changes, see Table 1.

TABLE 1. SOME ROCK STRESS MEASUREMENT METHODS

ABSOLUTE STRESS MEASUREMENT	STRESS CHANGE MONITORING
CSIRO Hollow Inclusion cell (3D) Borehole slotter stressmeter (2D) USBM borehole deformation gauge (2D) Hydraulic fracturing method (2D) CSIR "doorstopper" (2D) Flat or cylindrical pressure cell (1D)	CSIRO Yoke gauge (2D) CSIRO Hollow Inclusion cell (3D) Vibrating wire stressmeter (1D) Flat or cylindrical pressure cell (1D) Seismic monitoring of a rock volume

Stress changes can occur in the rock mass in the vicinity of an excavation, particularly large stopes. The creation of a large void causes the rock stress field to "flow" around the void. The stress carried by the rock removed when the void was formed is redistributed to other areas of the rock mass around the void. This redistribution of stress around the void may cause stress increases in some areas and stress decreases in others. For example, the wall rocks in the central area of a high narrow stope may experience a significant **reduction** in stress level. However, rock in the abutments of the stope, or crown pillar if one was formed, will probably experience an **increase** in stress level. These stress changes may be very subtle and **can have a significant influence on the ground conditions**.

It is not suggested that every mine should necessarily undertake a comprehensive programme of rock stress measurement. However, it is reasonable to expect **that mine management does recognise that rock stress is an issue that cannot be ignored.** When determining whether or not to undertake a rock stress measurement programme it may be necessary to consider a number of things including: size of the mine, mining depth, presence of stress related ground conditions, use of entry or non-entry mining method(s), major geological structure, production rates, mining history of the stope(s) and/or development heading(s), stope and pillar dimensions, presence or absence of fill, consequences of failure, etc.

It will be appreciated that all of these rock stress "measurement" methods require that strain, or some other parameters, are measured and then converted into a stress level by means of elastic or seismic theory. **The reliable determination of the rock mass stress field magnitude and orientation is not something to be undertaken lightly or in haste. Considerable experience, technical skill and the appropriate equipment plus technical backup are required for success.**

3.9 Rock strength

Recognised laboratory testing procedures are available to determine the intact rock strength. As the scale of the mining challenge increases the concomitant issues of intact rock strength and rock mass strength should be addressed.

The strength of the rock mass[8] is controlled by the complex interaction of a number of factors including:

- Intact rock substance compressive strength;
- Geological structure (planes of weakness) - particularly orientation, persistence, spacing and shear strength parameters;
- Groundwater; and
- Alteration of minerals on exposure to air and/or water with time.

As a result of the complex interaction of the above factors, that can occur when rock is subject to load, it has been found that the strength of rock, in general, is dependent on the **volume** of rock being loaded and the **direction** in which the load is applied. This volume and directional dependence of rock strength is not found in other engineering materials, eg concrete or steel.

Rock mass strength is probably the least well defined aspect of geotechnical engineering. There is a need to have a much better understanding of rock mass strength, ranging from small pieces of intact rock with a volume measured in tens of cubic centimetres to very large volumes of rock measured in tens of thousands of cubic metres. There are some obvious practical difficulties in conducting tests on large volumes of rock. **The limitations that exist in this area of geotechnical engineering need to be recognised, particularly with regard to the use of numerical stress analysis techniques.**

Back analysis, typically of instrumented sections of a mine and/or failures, can be a very useful approach to estimating the rock mass strength. As the phrase suggests, the method can provide estimates of some of the input parameters of a system by analysing its behaviour under load. The method **relies on instrumentation**[6, 7] to determine, directly or by calculation, changes in displacements, strains, pressures and stresses during mining. This approach generally requires a good knowledge of the geometry of the situation, stress field, likely mode of failure, influence of geological structure, use of appropriate numerical model(s), etc for success.

3.10 Groundwater

The hydrogeological environment of an underground mine should be understood to an appropriate level of detail. This information can facilitate the prediction changing pumping requirements due to the lagged effect of rainfall and the continued lateral and vertical expansion of the mine with time. Groundwater is likely to be more of an issue in a new mine or new area(s) of a mine where very little of the rock mass has been actively dewatered by mining activity. Exploration drilling should include **regular packer testing** to determine the **permeability of the rock mass** as well as noting the depth of any water loss or make during drilling.

Exploration diamond drill holes intersected by underground openings can be a potential source of high pressure and/or high flow rates of water. The surveyed downhole path of all exploration holes should be known and plotted on plans and cross-sections, not just the collar and the toe positions. The sudden unexpected in-rush of water from a drill hole can jeopardise the safety of the underground workforce in the vicinity or more generally if the flow rate is sufficiently large. Having the correct size hole packers or stempipes on site can minimise uncontrolled water in-flow. Effective grouting of all exploration holes requires a good understanding of the source of the water likely to be transmitted by the hole, ie surface run-off and/or water contained within fractured zones in the rock mass. Development into new areas of the rock mass, with limited prior drilling information and/or where high pressure groundwater is suspected, should be treated with caution. Drilling long surveyed probe holes, eg diamond drill holes, ahead of the face, through a stem pipe fitted with a valve of appropriate pressure rating, is one approach that may be applicable.

The combination of groundwater and exposure to air may have an adverse influence on the rock mass strength, particularly in soft rock ground conditions. The potential for **corrosion** of the ground support and reinforcement by groundwater, in association with air and the particular minerals present, also needs to be recognised, investigated and if necessary remedied.

Water under pressure in the rock mass can reduce the normal force acting across the joint which results in a reduction in the shear resistance mobilized by friction[9]. Briefly, the soil mechanics law of effective stress states that the total stress in saturated ground consists of two components:

- An effective stress component (the stress carried by the interparticle contacts in the ground); and
- Hydrostatic stress of the water in the voids (pore water pressure).

In **soft rock conditions** the pore water pressure can be a significant percentage of the total stress, resulting in a significant reduction of the effective stress. This causes a significant reduction in the strength of the rock mass compared to the drained condition. In **hard rock conditions** the reduction in the rock mass strength is considerably less because the intact rock strength is generally several orders of magnitude greater than the pore water pressure.

Some minerals and rock types, eg clays and argillaceous rocks, may exhibit a reduction in the strength of the rock mass on exposure to water or repeated wetting and drying. This behaviour may need to be considered in relation to the rock types selected as stope fill if hydraulic transport of the fill material is proposed.

3.11 Blast damage

The aim of any well designed rock drilling and blasting process should be to achieve the required degree of rock fragmentation with the minimum damage to the remaining rock. Blast damage to the rock mass is an unavoidable consequence of conventional drill and blast mining methods. However, much can be done to minimise excessive blast damage to the rock mass by the use of controlled drilling and blasting practices[10]. The factors that control the success of drilling and blasting include:

- Rock mass properties, primarily orientation, persistence and spacing of geological structure, presence of groundwater;
- Degree of **confinement** of the proposed blast;
- Degree of **rock fragmentation** required;
- Selection of the appropriate **hole diameter, burden, spacing and length**;
- Control of individual **hole collar position, hole bearing, inclination and length;**
- Placement of holes in a suitable **pattern** to achieve the required excavation geometry and/or development advance with each blast;
- **Determination of the actual blast hole location in three dimensions** compared to the design blast hole location, particularly in **long hole mining methods**, and **verification that the actual blast hole location is within the design tolerance,** eg automatic surveying of blast holes immediately after drilling, with **re-drilling** if necessary;
- Selection of the required **expansion volume** to allow for swell;
- Selection of appropriate **initiation system(s)**;

- **Initiation sequence** of the blast or blasts to fragment the required volume of rock;
- Selection of **appropriate explosive** or combination of explosives with the required energy levels, effective product life in the blast holes and the appropriate distribution of the explosive through the rock mass;
- **Compatibility** of the initiation systems and the explosive(s);
- Control of **explosive energy levels** in the perimeter holes;
- **Monitoring** of blasts can provide valuable information which may assist in improving the blast design;
- **Overbreak** in the design size of development and stopes can result in increased waste rock handling and ground support costs in development, and a reduction in the mined ore grade via increased dilution in stopes. Both of these areas can have an adverse impact on the mine's economic performance; and
- Use of **well maintained** drilling, explosives handling and charging equipment of appropriate **capacity and reach.**

The technique of drilling and blasting is a very large field that is constantly evolving and hence cannot be summarised in a few lines. Those interested in pursuing this matter further are referred to their suppliers of drilling equipment and explosives who are able to advise on drilling and blasting concerns.

3.12 Openings

There are a large number of different types of openings in an underground mine to provide access for the movement people, air, ore, waste rock, equipment, supplies and services. For the purposes of this discussion openings have been divided into two types:

- Permanent openings; and
- Temporary openings.

The meaning of the word permanent will depend primarily on the expected life of that part of the mine. It is suggested that a **permanent opening** may be taken to mean an opening with a **design life** of at least one to two years. Some examples of the two types of openings are listed in Table 2.

TABLE 2. SUGGESTED CLASSIFICATION OF OPENING TYPES

PERMANENT OPENINGS	TEMPORARY OPENINGS
Shafts	Stopes
Declines and inclines	Stope accesses
Main level development	Drill drives
Escapeways	Sill drives
Intake airways	Cut-off rise
Return airways	Mill holes (drawpoints)
Offices and lunch rooms	Extraction drives
Refuge bays	Working party magazines
Workshops	Stope ventilation rises
Electrical substations	
Crusher excavations	
Conveyor excavations	
Main pump stations	
Main magazines	
Fuel storage bays	
Vehicle service stations	

From Table 2 it can be seen that there are a considerable number of openings that could be classed as permanent openings. Mines with substantial ore reserves and mineral resources can be producing for **considerably** longer than two years. This suggests that a considerable number of openings in a large mine may be classed as **permanent openings.**

The regular use of permanent openings, eg main decline, by the workforce over a long period of time results in a **high level of employee exposure** to the ground conditions in these openings. The **potential risk of injury** to the workforce is higher because more people use these openings, particularly main declines and access ways, and are exposed to the ground conditions in these openings. Hence, a higher standard of ground support and reinforcement may be required in permanent openings to **manage the increased risk**.

3.13 Ground support and reinforcement

The terms ground support and ground reinforcement are often used interchangeably, however they refer to two different approaches to stabilizing rock[11]. **Ground support** is applied to the perimeter of the excavation to limit movement of the rock mass, eg steel sets, concrete lining, timber props and shotcrete. These methods typically require the rock mass to move on to the support to generate loads in the support. **Ground reinforcement** is applied to the interior of the rock mass to limit movement of the rock mass, eg rock bolts, grouted dowels, cable bolts and friction rock stabilizers.

These methods can typically provide active restraining forces to the rock mass soon after installation with little or no movement of the rock.

Ground support and reinforcement includes all the various methods and techniques of both kinds that may be used to improve the stability of the ground. Obviously, the number, size, shape and orientation of the excavations and the ground conditions should be considered when selecting the most appropriate ground support and reinforcement system or systems.

Selection of the appropriate method(s) of ground support and reinforcement is vital to successful ground control. **To achieve this the ground support and reinforcement should be matched to the ground conditions**.

There are a number of ground support and reinforcement design methods that can be used. **All these methods rely on having a good understanding of the prevailing ground conditions before undertaking the design.** The design methods that can be used include:

- Empirical methods (eg method proposed by the US Army Corps of Engineers[11]);
- Observational methods (eg New Austrian Tunnelling Method[2]);
- Rock mass classification methods[2] (eg RMR[3], Q[4], MRMR[5]);
- Stability graph method[12];
- Analytical methods (eg support interaction analysis[8]);
- Block analysis methods (eg SAFEX[13], UNWEDGE[14]);
- Numerical stress analysis methods[8,9]; and
- Seismic criteria (eg ejection velocity[15], allowable displacement, rock damage criteria[16]).

The above list has been arranged generally in an increasing order of complexity. It is suggested that the less complex methods be used first and as increased knowledge of the ground conditions is obtained the other more advanced methods may be applied, if this considered desirable. **Any deficiencies that are highlighted in the use of these methods should encourage further work to remedy these matters, extend the use of the method or develop a new method.**

Rock support and reinforcement design methods will continue to evolve and develop in the future. These methods, in keeping with the **engineering method**, do not present an exact closed form solution with one unique answer. Rather, they are based on underlying scientific principles, strength of materials concepts, engineering computational modelling, static and dynamic testing plus considerable observations of field performance to present a range of solutions. The important issue about any rock support and reinforcement design method is that it should be based on **sound geotechnical engineering practice. The inherent challenges in geotechnical engineering are absolutely no excuse for not applying the methods listed above or those of corresponding technical integrity which may be developed in the future.**

As previously stated, the design, installation and quality control of rock support and reinforcement systems for seismic rock conditions is one of the major challenges facing the mining industry. Considerable work has been undertaken in this area, however much more remains to be done.

4.0 GEOTECHNICAL CONSIDERATIONS

4.1 Introduction

During the period 1987 to 1996 a total of 2,451 accidents occurred involving the loss of at least one full shift in underground metalliferous mines in Western Australia. A total of 603 of these accidents were caused by rock falls. This represents approximately 25% of the total number of accidents. **Rock falls were the largest single cause of accidents in each year of this ten year period.**

During the period 1980 to 1996 a total of 66 fatalities occurred in underground metalliferous mines in Western Australia. Of these, 26 fatalities were caused by rock falls, representing 39% of the total. **Fatalities due to rock falls were more than three times more numerous than the next most common cause.**

The regulations list a number of important geotechnical issues that need to be addressed by management at each mining operation. **The regulations establish the performance standard that should be achieved by the mine on an on-going basis.** These performance standards are necessarily general and not highly prescriptive because it would be impossible to write a detailed set of prescriptive geotechnical regulations for the very diverse range of ground conditions, mining methods, mining history, degree of mechanization and size of mines in WA.

These regulations require that mine management are able to demonstrate that they have, in effect, adopted "best practice*" in the field of geotechnical engineering as applied to underground mining. The use of "best practice" means that practices and methods will evolve and improve continually. **The application of sound geotechnical engineering practice in the pursuit of safe, practical, cost effective solutions to rock instability issues is the basic aim of this guideline and Regulation 10.28.**

It is appropriate to consider the approach that may be required for a mine to comply with the regulations. Mine management will recognise that a well managed ground control plan is a necessary component of any successful mining operation. Such a plan is referred to as a **ground control management plan** in this guideline. An integral part of any **ground control management plan** should be a competent grasp of the current geotechnical literature (see section 8).

There have been a number of significant advances in geotechnical engineering during the past 15 years that are of direct relevance to underground mining. However, **there is no single answer to the best approach or method that will satisfy the regulations because of the wide variety of and variability in the ground conditions and the mining methods in use.**

* "best practice" - practice which is recognised as being developed on the basis of generally available current knowledge of technology and systems of work.

4.2 Total mine life

10.28 (1) The principal employer at, and the manager of, an underground mine must ensure that geotechnical aspects are adequately considered in relation to the design, operation and abandonment of the mine.

The regulations require that geotechnical issues be considered during the whole life of a mining operation, from its beginnings in the feasibility study stage, through the operation of the mine, to the final closure and abandonment of the mine. If it is recognised sufficiently early during the exploration and feasibility study stages of a potentially viable mineral resource project that ground control issues are important, then steps can be taken to ensure that the appropriate geotechnical data are collected from a **representative number** of cored bore holes, preferably oriented. **The recognition of potential ground control challenges at an early stage in the mine design is considered to be central to having a balanced ground control management plan.**

It will be appreciated that in the early stages of exploration there may be very little diamond core drilling undertaken. Re-logging the core that is available for geotechnical purposes, after it has been split for assay determination, is necessarily inefficient (double handling) and may give unreliable data on discontinuity characteristics. Once the potential for economic mining has been identified there appears to be a strong case for the geotechnical logging of a high proportion of all diamond cored bore holes as soon as the core becomes available.

A suggested percentage of all exploration cored bore holes to be logged geotechnically is presented in Table 3 for consideration. Obviously, the number of geotechnical holes required for a particular project will depend on the level of available geological knowledge. The production of a mineral resource estimate, and ultimately an ore reserve estimate, both fundamentally depend on a **progressive improvement in the level of geological knowledge** about the deposit during the exploration process.

TABLE 3. SUGGESTED PERCENTAGE OF CORED BORE HOLES TO BE GEOTECHNICALLY LOGGED

Stage of mine development	Suggested percentage geotechnically logged
Prefeasibility study	25 - 50 %
Feasibility study	50 - 100 %
Operating mine	25 - 75 %

Modern down hole geophysical logging methods may be used to extract some geotechnical data from diamond drill and, less optimally, RC hole walls. These down hole logging techniques should be calibrated in known ground conditions by comparing the results obtained from conventional geotechnical logging of whole diamond drill core with those obtained from down hole geophysical logging.

Regardless of the actual number of holes geotechnically logged, what is of fundamental importance is that those holes that are geotechnically logged constitute a representative sample of the ground conditions found in the ore zone(s) and the wall rocks of a potentially mineable deposit.

The size, scope and type of a potential or existing mining operation will obviously be major factors in determining the amount of effort and the resources that are required to develop and implement the **ground control management plan**. It will be necessary to apply considerable mining experience and professional judgement when establishing the **ground control management plan** at a mine for the first time. With experience, it will be possible to successively refine the plan over time to address the ground control issues identified as important to the maintenance of an acceptable standard of working conditions. The mining issues that should be considered when developing the **ground control management plan** include:

- Depth of mining;
- Expected ground conditions in the orebody and wall rocks;
- Size of the mining operation;
- Number, size, shape, orientation and proximity of orebodies being mined;
- Entry or non-entry method(s) of mining;
- Production rate;
- Size, shape and orientation of the excavations; and
- Level of mechanization.

4.3 Local-scale ground control

10.28 (2) The principal employer at, and the manager of, an underground mine must ensure that the following things are done in relation to workplaces, travelways and installations underground in the mine -

This regulation refers to all workplaces, travelways and installations in an underground mine. By implication it applies to all entry mining methods (see section 6.2) as well as all lateral and vertical development openings and installations where the underground workforce may be expected to carry out any mining related activity.

This regulation does not attempt to address the large-scale ground control issues. These are addressed in 10.28 (3).

4.3.1 Geological structure

10.28 (2) (a) due consideration is given to local geological structure and its influence on rock stability

The importance of geological structure and its potential for adverse influence on rock stability cannot be over-emphasised. There should be a thorough understanding of the geological structure on the local-scale in the workplace as a prerequisite for the successful management of ground control. **Mine geologists, mining engineers, supervisors and the underground workforce should all recognise that geological structure, on a scale from less than a metre to some tens of metres, is a major factor in most, if not all, rock falls.**

It is recommended that, to the extent that is reasonably practicable, systematic and on-going efforts should be made to understand the orientation and other geotechnical characteristics of the geological structure by using a variety of standard geotechnical methods including:

- Identification of the geotechnical domains in the rock mass throughout the mine;
- Geotechnical scanline sampling[1] in selected development that is mutually orthogonal, in three dimensions, and/or oriented core logging, typical of each domain, to establish baseline geotechnical data on planes of weakness for each domain with a minimum of bias;

- Scanline sampling of planes of weakness should include: orientation, persistence, spacing, joint roughness, joint wall rock strength, joint aperture, joint infill and seepage;
- Regular geotechnical area or window sampling[1] in each heading or stope to confirm the existence of major joint sets and identify any changes;
- Use of computer based geological structure data plotting, analysis and presentation methods, eg DIPS[17], to determine the orientation, persistence, spacing and other characteristics of individual joint sets;
- The transfer of this data to geological plans and/or computer models for use in geotechnical engineering and mine design.

A well managed ground control plan should include **regular discussions** of all local-scale ground control issues with the workforce both during visits to individual workplaces and in more formal on-going training sessions. In particular, **changes** in the geological structure encountered during the development of a heading or a stope need to be recognised early and appropriate steps need to be taken to **review** ground support and reinforcement practices and to modify these if necessary. The large-scale ground control issues should also be regularly and routinely discussed with the workforce, with the need for modifications to the ground support regime or other aspects of mining practice being dealt with on an ad hoc basis as frequently as necessary.

4.3.2 Rock damage from blasting

10.28 (2) (b) rock damage at the excavation perimeter due to blasting is minimized by careful drilling and charging

Substantial and unwarranted damage can be caused to rock at the perimeter of an excavation through the use of inappropriate drilling and blasting practices. There is a need to have standardised drilling and blasting patterns that have been determined using well founded and recognised blast design procedures[10]. Rock damage due to the drilling and blasting process can be minimized by the use of a number of methods including:

- Use of correctly adjusted and operating automatic hole lookout angle control and hole parallelism functions on development jumbos;
- Selection of appropriate hole diameter, spacing and burden for the perimeter holes and all other holes in the blast[10];
- Use of suitable low energy explosives in the perimeter holes;

- Use of decoupled explosive charges, with a cartridge diameter less than the blast hole diameter, to minimise blast damage at the excavation perimeter;
- Consideration of the influence of the penultimate row of blast holes on rock damage and, where appropriate, modification of the explosive type used to charge these holes;
- Design of the cut and initiation sequence of the overall blast; and
- Where necessary, seeking the advice of the explosives manufacturer(s) on the appropriate use of various combinations of explosive(s) and initiation system(s).

Mine managements need to ensure that the workforce is provided with on-going training in the safe and efficient handling and use of explosives and initiation devices. This should include the need to have soundly based development and production drilling and blasting practices that assist in minimising blast damage to the rock remaining at the perimeter of the excavation. The design of the blasting patterns should be optimised for the particular combination of ground conditions, initiation system, explosive product, initiation sequence, hole diameter, length of round and geometry of the opening. A critical review of drilling and blasting procedures is recommended on a regular basis to ensure that the minimum practical blast damage is occurring to the rock remaining at the perimeter of the excavation.

There are a number of commercially available, computer based, drilling and blasting design packages that may be used on a consulting basis. The application of recognised drilling and blasting design practices and procedures developed to suit local conditions should be an integral part of a balanced ground control management plan.

While consultation of the workforce on such matters is recommended, it is not appropriate that fundamental decisions on important aspects of blast design and practice be left in the hands of individual miners on the job, without any blast engineering support.

4.3.3 Opening size and geometry

10.28 (2) (c) due consideration is given to the size and geometry of openings

The size, shape and orientation of openings relative to the geological structure needs to be recognised as a major factor controlling the number, size and shape of potentially unstable blocks that may form. It is strongly advised that the design and selection of ground support and reinforcement takes due consideration of the size, shape and orientation of the openings in relation to the geological structure in the workplace.

The magnitude and orientation of the pre-mining rock stress field also needs to be considered in relation to the size, shape and orientation of the openings. The induced rock stress field caused by the openings and their interaction with each other and the pre-mining stress field should also be recognised as a ground control issue. Significant and potentially adverse stress re-distributions can occur following blasting, particularly large stope blasts. Such stress re-distribution can have adverse short term and long term consequences for rock stability and the ground support and reinforcement methods employed.

The numerical methods of block analysis or stress analysis mentioned in sections 3.13 and 4.4.2 can be used to assess the likely interaction between the size and shape of the development openings, geological structure and the required levels of ground support and reinforcement. The influence of the rock stress field on the opening geometry can be can investigated using stress analysis methods (see Table 4).

4.3.4 Scaling

10.28 (2) (d) appropriate equipment and procedures are used for scaling

Refer to the Guidelines - Underground Barring Down and Scaling for a discussion of some issues associated with scaling.

4.3.5 Rock support and reinforcement

10.28 (2) (e) appropriate measures are taken to ensure the proper design, installation and quality control of rock support and reinforcement

Design:

It is recommended that the design of ground support and reinforcement should be based on a thorough understanding of the following points, particularly item 1:

1. Geological structure of the rock mass in and around the workplace;
2. Rock stress levels and the **changes** in rock stress around excavations during the life of the excavation;
3. Rock strength;
4. Behaviour of the rock support or reinforcement system under load;
5. Groundwater regime (particularly corrosion); and
6. The potential for mining induced seismicity.

The essential geotechnical issue is that the rock support and reinforcement should be matched to the ground conditions; anything less could not be said to be sound geotechnical engineering practice.

The rock support and reinforcement design methods that may be applicable have been listed in section 3.13.

Corrosion is an important factor that needs to be considered in the design and selection of the rock support and reinforcement. The influence of corrosion will mean that virtually none of the conventional forms of rock support and reinforcement can be considered to last indefinitely; they all have a finite **design life**. The two main causes of corrosion are: oxidation of the steel elements, and galvanic consumption of iron by more noble (inert) metals, for example copper. The groundwater or artificially introduced mine water, for example hydraulic fill water, needs to be checked to determine if it has the potential to cause corrosion of the rock support and reinforcement.

The terms "**temporary ground support**" and "**permanent ground support**" are considered to be inappropriate for use in relation to rock support and reinforcement[9]. The word temporary necessarily means that the rock support and reinforcement, to which it refers, will be removed and replaced with something else. **Realistically, this almost never happens in the mining environment.** The use of these terms should be avoided as far as practicable.

A preferred support and reinforcement terminology should include the use of terms such as primary support, secondary support, tertiary support, etc or level 1 support, level 2 support and level 3 support, etc, when describing the various stages or levels of ground support and reinforcement. The basis for this terminology should be either the timing of installation or the load capacity of the support, depending on individual mine preference.

It should be recognised that the various levels of rock support and reinforcement, together with their surface fittings, combine to form an overall **ground support** and **reinforcement system** that consists of different layers. Each layer has its own unique contribution to make to the success of the system. The rock support and reinforcement design method used should ensure that the appropriate elements of support and reinforcement are combined in such a manner as to produce an effective **overall support and reinforcement system that is matched to the ground conditions for the design life of the excavation.**

Experience in the WA mining industry during the past five or so years has indicated that **seismic rock conditions** can be experienced at comparatively shallow depths in the range of 400 to 800 m below surface. **Seismic rock conditions present a potentially serious safety hazard to the underground workforce.**

The successful design, installation and quality control of rock support and reinforcement systems that are appropriate for seismically active ground conditions is a very important issue facing the WA mining industry.

It should be noted that all engineering design procedures are based on various simplifying assumptions that may restrict the application of a particular design procedure in certain circumstances. There should be a clear understanding of the origins and the limitations of the various design procedures when applying them in geotechnical engineering.

As the field of geotechnical engineering evolves over time, there will, undoubtedly, be further development of new appropriate design procedures; the important point being that these design procedures should be based on **sound geotechnical engineering practice.**

Installation:

There are two aspects of rock support and reinforcement installation that should be recognised and appropriately addressed:

1. Installation of the rock support and reinforcement element into the previously drilled hole in the rock; and
2. Equipment employed to install the above element in and/or on the rock mass.

Suppliers of **rock support and reinforcement elements** are encouraged to provide an appropriately detailed set of instructions for the correct installation and testing for each element type. Training courses and materials should be readily available to ensure that the workforce is **fully conversant** with the type(s) of ground support and reinforcement in use. There needs to be a **thorough understanding** by all those concerned with their use of the **strengths and limitations** of all the rock support and reinforcement elements that are employed.

The universal application of any one particular type of rock support or reinforcement, regardless of the ground conditions and the excavation geometry, is simply unacceptable.

The end user of the rock support and reinforcement should be able to demonstrate that they are following the manufacturer's instructions for the correct installation of the equipment.

The **equipment used to install** the rock support and reinforcement elements including surface restraint elements should be, where practicable, **purpose designed and built** for the particular range of elements in use at the mine. Ideally, in mechanised mines, specialised rock bolting jumbo(s) should be used in the mining cycle. Where this is not practicable, **appropriate work procedures** should be developed and implemented to minimize the hazards to the workforce when installing rock support and reinforcement elements including mesh, straps or other surface fittings. It is recommended that the following issues be acted upon:

- **Ground conditions** in the area where the rock support and reinforcement elements are to be installed are understood;
- **Timing** of the reinforcement installation should take account of the potential for early deterioration of the ground conditions and the ability of the reinforcement to contain this;
- **Progressive scaling** of the workplace should be conducted prior to and during the installation work;

- **Reach and capacity of the equipment** should be matched to the opening dimensions;
- **Placement** of the support and reinforcement element(s), including **mesh**, on the equipment prior to installation should be carried out from a **secure position**;
- **Correct alignment** of the support or reinforcing element relative to the orientation of the previously drilled hole;
- Appropriate operation of the **insertion device**, eg if a drifter is being used, the mode of drifter operation should be "**percussion off**" or "**no percussion**" while travelling up the slide;
- Preferable to use **rotation only (no percussion)** when tensioning threaded reinforcement elements;
- **Required torque** that needs to be applied to the rock bolt or dowel nut can be achieved without damage to the individual components; and
- **Movement of people** in close proximity to the installation equipment should be controlled.

Quality control:

The importance of quality control to the successful design and installation of an adequate ground support and reinforcement system needs to be clearly recognised and proper quality control procedures should be put in place. The supplier of the rock support and reinforcement system elements should provide information on the factors that determine the quality of the installation. It is recommended that the following issues be acted upon:

- **Storage and handling** of the rock support and reinforcement elements on the surface, while in transit and underground should be such as to minimise damage and deterioration to the elements;
- **Intact rock strength** should be adequate to develop the full capacity of expansion shell rock bolts - expansion shell bolts are generally ineffective in soft rock conditions;
- Recommended **hole diameter range** for the particular type of support or reinforcement is being achieved consistently in **all** the rock conditions likely to be encountered;
- Correct **hole length** is drilled and holes are flushed clean of all drilling sludge;

- **Orientation** of the hole is appropriate for the excavation geometry and expected block movement - axial tensile loading of the steel elements installed in the rock is generally preferred; shear loading should be avoided;
- Hole should be drilled **nearly perpendicular** to the rock surface - use of hemispherical ball and domed plates may be required where this cannot be achieved;
- **Load capacity** of the anchorage method, bar or tendon and surface restraint fittings should be appropriately matched to prevent the premature failure of any one component;
- All steel and other components designed to be encapsulated in resin or cement grout should be **clean** of all oil, grease, fill, loose or flaking rust and any other materials deleterious to the grout;
- Where **full grout encapsulation** of the steel elements is required, the method of grouting should show a grout return at the collar of the hole; other methods that can demonstrate complete hole filling may also be appropriate;
- **Correct tensioning or loading** procedures should be used for the various rock support and reinforcement systems;
- **Plates** and/or **straps** against the rock surface should have the **required thickness** to prevent nuts or barrel and wedge anchors being pulled through the plate and/or strap at the ultimate tensile strength of the tendon when loaded against the rock surrounding the bore hole;
- **Corrosion** issues are recognised and remedied;
- **Blast vibrations** may loosen threaded reinforcement systems;
- **Load tests** are regularly carried out on point anchored rock bolts and friction anchored rock bolts;
- **Fully grouted** reinforcement systems should be checked on a regular basis to ensure that the grout strength and encapsulated length of the bar or tendon is adequate;
- Implement an **action plan** when it is found that the load capacity of the installed support or reinforcement system, grout strength and/or encapsulated length does not meet specifications;
- **Storage** of resin grouts should be at the temperature range recommended by manufacturer;
- Resin grouts are **consumed before** their "use by" date, or within a specified period of time;

- **Mixing** of resin grouts should be for the recommended time and at the recommended speed **- these should not be exceeded;**
- Cement grout is mixed at the **recommended water: cement ratio**, at the recommended angular speed in the specified equipment for the required time;
- **Water** used for cement grout mixing is of the required **quality** or the cement used should be able to develop the required uniaxial compressive strength with the run of mine water supply;
- Any **additives** (eg retarders, accelerators, fluidizers, etc) to the cement grout mix are added in the recommended amounts and at the specified time in the mixing and pumping process;
- All grout mixing and pumping equipment to be **cleaned and maintained on a regular basis;**
- Any pumping equipment used to pressurise rock support and reinforcement should be **regularly maintained** and operate at the **recommended pressure**;
- **Shotcrete mix specification** should state the **slump** of the mix, the **uniaxial compressive strength** and a measure of the **toughness** of the product at **specified time intervals** prior to or following mine application, as appropriate;
- Samples of the **mine shotcrete mix** should be collected at specified intervals, **under normal mine operating conditions**, and **tested** in a NATA registered concrete testing laboratory for compliance with the shotcrete design specifications; and
- **Shotcrete thickness** should be **tested regularly** during placement to ensure that the specified thickness has been applied - a means of permanently marking the shotcrete surface with a depth gauge probe may be appropriate.

4.3.6 Timing of support

10.28 (2) (e) the installation of ground support is timed to take into account rock conditions

The **timing** of the installation of ground support and reinforcement should be considered as an integral part of the design to limit the potential for ravelling of the rock mass. In those headings or workplaces requiring control, the delay in the installation of the ground support should be minimized as far as is reasonably practical. It is recognised that up to 24 hours may elapse from the firing of a development face, before the heading is clear of post-detonation explosive fumes, watered down, scaled and cleaned out ready for the installation of ground support and reinforcement. Extended delays in the installation of ground support, in the order of weeks to months, may jeopardise the effectiveness of the ground control because of the rock mass loosening and consequent reduction in the shear strength that may occur.

When the **ground conditions are sufficiently poor,** the available time that the excavation will remain open and stable (the stand-up time) may be considerably less than the 24 hours mentioned above. In these situations **special measures** may be required to **promptly install ground support and reinforcement prior to the removal of broken rock** from the face. Shotcrete applied to the exposed backs and walls, before the heading is cleaned out, is one approach that may be necessary or effective. **Rapid placement of the ground support as soon as practicable after blasting, minimising the time that the ground has to stand unsupported, is likely to be important for successful mining in these ground conditions.**

Ground support and reinforcement should be installed and tensioned, if appropriate, preferably on a hole by hole basis or at the very minimum on a row by row basis, **before** advancing. If the ground conditions are considered to be sufficiently poor, or the potential for failure of a block is judged to be high, then a **hole by hole installation technique should be used**. The drilling of a large number of holes, prior to the installation of the ground support, is **not** considered to be an appropriate system of work.

4.4 Large-scale ground control

10.28 (3) The principal employer at, and the manager of, an underground mine must ensure that the following things are done in relation to all development openings and stoping systems underground in the mine -

The stability of a large stope, series of stopes plus associated development and the whole mine structure needs to be recognised and addressed in a systematic manner using sound geotechnical engineering practice. The failure to adequately address the large-scale mine stability issues can create, and has created, situations involving the **sudden and unexpected collapse of very large volumes of rock and fill materials.** The incremental creation of very large volumes of apparently stable stope voids (unfilled), in marginal ground conditions, can eventually reach a point where, further small changes to the stope dimensions and/or time dependent deterioration of the rock mass, can produce sudden catastrophic collapse of large sections of the mine.

Ground conditions can constrain the size of single or multiple openings created during the mine life. **To ensure the overall integrity of the mine structure, the mining method(s) should be matched to the ground conditions.**

The importance of a systematic approach to mine planning and design using soundly based geotechnical engineering methods cannot be over-emphasised. A modern underground mechanised mine is a complex engineering system with many sub-systems that need to function in an integrated manner for the mine to operate safely and economically. **Underground mine planning and design**[18] has as its goal an integrated mine systems design, whereby a mineral is extracted and prepared at a desired market specification at a minimum unit cost within the applicable social and legal constraints.

The words “planning” and “design” are sometimes used interchangeably, however they are more correctly seen as separate but complementary aspects of the **engineering method. Mine planning** deals with the correct selection and coordinated operation of all the sub-systems, eg mine production capacity, workforce numbers, equipment selection, budgeting and scheduling. **Mine design** is the appropriate engineering design of all the sub-systems in the overall mine structure, eg drilling, blasting, loading, haulage, transportation of workforce and supplies, electric power, water, ventilation, pumping, dewatering, fill systems, ground support and reinforcement, stope and pillar dimensions.

It is strongly recommended that a formal mine planning and design system be established early in the life of a mine. Such a system might involve the regular informed discussion, as often as required, of a range of planning and design issues in the current operational areas and the new areas of the mine. The **“mine planning**

and design meeting" should be an interdisciplinary meeting requiring the involvement, as necessary, of a range of expertise including: survey, geology, mining engineering, ventilation, drilling and blasting, geotechnical engineering, mechanical engineering, electrical engineering, supervision and management (principal and contractor).

A **formal mining approval** process for the development and/or mining of currently producing or undeveloped ore reserve blocks should be implemented. This formal mining approval process should include the production of plans, cross-sections and longitudinal projections of the ore reserve block(s), as appropriate, plus a **written description** of the proposed mining work to be done and the issues that should be addressed. A draft mining plan and the associated notes for the ore reserve block(s) in question should be issued, in a timely manner, for discussion at the next "mine planning and design meeting". Following discussion and resolution of the issues, final approved mining plan(s) and notes should be issued. It has been found that the mining approval notes can form a valuable summary as to why certain decisions were made in the past.

Approval of the plan(s) should require the signature a number of people including those responsible for: survey, geology, ventilation, drilling and blasting, geotechnical, planning and design aspects plus the Underground Manager and the Registered Manager, as appropriate.

An underground mine may be considered to be an engineering structure that is made up of a number of components including:

- Vertical and lateral access development excavations;
- Stopes both filled and unfilled (including caving methods);
- Pillars of various dimensions and orientations; and
- Abutments.

These excavations and regions of rock interact in subtle and often complex ways that can be difficult to predict. It is apparent that the application of soundly based geotechnical engineering methods to the mine planning and design process can result in significant improvements to mine safety, productivity and economic efficiency.

4.4.1 Geotechnical data

10.28 (3) (a) geotechnical data (including monitoring of openings when appropriate) is systematically collected, analysed and interpreted

It is strongly advised that mines adopt a systematic approach to the collection, analysis and interpretation of geotechnical data as it applies to mine design. Mine design includes the design of all vertical and lateral development and all stoping systems or mining methods to be used in the mine. The geotechnical data referred to here includes:

- Geological structure;
- Rock stress magnitude and orientation;
- Rock strength; and
- Potential for mining induced seismicity to occur.

The inherent **uncertainty** associated with geotechnical engineering means that in some circumstances it may be necessary to install monitoring equipment to verify the stability or otherwise of selected areas in the mine. The basic types of monitoring equipment[6,9] currently available include:

- Displacement and convergence monitors[6];
- Absolute stress measurement and stress change monitors[6,7]; and
- Seismic monitoring systems[19].

A very wide range of displacement monitoring equipment is available including:

- White paint marks across prominent joints;
- Grided clear plastic or glass slides glued across prominent joints suspected of possible movement;
- Displacement monitoring pins across faults;
- Tape extensometers to measure closure of openings; and
- Multipoint extensometers connected to mine wide integrated monitoring systems.

Records of **visual observations** of ground behaviour, made during **regular underground inspections with adequate lighting**, play a very important part in building up a **history of ground behaviour**. Considerable judgement, experience and technical support are required for the selection, location, operation and maintenance of advanced monitoring equipment. **Simple, robust monitoring equipment combined with regular recorded visual observations, preferably made while on foot, is considered to be a good starting point for most mines.** The early collection and analysis of monitoring data is essential to develop an understanding of the ground conditions and to refine the mine design process. If the need for more frequent and/or wide spread monitoring develops during the mine life, then more advanced instrumentation methods can be used to supplement the visual observations.

The use of non-entry mining methods, typical of large, mechanised, high capacity mines, results in a mining method that requires a **high level of technical input** for successful mine planning, design and operation. **It is quite common to find advanced ore reserve estimation procedures being used in large mechanised mines. A balanced approach to the mining process necessarily requires that a similar level of effort be devoted to the geotechnical aspects of mine planning and design.**

For geotechnical data to be systematically collected, analysed and interpreted it may be necessary to demonstrate that a number of activities were being carried out on a regular basis including some of the following:

- Definition of **geotechnical domains** to classify volumes of rock with similar geotechnical properties;
- **Regular geotechnical inspections** and assessment of development in the vicinity of large active stopes before and after stope blasting to monitor and **record changes** in the observed ground conditions;
- Regular inspections and assessment of **stability conditions**, where possible from existing development, of stope walls and backs where significant areas are exposed in non-entry mining methods;
- Regular **photographic record** of stope walls, backs, crown pillars, drawpoint conditions and fragmentation; date should be recorded on the photograph;
- Use of **displacement monitoring** equipment, eg extensometers, to measure displacement of stope wall(s) where it is considered necessary, eg proximity of nearby development and/or concerns about the ability of the stope walls to remain stable for a sufficient length of time to complete extraction and fill the stope;
- Use of absolute and/or incremental **rock stress measurement techniques** in large, complex and/or seismically active mining environments to determine the pre-mining rock stress field and/or changes in the rock stress field where there is the potential for rock instability involving large volumes of rock in critical locations, eg open stope crown pillar below filled stope(s);

- **Laser surveying** techniques, eg the Cavity Measurement System (CMS) developed by the Noranda Technology Centre in Quebec, Canada, to determine the extent of over-break, under-break and non-break in large open stopes; may also be of use in determining the three dimensional void shape and/or volume where caving and/or collapse voids have formed; re-surveying on a regular basis may also be required;
- Use of **longitudinal projection(s)** to summarise stope geometry changes during blasting, date and number of rings fired, estimate of tonnage broken, estimate of extent and depth of wall sloughing - preferably using laser surveying techniques (eg CMS) or by visual estimate, plus observations of ground conditions; and
- **Comparison** of the **observed ground conditions and instrumentation monitoring results with the results** of **numerical modelling** to verify that the observed ground conditions and those predicted by numerical modelling are in reasonable agreement; if not then measures should be taken to determine the reasons for the apparent discrepancies.

4.4.2 Stope and pillar dimensions

10.28 (3) (b) appropriate stope and pillar dimensions are determined

A well managed mine needs to use recognised methods for designing the appropriate dimensions of stopes and pillars. It will be appreciated that some of the design methods currently available may apparently produce wide variations in the results. Use of these methods requires considerable mining experience and sound judgement. It is expected that these methods will be further refined as our geotechnical understanding of the rock mass improves.

Stope wall and back areas plus pillar dimensions need to reflect the ground conditions, including the rock stress field, in which they are mined. Consideration should also be given to **changes in the rock stress field** as a result of individual stope extraction and the overall extraction sequence. Experience may be a useful first approximation to estimate initial stope dimensions. However, there needs to be a systematic approach to incorporate the experience of previous stope and pillar performance into the mine design process. Development designs and schedules should be sufficiently flexible to accommodate reasonably expected design changes that may be found to be necessary.

The design methods generally in use include:

- Empirical methods[2,5,8,12] based on precedent experience; and
- Numerical stress analysis methods[8,9].

Empirical methods

The empirical design methods allow mining experience in a particular set of ground conditions to be incorporated into the stope design process. These methods typically use one of the **rock mass classification methods**[2], or a modified version thereof, to relate the stope wall geometry to the expected ground conditions. The stope wall geometry may be expressed in terms of the "hydraulic radius" determined by dividing the exposed wall area by the wall perimeter. Empirical design charts[8,12] have been produced to aid the stope wall design process.

Regular visual observation of stope and pillar performance and where practical, instrumentation of stope walls and backs, combined with a good understanding of the ground conditions enables the incorporation of **mining experience** into the empirical design process. Empirical methods have their limitations as they are essentially an averaging process. Several geotechnical parameters are assessed and given a rating on the basis of simple index tests or visual observations and tabulated numerical values. The inherent variability of the rock mass can be obscured by the need to make it conform to an arbitrary set of tabulated numbers. Notwithstanding these **limitations**, the use of empirical design methods is seen as an important **first step** in the overall mine design process.

Numerical analysis methods

Numerical methods of stress analysis or block behaviour, in two or three dimensions, allow the interaction of nearby stopes and development openings to be considered in much more detail than is the case with empirical design methods. The use of numerical methods generally requires considerably more input data including the geometry of development openings, stopes and pillars, extraction sequence, rock stress field, rock mass properties and location and orientation of geological structure. Some of the numerical methods that may be used are listed in Table 4.

TABLE 4. SOME NUMERICAL ANALYSIS METHODS

ANALYSIS METHOD	TWO DIMENSIONAL	THREE DIMENSIONAL
Domain methods:		
Finite element	FESOL	NASTRAN
Finite difference	FLAC^{2D}	FLAC^{3D}
Distinct element	UDEC, PFC^{2D}	3DEC, PFC^{3D}
Boundary methods:		
Boundary element	BITEMJ, EXAMINE^{2D}, BESOL^{2D}	MAP3D, EXAMINE^{3D}
Displacement discontinuity	EXAMINE^{TAB}	MINSOL, SUBSOL, BESOL^{3D}, NFOLD
Hybrid methods:		
Finite and boundary elements	PHASES	BEFE

The development of numerical methods has proceeded at a rapid rate during the past 10 years and this is likely to continue. As shown above, there are now currently available a wide range numerical methods that can be run on most high end personal computers that are commonly found at mine sites.

The application of user-friendly numerical stress analysis codes **may appear** very straight forward at first sight. An appreciation of the **challenges** in: selecting the appropriate stress analysis code, having a sufficiently good model representation of the actual mine geometry being analysed (eg complex 3D geometry being poorly approximated by a 2D cross-section), the quality of the input data versus the inherent variability of the actual rock mass conditions, and having the **mining experience and judgement** required to correctly interpret the results in the context of **actual underground observations**; should all help to restrain the **unthinking use** of numerical stress analysis methods.

Considerable engineering judgement and mining experience should be exercised to determine the appropriate level of analysis for stope and pillar design. Generally, in small scale mines with good ground conditions it may be appropriate to use a combination of mining experience with one of the empirical stope design methods. In larger mines employing bulk mining methods, those with challenging ground conditions including potential seismic rock conditions, it may be preferable to conduct a preliminary design using the empirical design methods in conjunction with one or more appropriate methods of numerical analysis combined with mining experience and stope monitoring techniques.

4.4.3 Sequencing stope extraction and filling

10.28 (3) (c) rationale for sequencing stope extraction and filling (if appropriate) is determined

The need to consider sequencing of stope extraction and filling (if appropriate) stems from the requirement to **minimise, as far as practical, adverse levels of stress concentrations** in stope backs, walls, pillars, abutments and around development openings. These adverse levels of stress concentration take the form of very high compressive, very low compressive or possibly tensile stresses. If little regard is paid to the sequence of stope extraction, the end result may be adverse high compressive stress concentrations in remaining ore reserve blocks, with the attendant problems of blast hole closure and mining induced seismicity in a high stress environment or ravelling of the stope walls in a low stress environment.

The comments made above in relation to numerical analysis methods apply equally to this section in regard to the determination of the stope extraction sequence. These methods can be used to compare various alternative extraction sequences with a view to selecting the most appropriate one.

Production schedules

A review of **previous production schedules** and **mining history** can provide valuable in-sights as to why particular geotechnical problems may have developed. Collection of geotechnical data, including **regular visual observations** of ground behaviour, during the various stages of extraction can be very useful in helping to calibrate numerical models used to **back-analyse failures.**

It is reasonable to expect a mine to have short term and long term production and development schedules, based on known ore reserves. These schedules should identify, amongst other things, areas requiring ground support and reinforcement, stope extraction and filling sequences and pillar formation for a range of time frames during the mine life. For example, it may be reasonable to expect that a mine has a detailed short term production schedule over say one to two year time frame, depending of course on the size and complexity of the mine. Accompanying this detailed production schedule should be a series of plans, or a computer based model, that show a range of issues including:

- Development requirements, priorities, ground conditions and predicted rock support and reinforcement requirements;
- Development and stope services requirements, eg ventilation, electric power, water and pumping, etc;
- Proposed stope and pillar extraction sequence; and
- Proposed stope filling sequence.

A "life of mine" production schedule should also be available to present an overview of mine development and production requirements for the total life of the mine. This schedule should highlight, for example, the formation of permanent and recoverable crown or rib pillars, propose pillar recovery sequences, access requirements and suggest possible mining methods for the recovery of non-permanent pillars.

Mine fill

The role and design of mine fill needs to be recognised as an **integral part** of the stope planning and design process. There needs to be a recognition that the stoping process is not complete until the stope void has been filled as completely as is practicable with a suitable material. The creation of large volumes of unfilled stope void can result in a mine structure where large-scale displacement (collapse or caving) may occur in an uncontrolled manner with little prior warning.

Mine fill has a number of very important, but not widely understood, roles to play in large-scale ground control, including:

- **Support** of individual rock blocks on the surfaces of stope walls, pillar walls and backs (if tight filled);
- **Lateral confinement** of the rock mass, thus increasing its compressive strength;
- Provision of an adequate **working surface** in entry stoping methods;
- Enabling the exposure of **stable fill faces** that are capable of standing during the extraction of adjacent pillars; and
- **Damping** the vibrational response of the rock mass during seismic events[20].

The provision of small amounts of lateral confinement to the rock mass, by the fill, can have a very beneficial influence in improving the strength of the rock mass. This fact is demonstrated in triaxial testing of rock core where a small confining pressure can increase the strength of the rock. Fill has the potential to play a significant role in large-scale ground control by providing support over very large areas of stope walls. **The importance of the role of fill in large-scale ground control is often under-estimated.**

The systematic use of an appropriately engineered stope fill system in a mine can allow the mining of higher extraction ratios in a given orebody compared to a mine with no stope fill, assuming a non-caving method of mining is used. The improved safety conditions and higher extraction ratio are of direct benefit to the economic performance of the mine.

The inherent **limitations of unfilled open stoping methods**, particularly when combined with very high extraction ratios, poor quality ground conditions and a lack of geotechnical engineering need to be recognised by mine management. There are **limits to the wall and/or back areas** that can be exposed before significant levels of dilution, crown pillar collapse, caving and/or mining induced seismicity occur. The very short term advantages that can be associated with unfilled open stoping methods need to be carefully weighed against the potential requirement to introduce a stope fill transport and placement system, often at short notice, to fill large unplanned voids.

Water should not be allowed to accumulate in filled stopes, particularly those filled with uncemented sand fill. The accumulation of water in sand filled stopes can potentially result in the following:

- **Liquefaction** of the fill by dynamic loading;
- Hydraulic pressure on fill bulkheads or barricades; and
- Hydraulic pressure on lined ore passes or ventilation rises in the fill.

The dynamic loading of a **saturated** sand fill mass, by seismic events and/or nearby blasting, may cause **liquefaction** of the fill mass with potentially catastrophic consequences. Excess hydraulic pressure may result in the sudden unexpected collapse of one or more fill bulkheads or lined passes which may result in the flooding of large areas of the mine resulting in a major hazard to the workforce.

The removal of crown pillars below filled stopes containing significant volumes of water should be treated with extreme caution and suitable measures to drain the water should be undertaken **before** the pillar is removed.

4.4.4 Production blasts

10.28 (3) (d) there is adequate design, control and monitoring of production blasts

Large stope blasts have a high potential to cause major damage to the rock in and around nearby development openings and to act as catalysts provoking seismic events. Non-entry stoping systems, eg long hole open stoping, are much more suited to mass blasting techniques than are entry stoping systems, eg cut and fill or room and pillar. The location of permanent development openings, eg lateral or vertical accessways or workshops, in close proximity to non-entry stoping systems is undesirable from a consideration of blast vibration issues. Large-scale production blasts, in close proximity to permanent installations, may require the consideration of the effects of blast vibrations on the integrity of the openings and their associated ground support and reinforcement in the zone of influence of the blast.

There has been a considerable amount of work[10] done on the development of blast design tools by organisations such as the Julius Kruttschnitt Mineral Research Centre (JKMRC) in Brisbane, international research groups, consultants and explosives manufacturing companies. It is strongly recommended that mines give serious consideration to the use of one of these blasting design methods when designing large stope production blasts.

The detonation of explosives in the rock mass, particularly large stope blasts, can **trigger seismic activity** or audible rock noise. The occurrence of this should be recorded, noting for example the location, time, subjective description, number of events, any rock falls, etc. It may be possible to determine a reasonable explanation for these events. However, if the **rock noise continues** for some time, or occurs at unexpected times, then further investigation of the situation may be advisable as this could be a pre-cursor of more serious seismic activity in the future. These effects, may of course, be just natural re-adjustments in the rock mass and of no particular concern (so long as their cause and effects are understood). Typically, rock noise does not result in damage to the surface of openings or the installed ground support and reinforcement. The occurrence of rock noise does not necessarily mean that a seismic monitoring system should be installed immediately. However, if **damage is occurring** to the rock mass at the **surface of openings** and/or if the **ground support and reinforcement is being damaged or broken,** then **further investigation** of the seismic activity **should be undertaken.**

4.4.5 Rock support and reinforcement

10.28 (3) (e) rock support and reinforcement are adequately designed and installed

The comments made in section 4.3.5 dealing with rock support and reinforcement in local-scale ground control apply equally here, with the additional consideration that the geometry of the mine, often over a large area, should also be taken into account. The type of **stoping system** being used, either entry or non-entry, should be considered when designing and selecting the most appropriate ground support and reinforcement method(s). **Entry stoping systems** result in the exposure of the workforce to potentially large areas of stope back that require scaling and ground support after each lift. In **non-entry stoping systems**, all the mining work is carried out from development openings that generally require ground support only once, if it is installed in a timely and effective manner.

A **balanced geotechnical stope design** process should involve the integrated consideration of a range of issues including:

- Orebody geometry;
- Ground conditions in the backs and walls;
- Rock fragmentation requirements; and
- Ground support and reinforcement requirements.

The recent trend to higher levels of mining mechanisation and efficiency has led to the increased usage of cable bolting[12] for large stope wall and/or back areas. The development of modified cable bolt strand geometries, eg the Birdcage cable bolt and the Garford bulb bolt, has come about in response to the need to improve or adapt cable bolt performance to a variety of ground conditions. There needs to be a clear understanding of the **ground conditions and how they may change** in response to mining when selecting the type of cable bolt strand to be used. In addition, the technical merits of the various types of cable bolt strand also need to be well understood.

Significant **changes** can occur in the rock stress field around stope or series of stopes during extraction. These stress changes can have an important effect of the amount of radial confinement that is experienced by the rock reinforcement. **A reduction in the confining stress, normal to a cable bolt, may adversely effect the load transfer capacity of a cement grouted cable bolt**[12].

The **marginal cost** associated with the different types of cable bolt strand is **insignificant** in comparison to the fixed costs associated with the hole drilling, installation and grouting (eg equipment depreciation, drilling consumables, transportation, grouting and labour). Hence, **it is vital to ensure the correct cable bolt strand type is selected for the ground conditions and expected ground behaviour (particularly a large decrease in the rock stress field).**

5.0 GROUND CONTROL MANAGEMENT PLAN

It is suggested that a **ground control management plan** be produced for a mine using a combination of in-house and outside expertise in the field of geotechnical engineering. The **ground control management plan** should be critically reviewed at least annually, or more frequently if necessary, to correct areas of deficiency exposed by experience in the previous twelve months or by active investigation, analysis, planning and design of new mining areas that will be developed in the near future.

The **ground control management plan** should address each of the geotechnical considerations raised in Regulation 10.28 of the Mines Safety and Inspection Regulations 1995.

An effective **ground control management plan** should apply **sound geotechnical engineering practice** to the management of ground control challenges during the whole mine life. Development of the **ground control management plan** may be facilitated by the use of **qualitative risk assessment techniques**[21]. These techniques can assist in identifying the high risk aspects of a mine and develop a range of appropriate controls to effectively manage the risks. A range of geotechnical and risk assessment expertise is available in a variety of organisations such as mining companies, geotechnical consulting companies, risk assessment companies, research organisations and universities, who may be able to provide the required input to the development of an appropriate **ground control**

management plan. The successful implementation, review and, where necessary, modification of the **ground control management plan** is the responsibility of the principal employer and the mine management team.

A balanced **ground control management plan** should recognise and address the "**downside**" as well as the "**upside**" of possible courses of action. The open informed discussion of the **potential risks** associated with alternative courses of action, practices, methods, equipment, technology, limitations of knowledge or data, and any other deficiencies, is considered central to **sound geotechnical engineering practice. Those with knowledge and experience in geotechnical engineering have a duty of care to inform their colleagues or client(s) of the inherent strengths and weaknesses of any preferred course of action in an objective and unbiased manner.** Responsible risk management practice requires those having sound knowledge of geotechnical engineering to communicate that knowledge. Similarly, those in **management should take timely, balanced and documented decisions regarding the application of that knowledge and ensure that these decisions are promptly communicated to the relevant people.**

The **ground control management plan** should recognise the importance of developing an **underground mining culture** in the workforce that understands the vital importance of the rock mass, as well as the people and equipment, to a viable mine. A failure to recognise the important role of the rock mass, at all scales, in underground mining will result in disaster. It will be necessary to have a **team approach,** involving the whole underground workforce, if the ground control challenges facing underground mining are to be overcome in a safe and cost effective manner.

6.0 HAZARD RECOGNITION

It is recognised that the implementation of a **ground control management plan** presents a major challenge for mine management. Obviously, it is the exposure of the workforce to potentially hazardous conditions that may result in the occurrence of accidents and fatalities. A sound understanding of the ground conditions is vital for the selection of the most appropriate mining practices and method(s) for a new or existing mining operation. The level of **risk**, both in human and economic terms, will be substantially **increased** if the ground conditions are not well understood.

Recognition and assessment of hazards[22] forms a critical part of a **ground control management plan.** For this discussion a mine may be considered to be made up of four main types of excavations:

- Temporary development excavations (lateral and vertical);
- Permanent development excavations (lateral and vertical);
- Entry mining methods; and/or
- Non-entry mining methods (including caving methods).

Considerable mining experience and professional judgement are required for hazard recognition and the selection of appropriate mine design strategies.

6.1 Development excavations

These excavations include temporary and permanent development excavations, lateral and vertical, that are accessible to the workforce. They generally have a uniform cross-section and can have a total length that may be measured in tens or even hundreds of kilometres. Permanent excavations have an operating life that can be measured in years to tens of years and there is some flexibility in their location and orientation relative to stopes. The permanent nature of many access declines and shafts means that an appropriate level of effort should be put into determining the ground conditions ahead of or prior to excavation. The location of temporary development excavations is often highly constrained by operational requirements.

The rock mass should be divided up into volume domains based on similar geotechnical characteristics as determined from drill hole information or scanline sampling[1]. An initial estimate of the ground support and reinforcement requirements for each domain should then be determined. As more experience was obtained with mining in each domain it should be possible to successively refine the ground support and reinforcement requirements.

It is important to recognise that **ground conditions can change** during mining due to a number of factors including:

- Loosening of the rock mass due to blast vibrations;
- Drainage of water from soft rock formations and jointed rock;
- Deterioration of some rocks on exposure to air or water over time;
- Sudden changes in stope geometry, eg formation of a cut-off slot;
- Stress reductions, low stress levels, or stress shadows, in and near the walls of large stope blocks; and
- High stress levels in abutments, post pillars, rib pillars or crown pillars.

The installation of a particular level of ground support and reinforcement in say a strike drive or cross-cut, initially remote from stoping, may not be adequate when that same development is in a **highly stressed abutment** of a large stope. These factors should be recognised and acted upon **prior to a significant deterioration in the ground conditions.**

6.2 Entry mining methods

Entry mining methods[18] include cut and fill, room and pillar, bench and fill, gallery stoping and shrinkage stoping. They have the common feature that the workforce is exposed to the potential hazard of rock falls from or collapse of large areas of stope backs and walls, particularly in wide orebodies. Entry mining methods require successive slices or lifts to be mined from the orebody, and hence the need to scale and install ground support each lift. Therefore entry mining methods generally require a **high level of effort in local-scale ground control**, however this provides a benefit in greater control over such factors as ore grade, minimising dilution and maximising recovery as well as improving safety.

Ground conditions have a very strong influence on mining method selection and hence they should be well understood before a commitment is made to the development of multiple stopes. The mining of a **trial stope** is obviously one approach that could be used in a new mine where there may be some concern about the suitability of the mining method for the ground conditions.

6.3 Non-entry mining methods

Non-entry mining methods[18] include open stoping, sub-level caving and block caving. Where orebody geometry and ground conditions permit there is a general trend to the more productive non-entry mining methods. These mining methods require a **much higher level of technical input** into large-scale ground control primarily because of the large dimensions of the stopes or the area being caved.

The exposure of the workforce to potentially hazardous conditions is reduced where the work is conducted in development size openings that are usually supported during initial development of the stope. However, the potential exists for large-scale pillar and/or wall collapse in open stope mining methods. Such occurrences may cause rapid flow of materials into nearby mine openings, air-blast problems, dilution and blockage of drawpoints. Conversely, caving methods may hang-up or not cave in a controlled manner. The down dip advance of the stope abutment can cause substantial adverse changes in the ground conditions, primarily because of **increased mining induced stresses,** to the possible detriment of existing or new development in these regions.

Engineered fill is an integral part of the design and operation of some non-entry stoping systems. The design duty, transport, placement and quality control aspects of the fill system should be addressed in a systematic manner to ensure adequate and consistent fill performance during the life of the mine. As discussed above, fill has a significant role to play in preventing significant stope wall collapse. With the move to increased underground mining, the WA mining industry is well placed to take advantage of the considerable national and international experience in the development of engineered fill technology as applied to deep level non-entry mining methods.

6.4 Underground rock failure report form

In order to gather relevant information on rock failure events in underground mines it is proposed to introduce a single page underground rock failure report form, see Appendix B. This information will be used to analyse a number of factors including: failure location, failure dimensions, induced stress change, rock failure mode, geotechnical features, rock mass quality, excavation details, rock support and reinforcement details and monitoring information. The purpose of the form is to improve the understanding of rock failure modes which should assist in the development of remedial measures by modifying support and reinforcement design. The information will be analysed and reported to the mining industry on a regular basis.

7.0 CONCLUSIONS

Geotechnical engineering has developed to the stage where it is now clearly an essential and integral part of the total mining process. The recent development of powerful geotechnical analysis software can aid the application of geotechnical engineering to major mining challenges. The application of current geotechnical knowledge, methodology and hardware is a vital part of sound ground control. A considerable corpus of current geotechnical information now exists in the public domain. A small sample of this is provided in section 8 of this guideline. The combination of sound mining experience and professional judgement, with current geotechnical analysis and design methods, is considered to be a powerful engineering tool with which a well managed mine should equip itself.

Regulation 10.28 of the Mines Safety and Inspection Regulations 1995 lists a number of important geotechnical issues that should be addressed by mine management at the planning stages, during operation and at the completion of a mine. The duty of care requires a well informed mine management to be aware of the recent developments in geotechnical engineering and make appropriate use of soundly based geotechnical methods. Anything less could not be said to be reasonable risk management practice.

It is suggested that one means of complying with the new regulations may be to develop a suitable **ground control management plan** that applies current geotechnical engineering to a range of issues at both the local-scale and the large-scale. Considerable judgement and mining experience are necessary to determine the appropriate level of detail at which the ground conditions need to be investigated and for the selection of appropriate design methods.

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APPENDIX A

GLOSSARY OF TERMS

The following **brief** explanations of some geotechnical and mining terms are not intended to be dictionary definitions or detailed technical explanations.

Abutment. The areas of unmined rock at the edges of a stoping block that carry may large regional loads. Generally a zone of support for ground arching.

Arching. The transfer of rock stress or load from an active mining area, eg stope back, to a more stable area or abutment; this may result in the release of rock blocks.

Bedding planes. Parallel beds or planes of weakness in the rock formed when there was a change in the deposition of minerals under water.

Bedding plane slip. The relative movement or slip of continuous bedding planes or foliation planes in response to large areas of stope wall moving into a void, filled or unfilled. May be observed in areas where extensive stoping has been carried out in a well bedded rock mass.

Cable bolts. One or more steel reinforcing strands placed in a hole drilled in rock, with cement or other grout pumped into the hole over the full length of the cable. A steel face plate, in contact with the excavation perimeter, is usually attached to the cable by a barrel and wedge anchor. The cable(s) may be tensioned or untensioned. The steel rope strand may be plain strand or modified to improve the load transfer between the grout and the steel strand.

Compressive stress. A stress or pressure that tends to push or clamp objects together. The state of stress found in the rock mass before mining occurs. Tends to hold the rock mass together.

Controlled blasting. The art of minimising rock damage during blasting. It requires the accurate placement and initiation of minimal explosive charges in the perimeter holes to achieve efficient rock breakage with least damage to the remaining rock around an excavation.

Destressed zone. A zone of rock around the perimeter of an excavation where the rock stress field has exceeded the strength of the rock mass at some time during its mining history. The rock mass is in a post-peak loading condition and it may be capable of carrying significant loads with low levels of lateral confinement being provided by reinforcement.

Dilution. The contamination of ore with barren wall rock during stoping operations.

Dip. The angle a plane makes with the horizontal.

Discontinuity. Any significant mechanical break or fracture of negligible tensile strength in a rock.

Dowel. An untensioned rock bolt, anchored by full column or point anchor grouting, generally with a face plate in contact with the rock surface.

Earthquake. The local shaking, trembling or undulation of the ground surface and the radiated seismic energy caused most commonly by sudden fault slip, volcanic activity or other sudden stress changes in the Earth.

Elastic. Capable of sustaining stress without permanent deformation. Tending to return to its original shape or state when the applied stress is removed.

Elastic limit. See yield point.

Fault. A naturally occurring plane or zone of weakness in the rock along which there has been movement. The amount of movement can vary widely.

Fill. Waste sand or rock, cemented or uncemented in any way, used either for support, to fill stope voids underground, or to provide a working platform or floor.

Foliation. Alignment of minerals into parallel layers; can be planes of weakness in rocks.

Footwall. The rock below the orebody.

Friction rock stabilisers. Steel reinforcing elements, typically a "C" shaped shell, that are forced into holes drilled in the rock. Frictional forces between the side of the hole and the element to generate forces to limit rock movement. The anchorage capacity of the device depends on the anchorage length above any plane of weakness and the frictional interference between the bore hole wall and the outer surface of the shell. Anchorage capacity is dependent on the hole diameter and the effective anchorage length in solid ground.

Geology. The scientific study of the Earth, the rock of which it is composed and the changes which it has undergone or is undergoing.

Geological structure. A general term that describes the arrangement of rock formations. Also refers to the folds, joints, faults, foliation, schistosity, bedding planes and other planes of weakness in rock.

Geotechnical engineering. The application of engineering geology, hydrogeology, soil mechanics, rock mechanics and mining seismology to the practical solution of ground control challenges.

Ground control. The ability to predict and influence the behaviour of rock in a mining environment, having due regard for the safety of the workforce and the required serviceability and design life of the openings.

Hanging wall. The rock above the orebody.

Hazard. A set of circumstances which may cause harmful consequences. The likelihood of its doing so is the risk associated with it.

Induced stress. The stress that is due to the presence of an excavation. The induced stress depends on the level of the in-situ stress and the shape of the excavation.

In-situ stress. The stress or pressure that exists within the rock mass before any mining has altered the stress field.

Instability. Condition resulting from failure of the intact rock material or geological structure in the rock mass.

Joint. A naturally occurring plane of weakness or break in the rock, along which there has been no visible movement parallel to the plane.

Kinematic analysis. Considers the ability or freedom of objects to move without reference to the forces involved.

Loose. Rock that should be removed by scaling to make the workplace safe.

Mineral resource. An in-situ mineral occurrence quantified on the basis of geological data and an assumed cut-off grade only. More correctly referred to as an Identified Mineral Resource. Strict professional and technical criteria exist for the determination of mineral resources.

Mining induced seismicity. The occurrence of seismic events in close proximity to mining operations. During and following blast times there is usually a significant increase in the amount of seismic activity in a mine. Mining induced seismicity is commonly associated with volumes of highly stressed rock, sudden movement on faults or intact failure of the rock mass.

Ore. Part of an ore reserve. See ore reserve.

Ore reserve. That part of a mineral resource that is considered to mineable in terms of tonnage and grade following an appropriately detailed study of the technical and economic criteria and data. The plural may also used to refer to a list of known ore zones that a mine has identified as being suitable for mining at some time in the future. Strict professional and technical criteria exist for the determination of ore reserves.

Overbreak. The excess rock broken outside the design perimeter of an underground excavation. Overbreak increases the amount of rock to be moved and may reduce mining efficiency. It may also increase the amount of barring down and ground support required.

Pillar. An area of ore left to support the overlying rock or hanging wall. There are temporary pillars recovered at sometime in the future and permanent pillars left in place for the life of the mine.

Plane of weakness. A naturally occurring crack or break in the rock mass along which movement can occur.

Plastic. Capable of deformation at constant stress once the yield point is exceeded. The ability of a material to undergo permanent deformation without returning to its original shape or failing.

Ravelling. The gradual failure of the rock mass by rock blocks falling/sliding from the opening perimeter under the action of gravity, blast vibrations or deterioration of rock strength. A gradual failure process that may go un-noticed. The term unravelling is also used to mean the same thing.

Reinforcement. The use of tensioned rock bolts and cable bolts, placed inside the rock, to apply large stabilising forces to the rock surface or across a joint tending to open. The aim of reinforcement is to develop the inherent strength of the rock and make it self-supporting. Reinforcement is primarily applied internally to the rock mass.

Release of load. Excavation of rock during mining removes or releases the load that the rock was carrying. This allows the rock remaining to expand slightly due to the elastic properties of the rock.

Risk. An expression of the probability - the likelihood - that a hazard will cause an undesired result.

Rock bolt. A tensioned bar or hollow cylinder, usually steel, that is inserted into a drill hole in the rock and anchored by an expansion shell anchor at one end and a steel face plate and a nut at the other end. The steel face plate is in contact with the rock surface.

Rockburst. The instantaneous failure of rock causing a sudden violent expulsion of rock material at the surface of an excavation. Can be a serious hazard to people and equipment. Sometimes used to describe a seismic disturbance to a surface or underground mine where damage results to the mine structure or equipment.

Rock mass. The sum total of the rock as it exists in place, taking into account the intact rock material, groundwater, as well as joints, faults and other natural planes of weakness that can divide the rock into interlocking blocks of varying sizes and shapes.

Rock mass strength. Refers to the overall physical and mechanical properties of a large volume of rock which is controlled by the intact rock material properties, groundwater and any joints or other planes of weakness present. One of the least well understood aspects of geotechnical engineering.

Rock mechanics. The scientific study of the mechanical behaviour of rock and rock masses under the influence of force fields.

Rock noise. Sounds emitted by the rock during failure, may be described as cracking, popping, tearing and banging.

Scaling. The art and function of making the ground safe using a scaling bar to locate and remove loose rock from the walls, face and backs of the workplace. Loose or potentially unstable rock is prised off the rock surface with a scaling bar. Also referred to as barring down.

Scaling bar. A solid steel bar with a straight chisel point at one end and a heel and toe chisel point at the other end, used to remove loose potentially unstable rock. Hollow aluminium bars, fitted with steel chisel tips at each end, can provide longer reach in high headings.

Seismic event. Earthquakes or vibrations caused by sudden failure of rock releasing stored strain energy. Not all seismic events produce damage to the mine structure, hence all seismic events are not necessarily rockbursts.

Seismicity. The geographic and historical distribution of earthquakes.

Seismology. The scientific study of earthquakes by the analysis of vibrations transmitted through rock and soil materials. The study includes the dynamic analysis of forces, energy, stress, duration, location, orientation, periodicity and other characteristics.

Shear. A mode of failure where two objects or pieces of rock tend to slide past each other.

Shear stress. A stress that tends to cause an object to slide.

Shotcrete. Pneumatically applied cement, water, sand and fine aggregate mix that is sprayed at high velocity on the rock surface and is thus compacted dynamically. Tends to inhibit blocks ravelling from the backs, walls and face of an excavation.

Slabbing. Unstable slabs of rock formed by close spaced foliation or bedding planes in the backs or walls. Can also be caused by high stress levels that produce flat slabs parallel to the walls or backs.

Smooth blasting. The use of closely spaced parallel perimeter holes charged with low strength explosives, fired after the main round. Can be used to reduce blast damage to the rock mass and improve rock stability.

Spalling. Stress induced failure of the rock mass that results in small, thin, curved, sharp edged pieces of rock ejected or falling from the backs or walls of an excavation. Generally accompanied by rock noise, usually associated with high rock stress.

Strain. The change in length per unit length of a body resulting from an applied force. Within the elastic limit strain is proportional to stress.

Strength. The largest stress that an object can carry without breaking. Common usage is the stress at failure.

Stress. May be thought of as the internal resistance of an object to an applied load. When an external load is applied to an object, a force inside the object resists the external load. The terms stress and pressure refer to the same thing. Stress is calculated by dividing the force acting by the original area over which it acts. Stress has both magnitude and orientation.

Stress field. A descriptive term to indicate the pattern of the rock stress (magnitude and orientation) in a particular area.

Stress shadow. An area of low stress level due to the flow of stress around a nearby excavation, eg a large stope. May result in joints opening up causing rock falls.

Strike. The bearing of a horizontal line in a plane or a joint.

Stope. An excavation where ore is extracted on a large scale.

Stope lift. A horizontal slice of ore mined from the back of a stope. Generally applied to cut and fill stoping methods.

Support. The use of steel or timber sets, concrete lining, steel liners, etc that are placed in contact with the rock surface to limit rock movement. The rock mass has to move on to the support before large stabilizing forces are generated. Support is applied externally to the rock mass.

Tectonic forces. Forces acting in the Earth's crust over very large areas to produce high horizontal stresses which cause can earthquakes. Tectonic forces are associated with the rock deforming processes in the Earth’s crust.

Tensile stress. A stress that tends to cause a material to stretch. Can cause joints to open and may release blocks causing rock falls.

Ultramafic rock. Typically, dark coloured rocks that have been intruded into the Earth or extruded underwater in a marine environment. May have been altered by heat and pressure producing foliation in the rock. Typically associated with nickel and gold deposits in WA. They can be low strength, sheared and altered and a potential source of challenging ground conditions.

Wedge. A block of rock bounded by joints on three or more sides that can fall or slide out under the action of gravity, unless supported.

Yield point. The maximum stress that a material can sustain without permanent deformation or rupture. The limit of proportionality between stress and strain. Also known as the elastic limit.

APPENDIX B

UNDERGROUND ROCK FAILURE REPORT FORM

INSPECTORATE	**☐ COLLIE ☐ KALGOORLIE ☐ KARRATHA ☐ PERTH**
PERSON REPORTING THE INCIDENT (mine type)	Name:.. Position:................................. Employer: .... Mine: ....Tel. No:................................. ☐ Gold mine ☐ Nickel mine ☐ Lead/zinc mine ☐ Other (specify) ....
DESCRIPTION OF INCIDENT (tick to indicate relevant area, more than one if required) (tick one or more) (tick one or more) (See Notes For Completion over)	**Failure location**: .... Depth(m) .... ☐ Shaft ☐ Decline ☐ Incline ☐ Drive ☐ Cross-cut ☐ Intersection (..........way) ☐ Stope ☐ Crown (Sill) pillar ☐ Rib pillar ☐ Rise ☐ Magazine ☐ Lunch room ☐ Refuge chamber ☐ Permanent opening (eg crusher chamber, pump station, workshop, substation, etc) ....☐ Other (describe) ☐ Back ☐ Hanging wall ☐ Footwall ☐ Side wall ☐ End wall ☐ Face ☐ Floor Date of failure:..Time: am/pm .... Estimated weight of failure: ....(tonnes/kg) Est. dimensions of failure:..(Width x Depth x Length (m)) (Depth of the failure zone is to be measured perpendicular to original rock surface) **Induced stress change:** ☐ Medium or high horizontal stress(..... x overburden stress) ☐ Area affected by mining causing stress increase or decrease (indicate which) ☐ Signs of rock mass degradation ☐ Stress fracturing of rock mass ☐ Rock mass loosening (tension?) ☐ Very low horizontal stress (stress shadow) **Rock failure mode:** ☐ Gravity fall ☐ Toppling ☐ Ravelling ☐ Sliding ☐ Arching ☐ Floor heave ☐ Fill/mud/water in-rush ☐Other................................ ☐ Rock bulking without ejection ☐ Rock bulking with ejection ☐ Rock ejection due to seismic energy transfer ☐ Rock falls due to seismic shaking
GEOLOGY OF FAILURE AREA (tick to indicate yes) (show parameter values used)	**Geological features of failure:** ☐ Joints (.................. joint sets involved with failure) ☐ Low strength intact rock (UCS < 25 MPa) ☐ Fault or shear zone ☐ Groundwater ☐ Swelling/squeezing rock ☐ Other .... ☐ Geotechnical mapping carried out in geotechnical domain of fall area in past year ☐ Diamond drill core logged geotechnically in domain of fall area Estimate intact rock uniaxial compressive strength (range) = ...MPa Estimate rock mass quality range or class (specify RMR, Q, MRMR, GSI): .... rating or class = ...
EXCAVATION DETAILS (tick to indicate yes)	Date mined:.............................Overall size of excavation:.........................(HxWxL (m)) ☐ Drill and blast design method used (name).. ☐ Automatic parallel hole control used ☐ Smooth wall blasting used ☐ Blast monitoring in this geotechnical domain during the past year ☐ Half hole barrels visible in walls and backs
ROCK SUPPORT AND REINFORCEMENT DETAILS IN FAILURE AREA (eg rock bolts, friction stabilizers, cable bolts, cone bolts, steel sets, shotcrete, etc) See Notes (eg plates, mesh) (tick to indicate yes)	Was rock support and/or reinforcement present in failure area? Yes / No

Type	....	....	....	....
Number	....	....	....	....
Length (m)	....	....	....	....
Diameter, etc (mm)	....	....	....	....
Pattern (m x m	....	....	....	....
Load capacity (t)	....	....	....	....
Date installed	....	....	....	....
Shotcrete thickness (mm)	....	....	....	....
Shotcrete toughness (J)	....	....	....	....
Corrosion? (Yes/No)	....	....	....	....

Surface fittings:
Support design method: ☐ Empirical method (name)..
☐ Observational method ☐ Rock mass classification (RMR, Q, MRMR, GSI)
☐ Stability graph method ☐ Analytical method ☐ Block analysis (SAFEX, Unwedge, other ....) ☐ Numerical stress analysis ☐ Seismic criteria
☐ Experience**!Unexpected End of Formula**... ☐ None used
☐ Other (name)

MONITORING DETAILS (tick to indicate yes)	Signs of failure observed or monitored prior to failure? Yes / No Any signs of high rock stress before and/or after the failure? Yes / No Was monitoring instrumentation installed prior to failure? Yes / No **Instrumentation type:** ☐ Displacement monitor ☐ Absolute stress measurement ☐ Stress change measurement ☐ Seismic monitoring system ☐ Other ....

NOTES FOR COMPLETION OF UNDERGROUND ROCK FAILURE REPORT FORM

1. This form does not replace the accident/incident report form.

2. This form is to be completed by person on the mine site familiar with the geotechnical issues associated with rock failure and who has inspected the failure area soon after the event. The completed form is to be sent by mail to the District Inspector.

3. Rock failure mode: the first four listed (gravity fall, toppling, ravelling, and sliding) are controlled primarily by the planes of weakness in the rock mass and the influence of gravity, and may be described as:

Gravity fall	Rock block(s) formed by three or more intersecting planes of weakness that are capable of falling freely under the influence of gravity, typically from the backs
Toppling	Thin slabs or plates of rock, formed by planes of weakness, capable of toppling from the hanging wall under the action of gravity
Ravelling	Gradual failure of the rock mass by blocks falling/sliding from opening perimeter under the action of gravity, blast vibrations or deterioration of rock strength
Sliding	Slip of rock block(s) on planes of weakness, typically from the walls

The next four may be described as follows:

Arching	Transfer of rock stress or load from an active mining area, eg stope back, to a more stable area or abutment, this may result in the release of rock blocks
Floor heave	Buckling of floor into the opening
Fill/mud/ Water in-rush	As stated, cross out as required
Other	Any other failure mode not covered above

The next four (rock bulking without ejection, ...,rock falls due to seismic shaking) are damage mechanisms associated with seismic events and are controlled by high rock stress levels. The following is a brief description of the possible failure or damage mechanisms[1]:

Rock bulking without ejection	Expansion of the rock mass due to fracturing caused by high stress levels, no ejection of the rock mass into the opening occurs
Rock bulking with ejection	Similar to above, but with ejection of the rock mass into the opening
Rock ejection due to seismic energy transfer	Rock blocks may be violently ejected from the periphery of an opening due to the transfer of seismic energy to the blocks from an incoming seismic stress wave
Rock falls due to seismic shaking	Incoming seismic stress wave accelerates a volume of rock that was previously stable under static conditions, causing forces that overcome the capacity of the support system

4. Rock mass classification methods may be applicable in characterising the rock mass. The methods that may be used include:

RMR	Rock Mass Rating method;
Q	Rock quality method;
MRMR	Mining Rock Mass Rating method; and
GSI	Geological Strength Index.

5. Corrosion? Was corrosion of the steel support or reinforcing elements a major factor contributing to their failure?

[1] Kaiser, P K, Tannant, D D and McCreath, D R, 1996. Drift support in burst-prone ground, in *CIM Bulletin*, 89(998):131-138.