Minerals Council of Australia

Management of Rockfall Risks in Underground Metalliferous Mines

A REFERENCE MANUAL

ACG

Australian Centre for Geomechanics

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by Yves Potvin and Paul Nedin

ACG

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The realisation of this guideline has been made possible by the initiative and vision of the MCA's Safety and Health Committee and minerals company chief executives who endorsed the concept at a roundtable meeting convened by the MCA in April 2002.

National Rockfall Management Guidelines – Metalliferous Sector –

PREFACE

The Minerals Council of Australia (MCA) is committed to a vision of a minerals industry free of fatalities, injuries and diseases and has adopted a national safety and health leadership strategy which identifies safety and health as the minerals industry's number one priority.

While implementation of this strategy over the last seven years has coincided with a consistent reduction in the number of injuries, a similar reduction in the number of fatalities has not been achieved. The main causes of fatalities continue to be rockfalls and mobile equipment.

In an ambitious initiative intended to eliminate rockfalls as one of the major causes of fatalities, company chief executives representing the metalliferous, coal and small mining sectors determined that a national guideline on rockfall management would be an effective tool to assist relevant personnel throughout their operations and should be developed as a matter of priority.

Recognising the significant differences between the metalliferous and coal sectors, it was agreed to develop separate guidelines for metalliferous rockfall and roof fall/rib fall in the coal sector. The Rockfall Management Guideline for the metalliferous sector has been developed first and a comparable Guideline for the coal sector is to follow.

In commissioning the Australian Centre for Geomechanics (ACG), under the leadership of Professor Yves Potvin, to develop this Guideline, the MCA was drawing on the expertise already demonstrated by the ACG in understanding the relationship between rockfall and fatalities in the metalliferous sector.

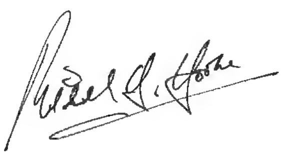
The Guideline has incorporated the experiences and perspectives of geotechnical professionals and other stakeholders who participated in a series of workshops convened across the country, including relevant MCA members.

This resource not only identifies the key components of a ground control management plan but also provides supporting information on techniques and methods drawing on internationally recognised good practice.

The publication will be an invaluable tool for all geotechnical personnel in the minerals industry and I am sure all will want access to this new and unique resource.

The Guideline has been endorsed by the MCA and companies in the metalliferous sector are encouraged to commit to its implementation as a basis for eliminating fatalities from rockfall.

I thoroughly commend this Rockfall Management Guideline to you as a practical, non-prescriptive approach to rockfall management and one which should bring us a step closer to our goal of a fatality and injury free industry.



MITCHELL H HOOKE
CHIEF EXECUTIVE
MINERALS COUNCIL OF AUSTRALIA
October 2003

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MANAGEMENT OF ROCKFALL RISKS

ROCKFALL: "AN UNCONTROLLED FALL (DETACHMENT OR EJECTION) OF GROUND OF ANY SIZE THAT CAUSES (OR POTENTIALLY CAUSES) INJURY OR DAMAGE."

A. Introduction

Rockfalls are a major hazard in underground mines with consequences ranging from insignificant to catastrophic (fatalities). The risk to personnel and damage associated with rockfalls must therefore be managed. A step improvement in the overall safety record of the Australian mining industry will result from the elimination of rockfall injuries and fatalities.

This "Reference Manual" has been developed as a supporting document to the "Industry Guideline for Rockfall Risks Management – Underground Metalliferous Mines", published in a separate booklet for ease of use. The Manual is a collection of techniques and examples of "good ground control practices" described in literature or locally developed and implemented in Australian mines. Trainers, technical personnel, mine supervisors and managers are invited to consult this reference manual in conjunction with the "Industry Guideline for Rockfall Risks Management – Underground Metalliferous Mines", for a systematic approach to manage the risk of rockfalls in their mines.

B. Background "The Australian Underground Mining Environment"

In most cases, rockfalls occur in distinct and localised areas of a mine. These "local events" are nevertheless the result of an overall system response to mining activities. The solution to the problem of rockfalls must therefore account for activities beyond the local areas where they occur and rest upon a sound understanding of the overall underground mining environment. The following sections briefly describe typical Australian mine settings in a geomechanical context.

B.1 OREBODIES

The size and shape of orebodies will have a large influence on the mining method, the extraction strategy and the overall approach to mining. The so-called "world-class" orebodies at operations such as Olympic Dam, Northparkes and Mount Isa Mines, amongst others, will tend to optimise productivity. The focus in this case is the rapid extraction and transportation of extremely large quantities of ore, also known as "bulk mining" or "mass mining". As a result, the rate of change or the disturbance imposed on the local mining environment can be significant. Since the change in stress and energy to the overall system (mining environment) is a function of the volume of rock displaced, "mass mining" involves huge transfers of energy from the extracted rock to the (remnant) rock left in place. The risk assessment of "mass mining" must account for the possibility of large amounts of energy being released either suddenly by caving, air-blasts and rockbursts, or gradually by stress re-distribution creating the potential for local or total crushing of drives or other mine infrastructure.

At the other end of the spectrum, the mining of small and often high-grade orebodies usually emphasises selective extraction and the total recovery of ore. The often short-term focus of mining projects involving small orebodies may impose limitations in capital expenditure. This may in turn produce limitations in infrastructure, mine fill system, shaft access, shotcrete plant, etc., limitations in equipment, mechanised bolting rigs, automated equipment, etc. and limitations in specialised personnel, rock mechanics specialists, geotechnicians, rehabilitation crews, etc. Although the extraction of the smaller orebodies will, in general, be less disturbing to the mining environment compared to mass mining, the resources available to plan and execute the exploitation of the mineral reserves at minimal risk can also be limited.

B.2 MINING DEPTH AND STRESS

Australian mining to date has been confined to relatively shallow depth in comparison to countries like Canada and South Africa. The challenge of mining at depth has multiple implications including the management of transport and logistics, ventilation including temperature and air quality and ground pressure (rock stress). This guideline is particularly concerned with stress. Stress magnitude is generally proportional to the weight of overburden and therefore increases with depth. In Australia, the two horizontal stress components, for example, east-west and north-south, are usually two to three times higher than the vertical stress (overburden weight) component. In Western

Australia, even higher stress gradients have been measured. Some Australian mines experience conditions at depths between 400 m and 500 m that are comparable to Canadian and South African "deep mining" conditions. This high stress regime, coupled with lower rock mass strength, results in comparatively high levels of support being used.

High stress conditions often lead to a seismically active and rockburst-prone environment. Rockburst is one of the most difficult hazards to control in mines because it involves complex mechanisms, and like earthquakes, generally occurs suddenly. Rockbursts can be very powerful and are highly unpredictable. There may be some precursor signs to rockbursts, but current technology is generally inadequate to reliably decode the sequence or patterns of events and provide a timely warning of impending rockbursts. Seismic monitoring equipment and special ground support systems designed to sustain dynamic loading (rockburst impact) have become essential to operate safely and efficiently in a rockburst-prone environment.

The strategies and controls required for operating in high stress environments must be carefully evaluated through a comprehensive risk assessment.

At the other end of the spectrum, mining in low stress or "de-stressed" environments can also impose specific challenges for controlling rockfalls, especially in a jointed rock mass. A "reasonable" level of ground pressure may contribute to the stability of the rock mass. Stresses acting normal (across) to structures, joints or discontinuities may effectively clamp them, locking the potential sliding movement and increasing the overall stability of the rock mass.

Low or de-stress conditions are common to remnant mining or mining adjacent to existing mine workings. In this environment, large blocks sliding, ground unravelling, mine headings breaking through to old openings or simply cave propagation of old workings are typical hazards that may need to be controlled.

B.3 ROCK MASS PROPERTIES

The range of rock mass properties encountered in Australian underground mines is broad, varying from very hard and brittle rocks that fracture violently like glass, to very soft rock that deforms like dough.

The hard and brittle rock masses can be prone to rockburst if the stress levels are sufficient to induce local failure. The very soft rock masses, like some of the "ultramafic" units encountered in the Kalgoorlie region in Western Australia, can react significantly to changes in stress. Contrary to the rockburst situation, which involves instantaneous and violent failure, the "soft" failure process is progressive over a period of time, but often cannot be stopped. Extensive reinforcement that can yield, and strong surface support, may be required to slow down the convergence and eventually the closure of drives in order to allow mining activities to be completed. Accurate scheduling and "just-in-time" mining become essential to operate safely and productively in extreme (very high or very low) stress conditions.

B.4 FROM OPEN PIT TO UNDERGROUND

A significant number of Australian deposits outcrop to surface or only extend to relatively shallow depths. It is a relatively common feature of Australian mines to undertake the initial extraction of orebodies with an open pit and complete it with an underground operation.

The geomechanics interaction between the extracted pit and the evolving underground operation must be carefully planned and managed. For example, slope stability problems induced by the undermining of the slope area can affect the stability of the underground portal generally located in the pit, or some surface infrastructure in the vicinity of the pit.

The extraction of the crown pillar separating the pit and the underground workings must also be carefully planned. The crown pillar is the structure "insulating" the underground operation from the open pit. Removing it will directly expose the underground workings to surface conditions such as rainfall and can also affect the ventilation network. Because crown pillars often have a regional support function, their removal may affect the stability of both the pit slopes and underground infrastructure. It is therefore imperative to carefully assess the multiple risks before proceeding with the extraction of the "surface crown pillar" and stopes immediately below it.

In caving mines, the orebody back break and associated subsidence have to be accounted for when planning for the transition from open pit to underground operation.

C. Good Practices in Ground Control

A process for managing rockfall risks is described in Figure 1. The process is iterative and should be ongoing for the life of the mine. It has the following six major steps:

1. Collect Data
2. Define Geomechanical Domain
3. Preliminary Design
4. Assess Rockfall Risks
5. Control Rockfall
6. Monitor

"Audit" and "Education and Training" have not been integrated as distinct steps of the process, as they can be applied at any stage of the process.

An effective rockfall management process must rely on:

- An implementation strategy supported at all levels of the organisation, from senior company executives to mine workers
- Quality work and good practices using recognised techniques for completing each step of the process

Australian underground mines operate in a variety of environments (See Section B) with each mine site having a unique set of conditions. Care has been taken not to prescribe specific techniques and methods to complete the rockfall management process, as their selection remains site-specific.

The following sections outline some of the suggested techniques and methods that could be considered as good ground control practices. This manual is not an exhaustive collection of good practices and it is recognised that other techniques and methods not described in the manual are capable of producing quality results. Methods and good practice for Step 7 "Audit" and Step 8 "Competency, Education and Training", are not covered in this manual.

Underground Rockfall Risk Management Process

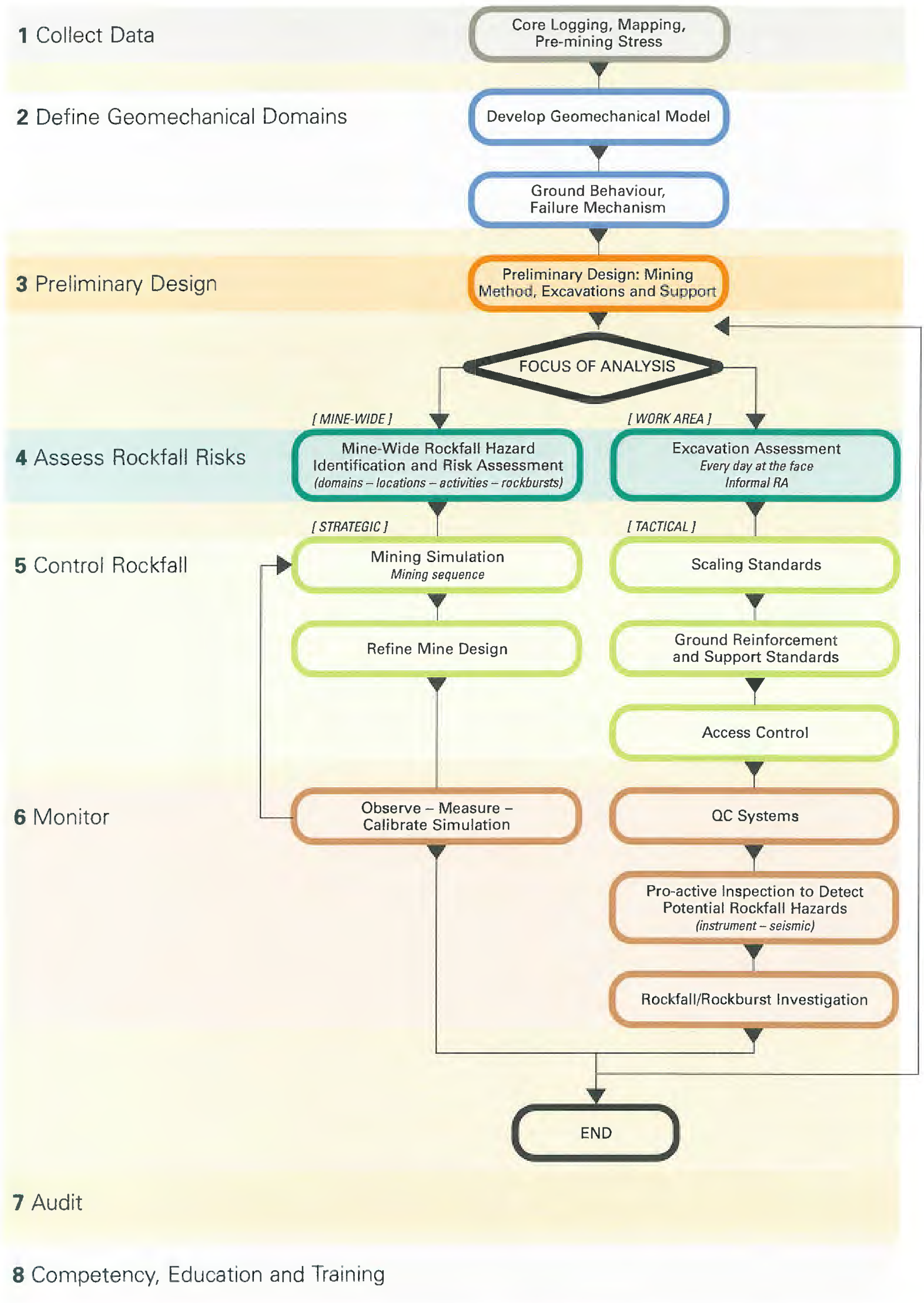
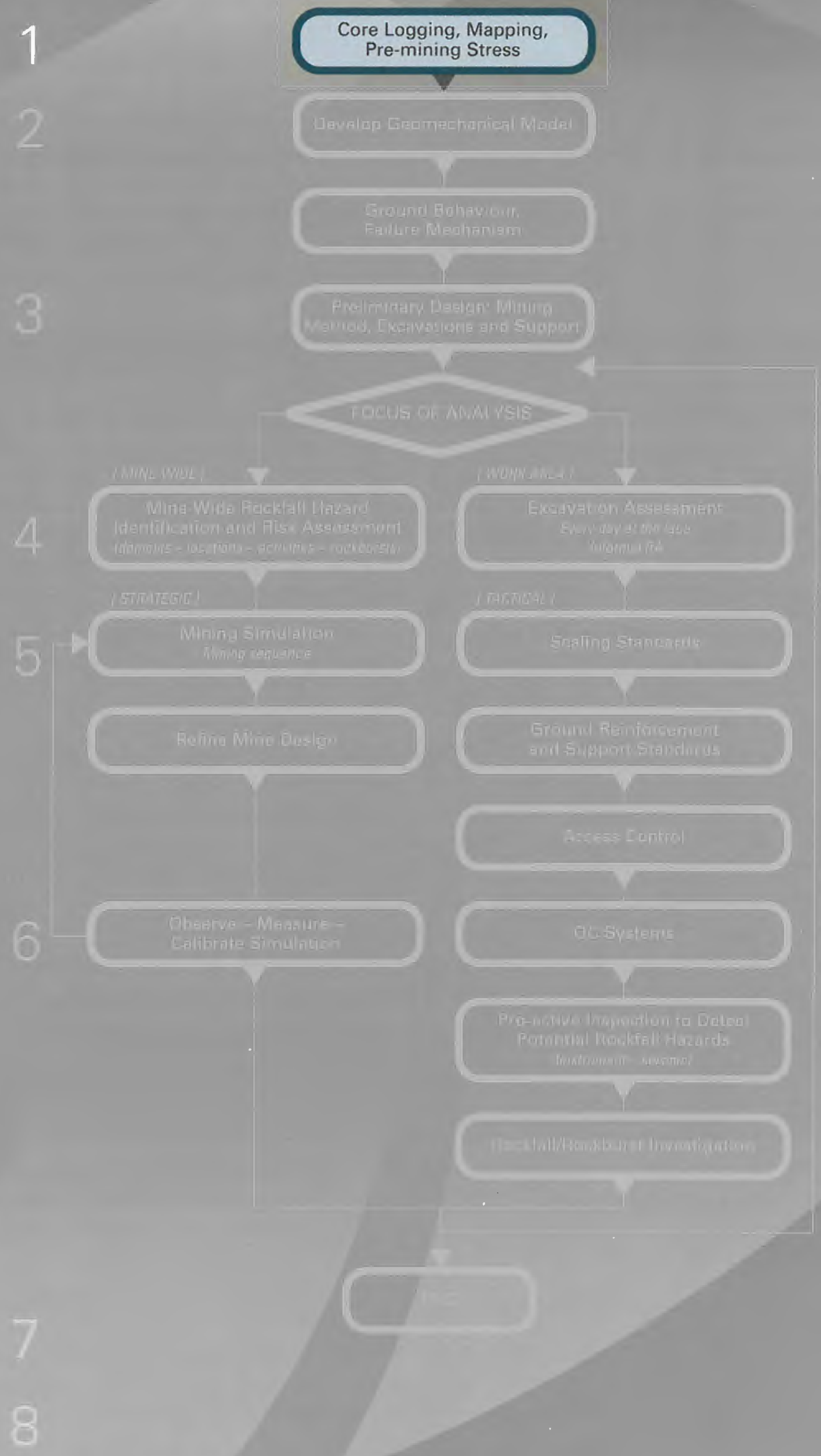


Figure 1: Flowchart illustrating the process for managing the risk of rockfalls in underground metalliferous mines
Step 7 Audit and Step 8 Competency, Education and Training can be undertaken at any stage of the process.
For clarity of the presentation, they have been listed outside the process framework

1 Geomechanical Data Collection



1. GEOMECHANICAL DATA COLLECTION

Most engineering designs, such as those used in building and bridge construction, rely on materials such as steel and concrete being able to sustain the combined forces acting on them at any time. Steel and concrete are man-made materials, built according to specifications under strict quality control systems. Their characteristics are well defined and when submitted to forces, their behaviour is easily predicted.

"UNDERGROUND MINES USE THE IN-SITU ROCK MASS AS THE BASIS FOR ITS INFRASTRUCTURE. ROCK MASS IS A NATURAL MATERIAL THAT CAN BE VERY COMPLEX AND VARIABLE. THEREFORE, DEFINING ROCK MASS CHARACTERISTICS CAN REQUIRE EXTENSIVE GEOMECHANICAL INVESTIGATIONS. THE INTACT ROCK FABRIC AND THE NATURAL PLANES OF WEAKNESSES (GEOLOGICAL STRUCTURES) ARE TWO OF THE MAIN CHARACTERISTICS TO BE DEFINED."

The sources of information (geomechanical data) can be collected from diamond drill core and from direct mapping of rock faces, both surface or underground. A portion of geomechanical data can often be directly extracted from geological information previously collected and interpreted by geologists for exploration and orebody definition purposes. For example, the lithology (different rock types), alteration zones, major fault network and even Rock Quality Designation (RQD), or fracture frequency, are often systematically collected from the very beginning of exploration projects and built-in geological models of the mine.

1.1 Geological Structures

"THE MAJORITY OF ROCK MASS FAILURES IN MINES ARE CONTROLLED OR ASSOCIATED WITH DISTINCT GEOLOGICAL STRUCTURES, GENERALLY THE WEAKEST PART OF THE ROCK MASS. THEREFORE, A DETAILED KNOWLEDGE OF GEOLOGICAL STRUCTURES MAY IMPROVE OUR CAPACITY TO UNDERSTAND FAILURE MECHANISMS AND PREVENT POTENTIAL ROCKFALLS."

Geological structures can be looked at, focusing on different scales, from a whole continent to the micro-fractures in the rock fabric. For the purpose of mine geomechanics, geological structures are divided into "major structures", including shear zones and faults (mine region scale), and the less extensive "minor structures" like joint sets bedding, etc. (local area of the mine scale).

1.1.1 MAJOR STRUCTURES

Major structures originate from large movements of earth that have occurred before, during and/or after the formation of orebodies. The network of faults generated by these earth movements are therefore of significant interest to geologists trying to understand how orebodies were formed. Faults are the weakness planes along which earth blocks have moved and may have a large bearing on the stability of the mine. Mining activities may re-activate earth movement along faults and cause significant damage to active mines. Understanding the geometry of the fault network and how mining activities can disrupt their stability can lead to a strategic approach to mining that minimises the potential for fault movement and the risk from regional instability and damage. Stability problems can be expected locally, in zones of intense faulting and at locations where faults intersect each other.

Mine geologists will note the location and measure the orientation and dip of all major structures identified in orientated core and existing excavations at a very early stage of a mining project. This information can be used to reconstruct the network of major structures on mine plans and to develop a three-dimensional structural model.

Figure 2 shows a section through a model of major structures, including other relevant mine infrastructure information.

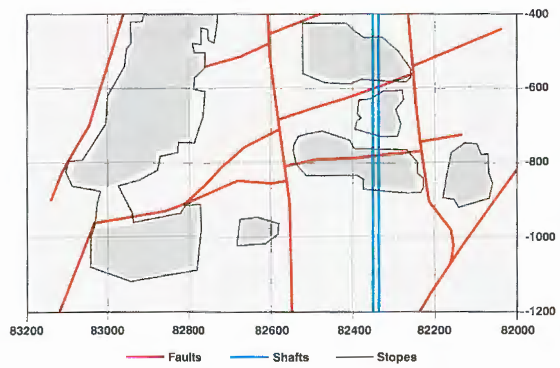


Figure 2: Generic section of a mine showing a network of major geological structures

1.1.2 MINOR STRUCTURES

Minor structures or joints are often subordinates of major structures. A sound understanding of the major structure network will provide an insight into the study of minor structures. Minor structures that are at least one metre long and repeat themselves at a noticeable interval (joint sets, bedding) are of particular interest to geomechanics practices.

Typically, the minor structural data collected includes the location, dip and dip direction. It is good practice to also note the condition of joints, (roughness, planarity, infill, continuity, spacing, etc.), as this information can be used for rock mass classification purposes (See Section 1.3). The study of minor structures is preferably done by face mapping, however, it can also be performed on oriented diamond drill core. The sampling technique can follow "scanlines" along the face or pre-defined "windows". Sampling bias can have a significant impact on the data interpretation. Therefore, faces of at least three different (preferably orthogonal) orientations should be mapped. Hoek, Kaiser and Bawden (1995) suggest that at least 100 measurements of dip and dip direction should be made in each structural domain. Good practice would suggest doubling the number of measurements. More complete discussions on structural data collection techniques are found in Hoek, Kaiser and Bawden (1995), and Hutchinson and Diederichs (1996).

Structural data can be presented by tracing the joint orientation on mine plans with the dip written beside the trace (See Figure 3) to facilitate visualisation of individual joints.

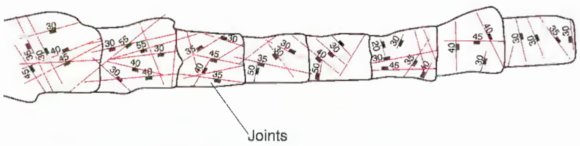


Figure 3: Generic plan view of a drive showing joint sets mapped with oriented traces on the plan

A stereonet is also commonly used to facilitate potential failure analyses. The process used to gather and represent structural data is illustrated in Figure 4. More complete discussions on structural data presentation techniques are found in Hutchinson and Diederichs (1996).

The interpretation of structural data is particularly useful for discrete investigation of potential failure mechanisms. Such investigations may lead to more detailed and accurate rock reinforcement and support designs (See Wedge Analysis Program in Section 3.2.4).

1.2 Rock Quality Designation (RQD)

There is a need to quantify the competency of rock masses as a common basis for communicating this type of information and developing rock engineering design guidelines. Rock Quality Designation, also known as RQD (Deere 1964), is one of the simplest systems to characterise the competency of rock mass (these systems are known as rock mass classification). It assigns a percentage rating to the rock mass, from 100% being the most competent, to 0% being the least competent ground condition. The interpretation of RQD value is given in Table 1.

ROCK QUALITY DESIGNATION DESCRIPTION	RQD VALUE
Very Poor	0 – 25
Poor	25 – 50
Fair	50 – 75
Good	75 – 90
Excellent	90 – 100

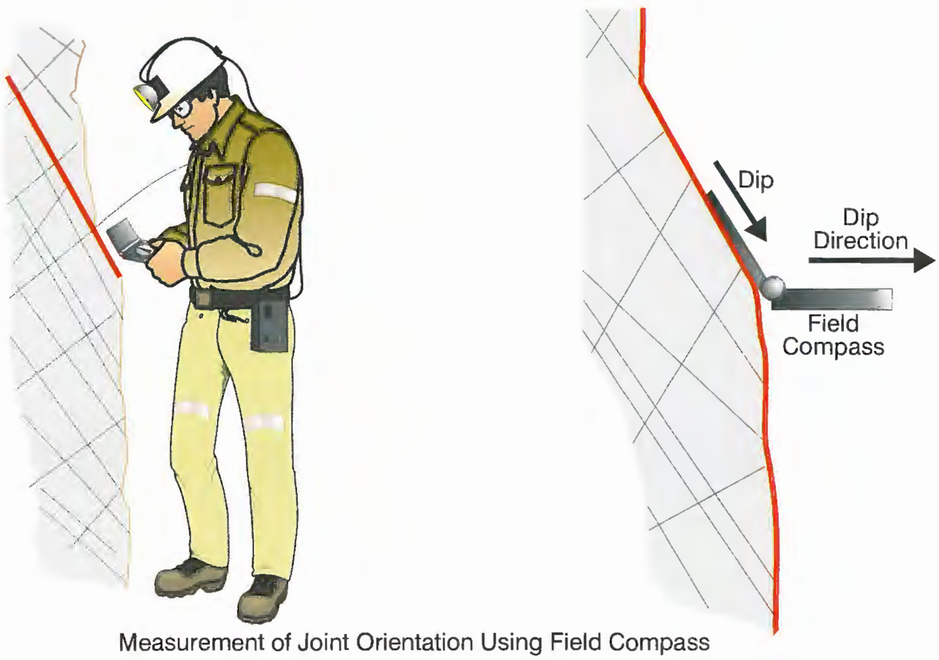
Table 1: Interpretation of RQD values (After Deere 1964)

The system relies entirely on the intensity of natural fractures present in the rock mass. As the intensity of fractures increases, the RQD rating will decrease.

Originally, RQD was developed for diamond drill core of diameter greater than, or equal to, 54 mm (Hutchinson and Diederichs 1996). However, Australian exploration drilling commonly uses smaller diameter boreholes. For example, surface delineation often drills BQ diameter holes (36.5 mm – 40.7 mm core) and when drilling long holes, NQ diameter (47.6 mm – 50.5 mm core) is often used. Although smaller diamond drill cores are more likely to suffer induced fractures from the drilling and manipulating process, Brown (1978) stated that the above core diameters are appropriate for geotechnical data collection (Villaescusa 1998).

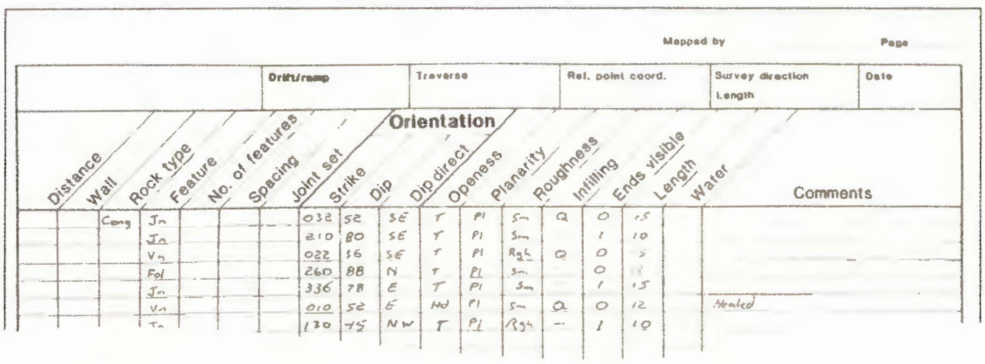
The RQD value is the ratio expressed as a percentage of the sum of all pieces of core lengths longer than 10 cm divided by the total length of core. Figure 5 illustrates the conventional method of calculating RQD.

Structural Data

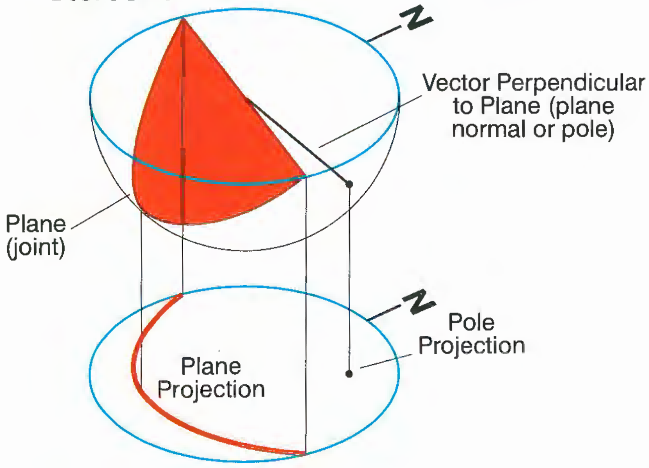


Measurement of Joint Orientation Using Field Compass

Data Sheet



Stereonet



Plot poles on stereonet

Identify pole clusters (joint sets)

Estimate or calculate representative orientations for each set

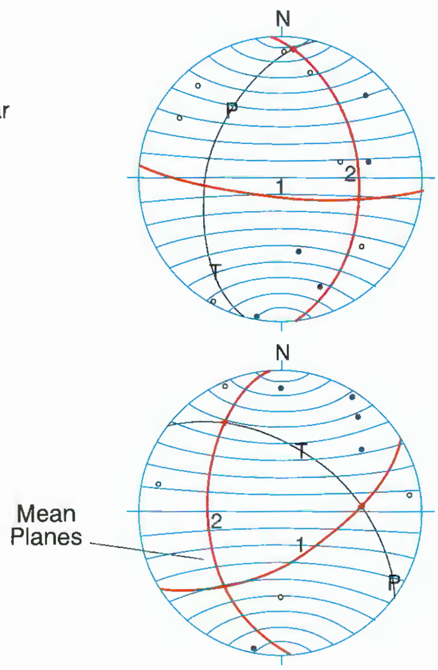


Figure 4: Illustration of the process commonly used to collect, record and present structural data (Reproduced after Hutchinson and Diederichs 1996)

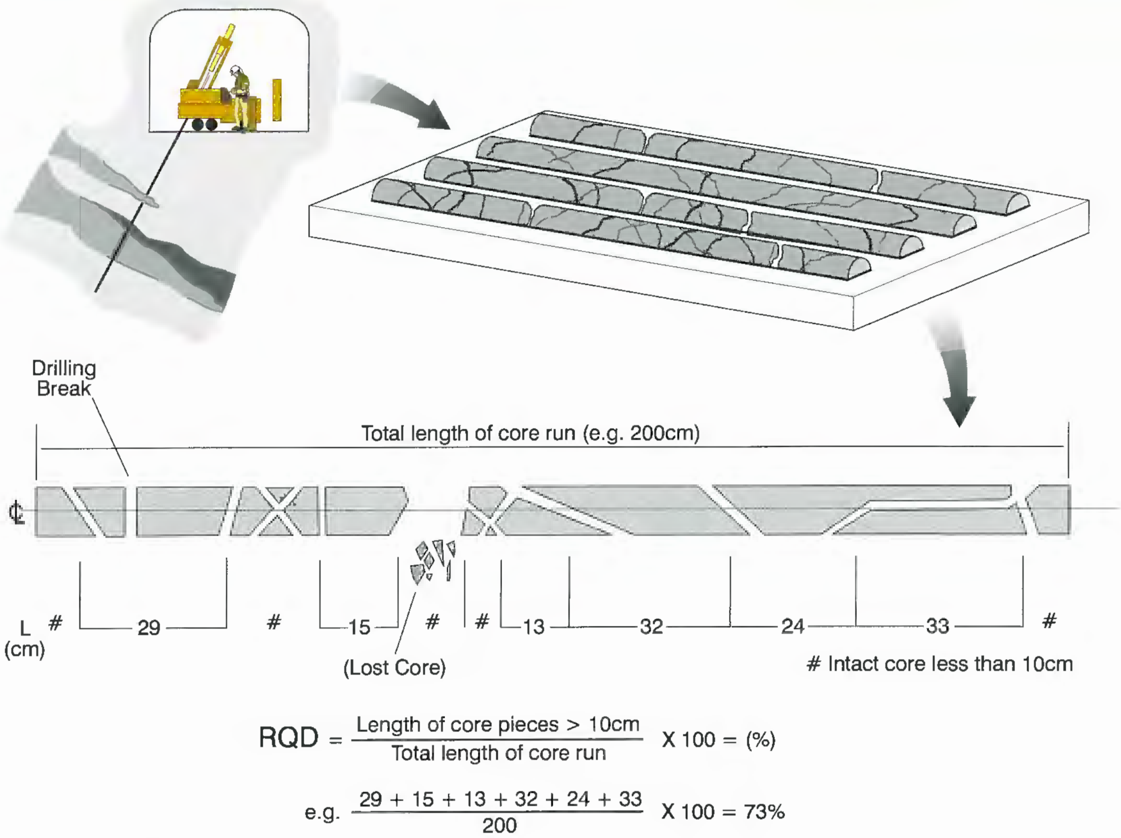


Figure 5: Illustration of the process commonly used to assess rock quality designation (RQD) values from core (Reproduced after Hutchinson and Diederichs 1996)

The typical length of core for which a RQD value is calculated, may vary typically from every metre to every 10 metres. Another approach is to use whatever lengths correspond to changes in ground conditions. Table 2 lists some practical tips to be kept in mind while measuring RQD. Table 3 (See page opposite) shows an example of a table that can be used to record geotechnical core logging data.

PRACTICAL TIPS IN THE CALCULATION OF RQD

- The unrecovered length of core must be included in total length of core
- Breaks created by handling should be ignored
- Stress induced breaks (core discing) should be ignored in the calculation
- RQD should be assessed on relatively fresh core (some core may deteriorate)
- Boreholes drilled at different bearing and dip should be considered

Table 2: Practical tips to be considered when assessing RQD from core (After Hutchinson and Diederichs 1996)

RQD should be considered as a crude and often "first pass" estimation of rock mass conditions that must be complemented with more sophisticated rock mass classification methods as required. RQD has multiple limitations, some of which are listed in Table 4.

SOME LIMITATIONS OF RQD

- Not sensitive to rock masses with joint spacing greater than 0.3 metres
- Does not account for the shear strength of joints
- Can be very sensitive to borehole orientation with regard to structures

Table 4: Incomplete list of limitations related to RQD estimation (After Hutchinson and Diederichs 1996)

Alternate methods have been proposed to calculate RQD from mapping joints in the walls of underground excavations. One of these consists of emulating the conventional RQD calculation on core, but applying it along a "scanline" or a ruler positioned against the wall of an excavation as shown in Figure 6.

Palmstrom (1982) also proposed a simple technique to estimate RQD from a modified window mapping method, counting the joints within a cubic metre of rock mass. More details on all the techniques to estimate RQD can be found in Hutchinson and Diederichs (1996).

Organisation: Project: Hole No: Page: of

Site: Inclination:

Geotechnical Borehole Log: Project No: Final Depth: Date:

Drilled by:

Drilling Interval	Recovery			RQD		Geo–technical Interval	Rock Type	Rock Competence			Weath-ering 1-5	Hard-ness 1-5	Jointing Distribution				Joint Surface Condition			
	m Drill	m Rec	% Rec	m	%			Solid m	Matrix m	Matrix Type			0°-30°	30°-60°	60°-90°	Total	Micro 1-5	Macro 1-5	Infill-ing Type	Wall Alter 1-3

MATRIX TYPE
M1 Fault
M2 Shears
M3 Intense fracturing
M4 Intense mineralisation
M5 Deformable material

WEATHERING
1. Unweathered
2. Slightly
3. Moderately
4. Highly
5. Completely

HARDNESS
1. Very soft
2. Soft
3. Hard
4. Very hard
5. Extremely hard

JOINT SURFACE

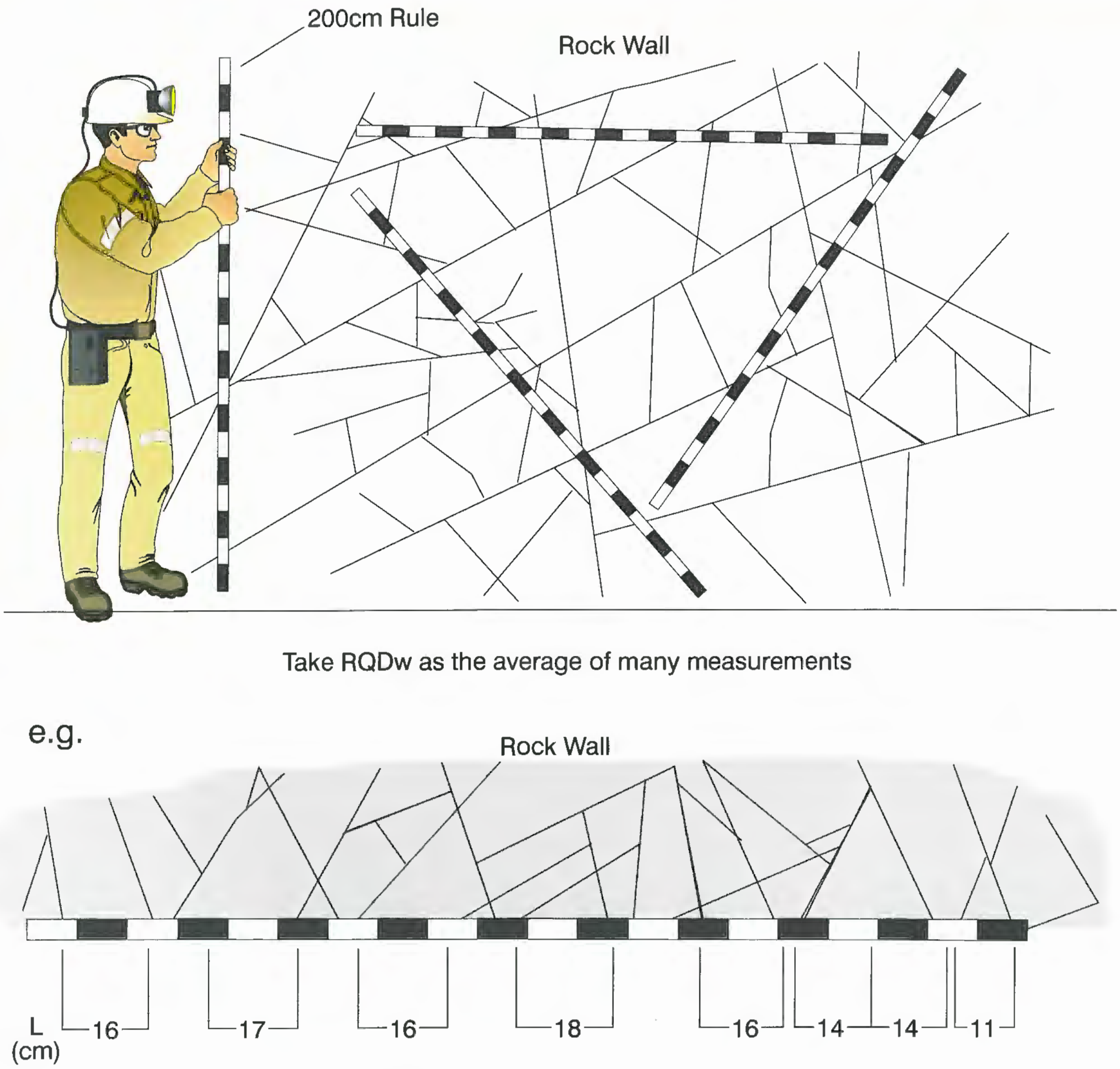
MICRO ROUGHNESS
1. Polished
2. Smooth planar
3. Rough planar
4. Slickensided undulating
5. Smooth undulating
6. Rough undulating
7. Slickensided stepped
8. Smooth stepped
9. Rough stepped / irregular

MACRO ROUGHNESS
1. Planar
2. Undulating
3. Curved
4. Irregular
5. Multi irregular

INFILLING TYPE
1. Gouge thickness > amplitude of irregularities
2. Gouge thickness < amplitude of irregularities
3. Soft sheared material – fine
4. Soft sheared material – medium
5. Soft sheared material – coarse
6. Non-softening material – medium
7. Non-softening material – coarse

JOINT WALL ALTER
1. Wall > rock hard
2. Wall > rock hard
3. Wall > rock hard

Table 3: Example of a geotechnical core logging table (After Stacey 2001)



$$RQDw = \frac{16 + 17 + 16 + 18 + 16 + 14 + 14 + 11}{200 \text{ (i.e. length of rule)}} \times 100 = 61\%$$

Figure 6: Illustration of the process commonly used to assess RQD from mapping walls of underground excavations (Reproduced after Hutchinson and Diederichs 1996)

1.2.1 DISCONTINUITY LINEAR FREQUENCY

As an alternative to RQD, the discontinuity linear frequency is also an index to estimate the intensity of jointing in a rock mass. It is simply calculated by adding the number of natural discontinuities per metre of sampling (diamond drill core or scanline on a rock face).

Villaescusa (1992) proposed the following Table 5, relating the expected ground conditions with both RQD and the discontinuity linear frequency.

ROCK QUALITY	LINEAR FREQUENCY	RQD
Very Poor	>17	0 – 20
Poor	12 – 17	20 – 40
Fair	7 – 12	40 – 60
Good	4 – 7	60 – 80
Very Good	1.5 – 4	80 – 95
Excellent	<1.5	95 – 100

Table 5: Relationship between RQD, discontinuity linear frequency and ground condition (After Villaescusa 1992)

The compilation of RQD or discontinuity linear frequency values into a model that can be electronically manipulated and displayed provides a useful design tool if there is enough information to develop a statistically reliable model. It can feed directly into more sophisticated rock mass classification systems or simply allow mine planners to identify and account for the intensity of jointing during the design process.

An example of an electronic RQD model is given in Figure 7.

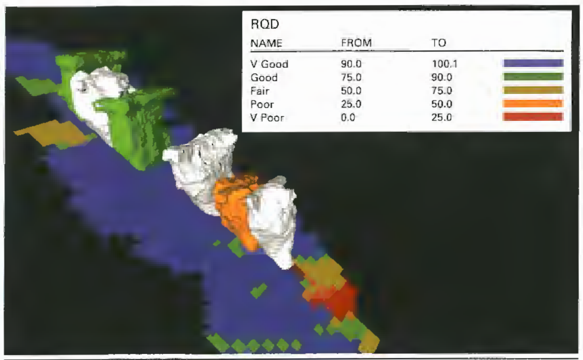


Figure 7: Example of computer generated graphics showing colour-coded RQD data, extracted from a RQD model

1.3 Rock Mass Classification

"ROCK MASS CLASSIFICATION TECHNIQUES ACCOUNT, IN A GLOBAL WAY, FOR THE COMBINED EFFECT OF GEOLOGICAL STRUCTURES CONTAINED IN THE ROCK MASS."

Rock mass classifications rely on systematic approaches to assess ground conditions for rock engineering purposes. Factors that may affect the stability or behaviour of rock masses, such as intact rock strength, joint frequency and shear strength, stress, ground water, are quantified and combined into a single number that is used as an index of rock mass quality. This index can then be related to rock engineering design parameters (excavation span, stand-up time, ground support requirement, ability to cave, slope stability, etc.).

A number of rock mass classification systems have been proposed and used, mainly for civil engineering tunnelling applications. Some of these have been adapted to mining applications over the last three decades. A more complete discussion and description of rock mass classification systems can be found in Hoek and Brown (1980), Hoek, Kaiser and Bawden (1995) and Hutchinson and Diederichs (1996). In recent years, only two rock mass classification systems (or variations of these schemes) are commonly used in Australian mines; the "Rock Mass Rating" (RMR) and the "Tunnelling Quality Index" (Q).

In essence, both systems are very similar as they rely on nearly the same parameters. The fundamental differences lie in the parameter weightings assigned within each system.

1.3.1 THE GEOMECHANICS CLASSIFICATION; "RMR" SYSTEM (BIENIAWSKI 1989; 1993)

The Geomechanics Classification System, also known as Rock Mass Rating (RMR), has an index which ranges from 0 for "very poor rock" to 100 for "very good rock" with the following intermediate classes:

DESCRIPTION	RMR	ROCK MASS CLASS
Very Good Rock	81 – 100	I
Good Rock	61 – 80	II
Fair Rock	41 – 60	III
Poor Rock	21 – 40	IV
Very Poor Rock	0 – 20	V

Table 6: Interpretation of RMR values, in terms of ground condition and rock mass classification (After Bieniawski 1989)

RMR is calculated by adding the individual ratings of the following 6 factors:

$$RMR = A1 + A2 + A3 + A4 + A5 + B$$

Where:

FACTOR	DESCRIPTION	RANGE
A1	Uniaxial Compressive Strength (UCS)	0 – 15
A2	Rock Quality Designation (RQD)	3 – 20
A3	Spacing of Discontinuities	5 – 20
A4	Condition of Discontinuities	0 – 30
A5	Groundwater	0 – 15
B	Orientation of Discontinuities	(-12) – 0

Table 7: Description and quantification of factors involved in the calculation of the RMR index

The details on how to estimate each factor are given in the above references. It is noted that the RMR does not account specifically for the number of joint sets. The greater the number of different joint set orientations that occur, the more likely blocks and wedges can be formed. The intensity of jointing (Factors A2 and A3) also accounts for a high proportion (40%) of the total weighting.

Laubscher and Taylor (1976), Laubscher (1977), and Laubscher and Page (1990), developed RMR further to create the Mining Rock Mass Rating (MRMR). The aim was to better reflect mining conditions, especially with respect to predicting geotechnical and mining parameters for sublevel and block caving methods.

The calculation of MRMR is based on adjustments to the RMR to account for the influence of mining. These adjustments are summarised in Figure 8. The estimation of adjustment parameters is subjective. Therefore, accuracy and confidence in the use of MRMR increase with experience.

1.3.2 THE NGI TUNNELLING QUALITY INDEX; "Q" SYSTEM (BARTON ET AL 1974)

The Tunnelling Quality Index (Q) developed at the Norwegian Geotechnical Institute based on extensive civil engineering tunnel case studies has a range of values varying on a logarithmic scale, from 0.001 to 1000. The rock quality assessment of the full range of Q values is given in Table 8.

DESCRIPTION	Q VALUE
Exceptionally Poor	0.001 – 0.01
Extremely Poor	0.01 – 0.1
Very Poor	0.1 – 1
Poor	1 – 4
Fair	4 – 10
Good	10 – 40
Very Good	40 – 100
Extremely Good	100 – 400
Exceptionally Good	400 – 1000

Table 8: Interpretation of Q index (After Barton 1974)

The Q index is calculated as follows:

$$Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF}$$

Where:

PARAMETER	DEFINITION
RQD	Rock Quality Designation
Jn	Joint Set Number
Jr	Joint Roughness Number
Ja	Joint Alteration Number
Jw	Joint Water Reduction Factor
SRF	Stress Reduction Factor

Table 9: Description of the six parameters involved in the calculation of the Q index (After Barton 1974)

In the Q index, the six parameters are grouped into three quotients related to the following physical characteristics of the rock mass. The first quotient *RQD/Jn* is representative of the rock mass block size, *Jr/Ja* is indicative of the shear strength and *Jw/SRF* can be regarded a "total stress" factor.

The details on how to estimate each parameter are given in Hoek and Brown (1980), Hoek, Kaiser and Bawden (1995), and Hutchinson and Diederichs (1996). It should be noted that the Tunnelling Quality Index does not directly account for the intact rock strength, that is Uniaxial Compressive Strength (UCS).

A common modification of the Tunnelling Index Q for mining applications consists of removing the effect of the stress reduction factor by equating SRF to 1. This is noted by using the sign (') and the quality index becomes Q'. This modification is justified by the fact that many empirical and numerical models using Q' as an input, already account for the effect of stress.

The confident use of rock mass classification systems, whether it is Q, Q', RMR or MRMR, requires adequate training. It is recommended that inexperienced users be supervised or, at a minimum, have their assessments verified regularly by experienced users of classification systems. The estimation of each parameter involved in the calculation of a classification index is somewhat subjective. It is often advisable to estimate a parameter by using a range of values when it cannot be precisely assessed. Table 10 is an example of a rock mass classification data logging sheet.

1.3.3 LIMITATIONS OF ROCK MASS CLASSIFICATION SYSTEMS (AFTER LANG 2003)

There needs to be recognition that rock mass classification systems have limitations. The following references are suggested reading:

> Brady, B.H.G. and Brown, E.T., 1993. 3.7.1 The nature and use of rock mass classification schemes, in *Rock Mechanics for Underground Mining*, second edition, pp 77-78 (Chapman & Hall: London).
>
> Hoek, E., Kaiser, P.K. and Bawden, W.F., 1995. 4.1 Introduction, in *Support of Underground Excavations in Hard Rock,* pp 27 (Balkema: Rotterdam).

Rock mass classification systems attempt to characterise the rock mass by determining a "numerical measure" of quality or rating for the rock mass. Such a measure is a worthwhile goal if it can be reliably and repeatedly obtained from a good understanding of the mechanics of the system. Attaining this goal may not be as simple as the rock mass classifications systems would suggest.

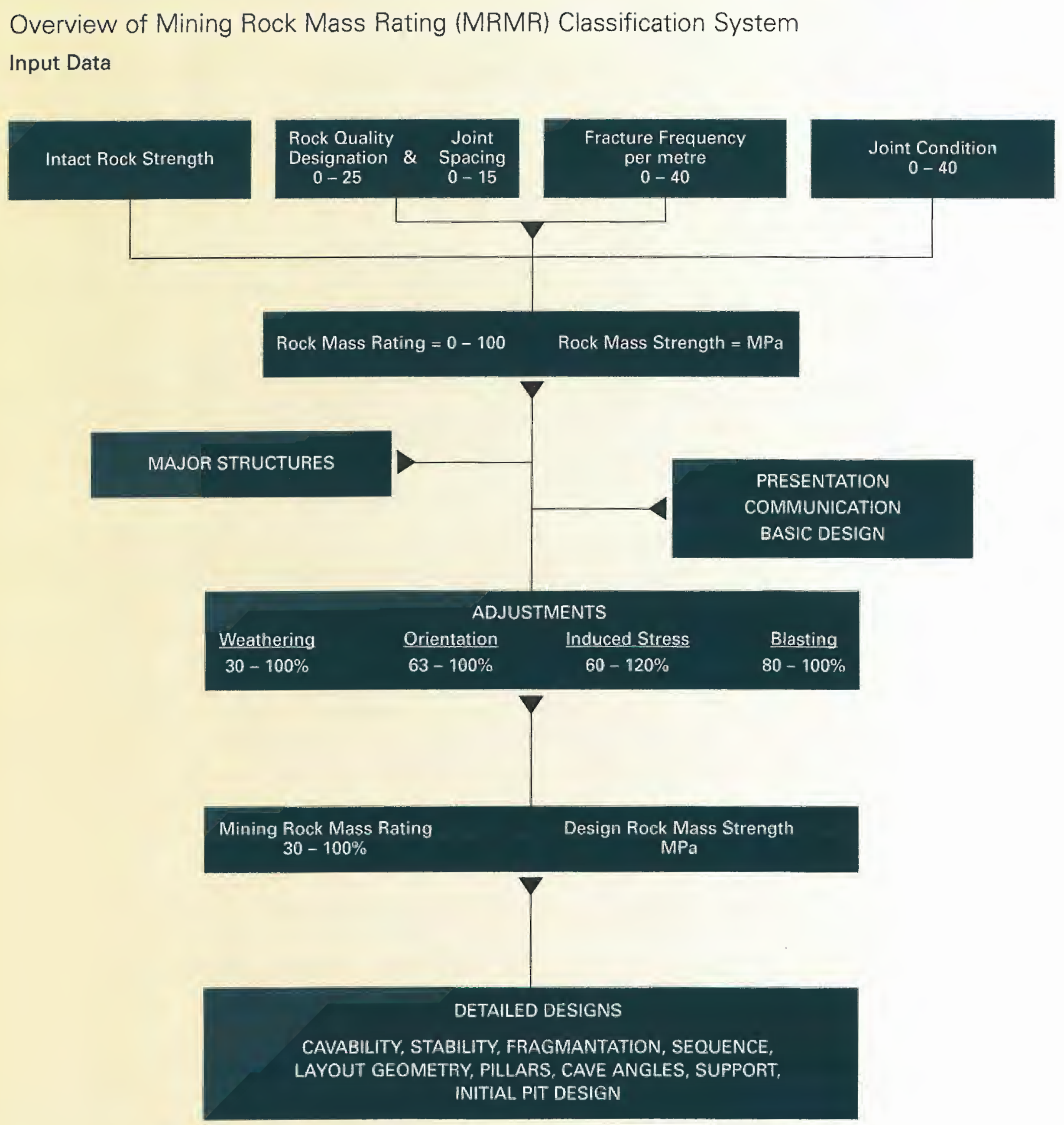


Figure 8: Description and quantification of adjustment factors for calculating the MRMR index (After Laubscher 1990)

ROCK MASS DESCRIPTION AND CLASSIFICATION SHEET		
DATE	MAPPED BY	SITE LOCATION
ROCK TYPE INTACT MATERIAL STRENGTH Soil ______ very soft rock ______ soft rock ______ hard rock ______ very hard rock ______ extremely hard ______	WEATHERING GROUND WATER BLASTING EFFECTS	CLASSIFICATIONS Q = RQD/Jn x Jr/Ja x Jw/SRF Bieniawski RMR = UCS+RQD+spacing+cond+water+orien Adjusted MRMR = (UCS+FF+cond(water)) x adj

ROCK MASS DISCONTINUITIES

Joint set Number	Type	Orientation		Joint spacing				Joint condition				Dip	Continuity	Strike	
		Dip	Dip dir	Min	Max	Average	No/m	Large	Small	Infill	Alt	Length	Ends	Length	Ends

RQD equivalent (RQD = 115 - 3.3 Jc where Jc = total number of joints/set/metre)	Jc =	COMMENTS
RELATIVE JOINTING ORIENTATIONS	N	

Table 10: Example of a table that can be used for the logging of rock mass classification data (After Stacey 2001)

Consider the behaviour of a jointed rock mass in a low to medium stress environment. The response of the rock mass will primarily be controlled by the geotechnical characteristics of the joints (planes of weakness). The complexity of the rock mass is such that a change in the dip and/or dip direction of one of the planes of weakness can completely change the rock mass' stability without any equivalent change in the rock mass classification rating. This illustrates that the sensitivity of classification systems to discrete block failure can be low.

Apparently "good" ground, as determined by one or more of the rock mass classification systems, can still contain rockfall hazards. A rockfall can occur with the intersection of three joints, whether the ground is "very good" or "very poor". The level of detail required to establish the risk of rockfall can never be determined by rock mass classification systems alone. This emphasises that none of the rock engineering methods (including rock mass classification systems) presented in this manual are to be used in isolation.

1.4 Intact Rock Properties

"ROCK MASSES ARE COMPOSED OF INTACT ROCK MATERIAL AND GEOLOGICAL STRUCTURES. ALTHOUGH ROCK MASS FAILURES ARE OFTEN CONTROLLED BY STRUCTURES, INTACT ROCK FAILURES ARE NOT UNCOMMON. THE RESPONSE OF INTACT ROCK UNDER LOADING CONDITIONS CAN PROVIDE INSIGHT INTO THE OVERALL ROCK MASS BEHAVIOUR. FOR EXAMPLE, THE COMBINATION OF STIFF ROCK AND HIGH STRESS CAN LEAD TO STRAIN BURSTING CONDITIONS. SOFT AND HIGHLY DEFORMABLE ROCK CAN LEAD TO DRIVE CLOSURE AND TIME DEPENDANT BEHAVIOUR."

Intact rock properties can be defined by a number of testing procedures, mostly performed in a laboratory and involve core samples tested under different loading conditions. Several rock properties can be derived from the analysis of load-deformation curves. A representative number of tests will be required to obtain statistically meaningful values of rock properties. The presence of weakness planes (cleavage, foliation, healed joints) within the sample can have a significant influence on the test results. The details of many intact rock-testing procedures are described in Brown (1978).

The Uniaxial Compressive Strength (UCS) is the pressure required to fail a piece of core loaded along its long axis according to a standard procedure. It is a widely used parameter in rock engineering and a parameter used in many rock mass failure criteria. The UCS is also used directly or indirectly in rock mass classification systems and within a number of empirical and analytical models.

Recording the axial deformation during the uniaxial loading of the specimen allows for the determination of the elastic modulus (E) of intact rock. The elastic modulus is the slope of the load-deformation curve taken at the linear elastic section. It is indicative of the rock material capacity to deform under load and is commonly used in a number of models, to simulate rock displacement (deformation). The Poisson's ratio can be calculated if the circumferential deformation is recorded during the test. The Poisson's ratio is defined as the ratio of the circumferential to the axial deformation of the core specimen under load. It is also used in rock displacement models. The elastic modulus and Poisson's ratio are commonly referred to as the elastic properties of intact rock.

Other intact rock properties that are not commonly used in underground rock engineering (which are not discussed in this manual) include uniaxial tensile strength, shear strength, triaxial compressive strength, stiffness and others.

1.5 Pre-Mining Stress

"THE PRE-MINING STRESS OR, MORE PRECISELY, THE GROUND PRESSURE LOCKED IN THE VOLUME OF ROCK SURROUNDING THE OREBODY BEFORE MINING ACTIVITIES ARE UNDERTAKEN, IS A SOURCE OF ENERGY THAT MAY LEAD TO ROCK MASS FAILURES. DEFINING THE PRE-MINING STRESS IS THEREFORE AN IMPORTANT PART OF ASSESSING THE HAZARD RELATED TO ROCK MASS FAILURE."

The vertical component of the pre-mining stress is related, and in most situations approximately equal to, the loading from the weight of overlying rock. In typical Australian conditions, the two horizontal stress components are often, but not always, orientated sub-parallel and sub-perpendicular to orebodies. Horizontal stresses are generally 1.5 to 3 times the magnitude of the vertical stress. The Australian high horizontal stress condition is believed to originate from tectonic sources. This differs from the typical South African stress environment for shallow dipping reefs, where the major principal stress component is near-vertical and approximates the overburden stress.

Since vertical and horizontal stresses increase in deeper strata, they are often expressed as a stress gradient with depth. For example, the vertical stress can be estimated by:

Sigma V = (Rock Density) x Gravity x Depth

And the horizontal components by:

Sigma H1 =
Constant 1 x (Rock Density) x Gravity x Depth

Sigma H2 =
Constant 2 x (Rock Density) x Gravity x Depth

The magnitude and orientation of pre-mining stress can be influenced by global, regional and local geological conditions and the geological (tectonic loading) history. Contrasts in rock mass stiffness and the presence of faults in particular can have a major effect on local stress regimes. As a result, the magnitude and orientation of stress can be highly variable, even within a mine site.

A number of techniques exist to measure in-situ stress. In Australian mines, the over-coring method using the Hollow Inclusion (HI) Cell is by far the most popular approach. The method essentially relies on bonding the HI Cell with glue to the walls of a borehole, at a distance often exceeding 15 m down the hole. A skilled technician is required for the installation of the cell and the technique remains sensitive to temperature and humidity. Description of this method and others can be found in Hoek and Brown (1980).

As most stress measurement methods are expensive and logistically challenging, the sampling is often limited to a few locations per mine, typically between 1 and 4. Sampling at different depths allows the stress gradient at the mine to be established. The sampling location, which uses an over-coring technique, is however limited to a few tens of metres from existing excavations. This is often a problem in "green-field" feasibility studies.

A research project in Western Australia has recently reported results with an alternative method to measure stress from diamond drill core, based on the analysis of acoustic emission during uniaxial compressive tests (Villaescusa et al, 2002). The technique, based on the "Kaiser effect", is less expensive and logistically more simple (no field work) than other methods and allows for remote measurements where no mine access other than diamond drill holes exist. The technique is experimental but early results are promising.

A number of authors have compiled stress measurement results and developed an empirical relationship to estimate stress regimes. Figures 9 and 10 graphically show compilations of stress measurements from around the world. World stress data (including measurements from Mount Isa and the Snowy Mountains) can also be found in Herget (1988). Figure 11 reproduced from Lee (1999) shows the trends in stress magnitudes from measurements made in the Kalgoorlie-Kambalda region.

Care must be taken when using these relationships to gain an understanding of local stress regimes because, as mentioned above, stress can be highly variable even at a mine site scale. An on-site stress measurement campaign is advisable in most situations.

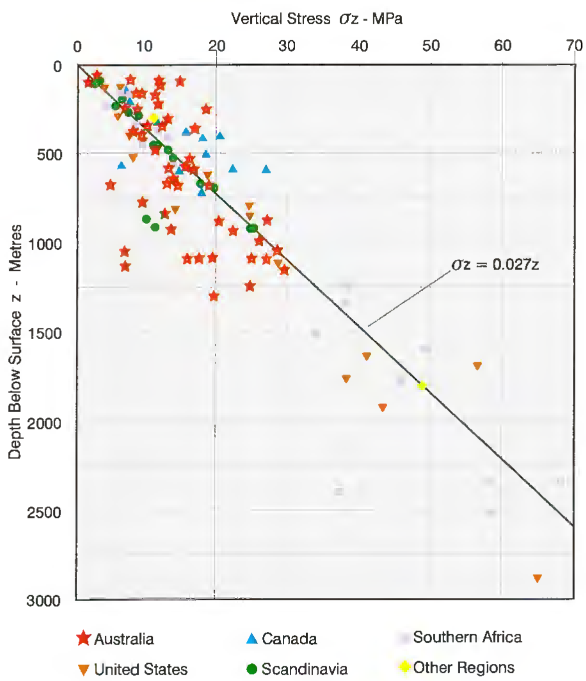


Figure 9: Compilation of vertical stress data against the depth below surface (Reproduced after Hoek and Brown 1980)

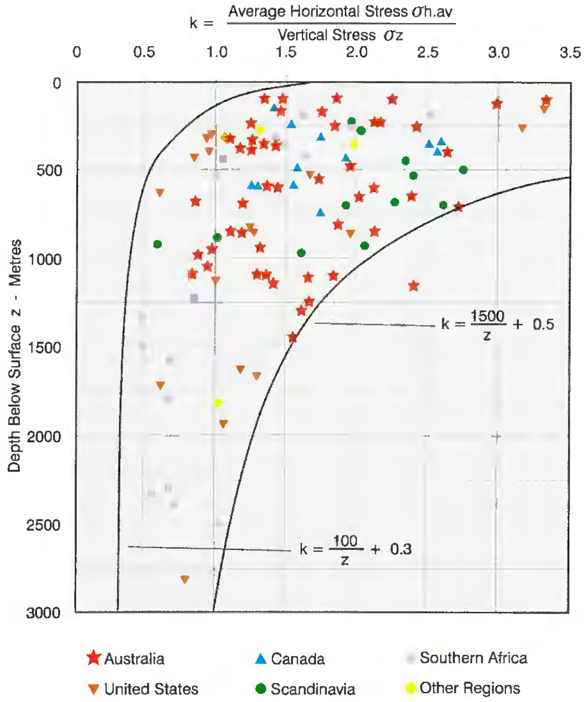


Figure 10: Compilation of average horizontal to vertical stress ratio against the depth below surface (Reproduced after Hoek and Brown 1980)

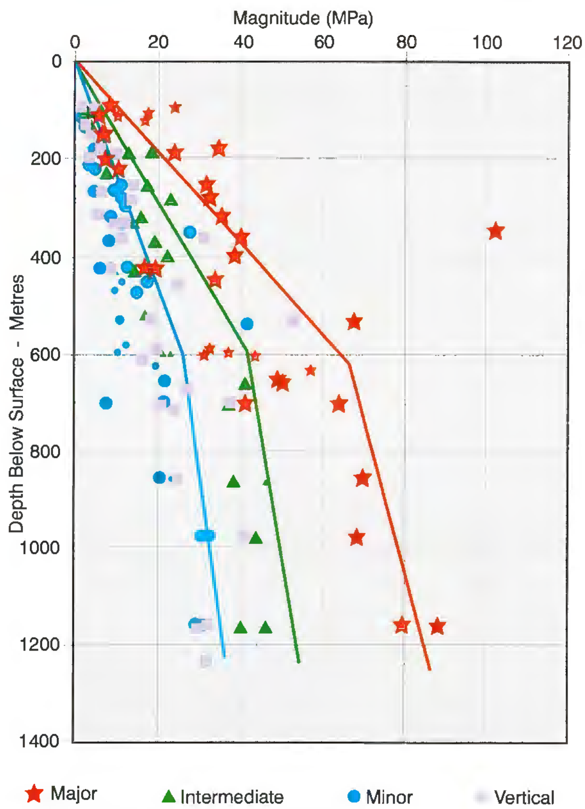
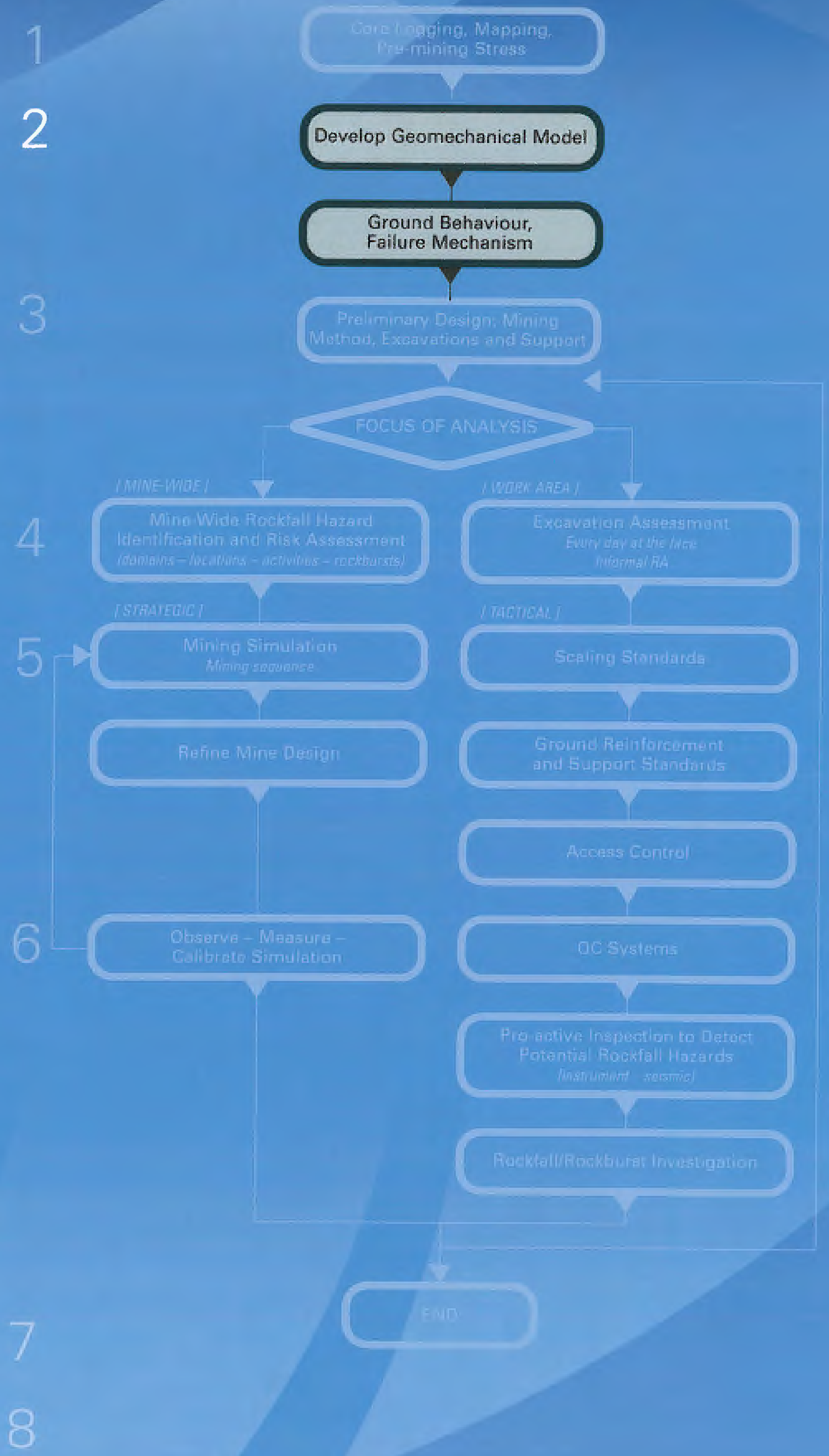


Figure 11: Compilation of stress measurement data from the Kalgoorlie-Kambalda region showing the magnitude of the principal stresses as a function of depth (Reproduced after Lee et al 1999)

2 Define Geomechanical Domains



2. DEFINITION OF GEOMECHANICAL DOMAINS

"THE OVERALL KNOWLEDGE OF GROUND CONDITIONS PREVAILING AT A MINE SITE IS BEST SUMMARISED IN A GEOMECHANICAL MODEL. RELIABLE GEOMECHANICAL MODELS ARE BASED ON THE APPLICATION OF RECOGNISED TECHNIQUES SUCH AS "RQD", "Q", RMR AND MRMR SYSTEMS TO CHARACTERISE ROCK MASSES. A SOUND UNDERSTANDING OF THE PRE-MINING STRESS REGIME IS ALSO ESSENTIAL."

2.1 Geomechanical Model

Geomechanical models facilitate data management and allow for the efficient storage, manipulation and presentation of geomechanical data. A number of mine planning and geological software packages have the functionality to integrate geomechanical models. The more advanced software will also allow "forecasting" or interpolating of rock quality values between existing data points. It is essential to have a detailed understanding of the quality and limitation of the data behind these models to ensure that interpretations made by users are valid.

Some of the main functions of geomechanical models include:

- Present an overall picture of the mine ground conditions and potential behaviour
- Define zones of elevated hazards
- Identify areas requiring further geotechnical investigation
- Basic input for future design works, including mining methods, regional support, excavation spans, reinforcement and support requirements

Geomechanical models will typically be divided into a number of domains. Within each domain, the rock will be expected to have a similar rock mass quality (Q, Q', RMR or MRMR) and exhibit similar properties and behaviour. It is common for mines to have a set of standard excavation and ground support designs for each of their geomechanical domains.

Geomechanical domains often have a strong association with the local geological setting of the mine. The ore zone and the host rock contacts may sometimes simply define domains. In more complex geological settings, rock types or major fault systems may influence local ground conditions and therefore dictate how geomechanical domains are delineated.

2.2 Ground Behaviour and Failure Mechanisms

Geomechanical domains are developed based on self-similar rock mass behaviour and potential failure mechanisms. This information needs to permeate to all personnel exposed to rockfall hazards. In particular, the underground workforce must be capable of recognising the potential failure mechanisms within each domain and how these might change over time as mining progresses.

It is good practice to summarise rock mass behaviour and potential failure mechanisms within each domain, using simple sketches and pictures. These can then be packaged into a "field manual" or a "catalogue" and be made widely available to the workforce. The pictorial series shown in Figure 12 illustrates examples of different ground behaviour, which were developed to enhance awareness of mine workers to failure mechanisms and ground control hazards.

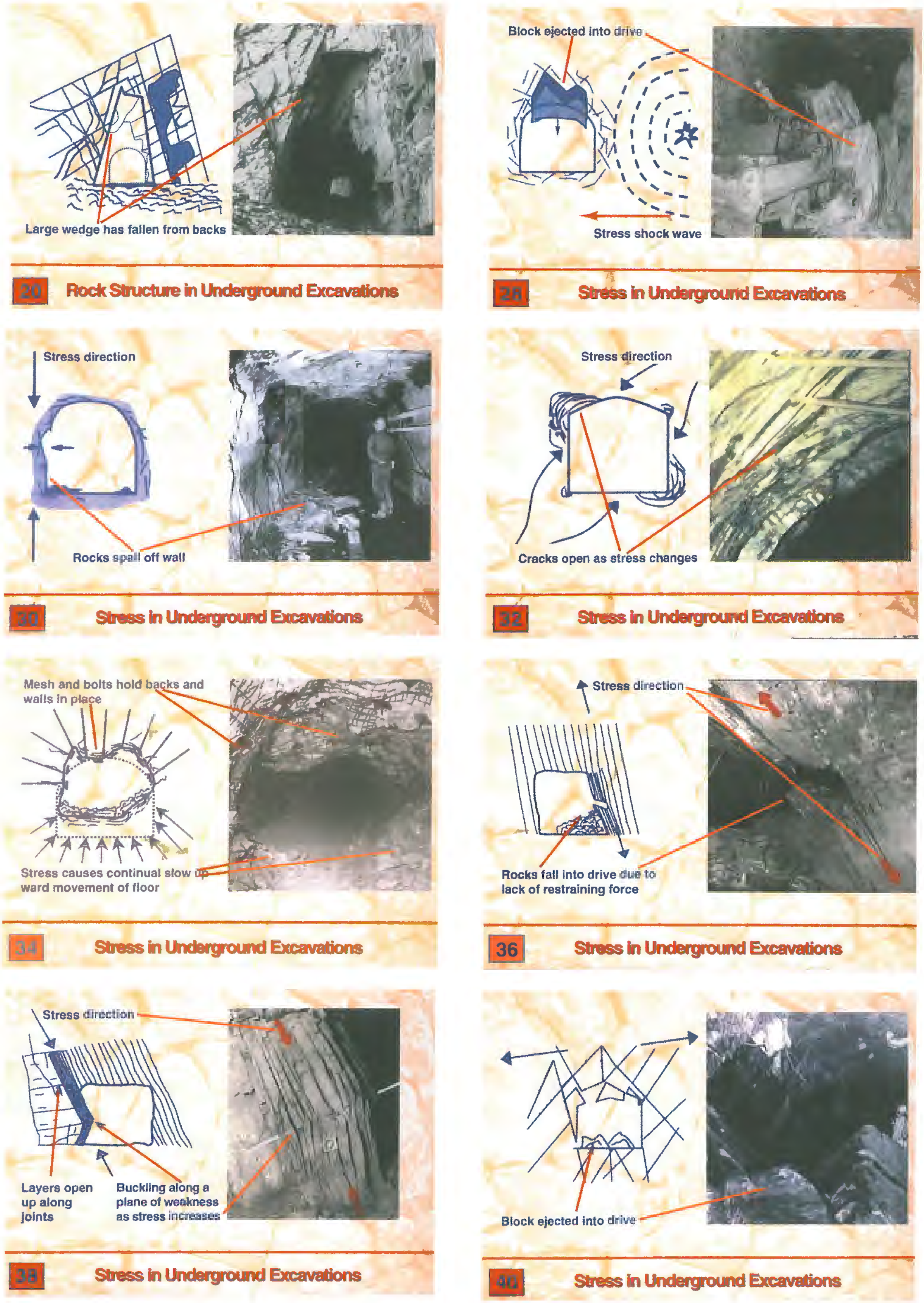
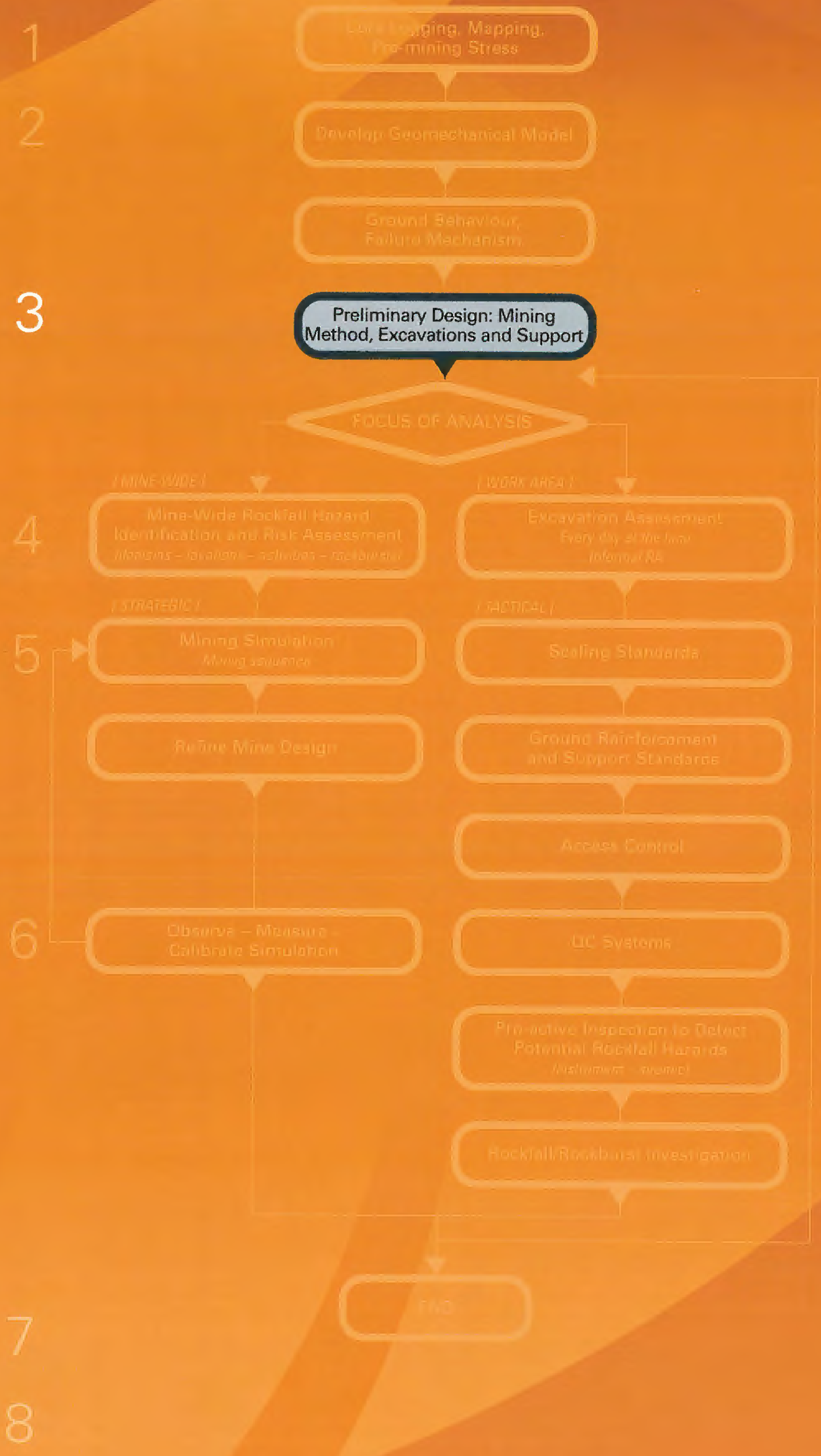


Figure 12: Example of failure mechanisms and ground behaviour illustrations to facilitate understanding and awareness of rockfall hazards (After Nedin and Potvin 2000)

3 Preliminary Design



3. PRELIMINARY DESIGN

"AT THE PRELIMINARY DESIGN STEP OF THE PROCESS, KEY MINING PARAMETERS SUCH AS MINING METHOD, FILL, EXCAVATION SIZE AND SHAPE AND GROUND CONTROL MEASURES ARE DEFINED. THIS DESIGN WORK MUST DELIVER PROFITABILITY FOR THE PROJECT AND OPERATE WITHIN THE EXISTING GEOMECHANICS CONSTRAINTS DICTATED BY IN-SITU CONDITIONS. THE QUALITY OF THE PRELIMINARY DESIGN WILL BE A FUNCTION OF THE QUALITY OF THE DATA ASSEMBLED WITHIN THE PREVIOUS STEPS AND THE APPLICATION OF GOOD AND RECOGNISED DESIGN PRACTICES. ONE OF THE AIMS OF THE PROCESS IS TO PRODUCE A PRELIMINARY DESIGN THAT MINIMISES FINANCIAL AND GEOMECHANICAL RISKS."

3.1 Mining Method Selection

In the past, mining methods were selected according to well-defined geomechanics "rules and boundaries". This had the benefit of producing minimal geomechanics hazards in a given geomechanical setting. For example, caving methods were generally applied in weak orebodies and strong host rocks. Open stoping methods operated in strong host rock while cut and fill and shrinkage methods prevailed in weak host rock and strong ore formations.

In recent years, these geomechanics "rules and boundaries" have moved further apart, opening larger windows of applicability to the lower cost mining methods. In certain situations, this may increase the inherent geomechanics hazards, which must be dealt with further down the process of the rockfall (or ground control) risk management system.

There are no reliable and accepted "recipes" for selecting mining methods. Most decisions are made based on the extensive experience of the specialists' team participating in feasibility studies. Morrison (1976), Brady and Brown (1985) and Hustrulid and Bullock (2001) provide general discussions on the topic of mining method selection. The selected mining method alone is a major influence on the nature of the rockfall hazard. Mining methods and rockfall risks are further discussed in Section 5.1.1.

3.2 Excavation Design

Underground excavations can be broadly divided into two categories. Those that allow personnel access (entry) and excavations such as open stopes that do not (non-entry). The exposure of personnel to rockfalls in entry excavations makes them higher risk locations. In non-entry excavations, rockfalls can also have severe consequences to personnel. On rare occasions and under certain circumstances, the air displacement that is associated with the sudden caving of large volume of rocks into a confined area, known as "air blast", may suddenly unleash extremely high quantities of energy. The uncontrolled propagation of instability initiated from a non-entry stope may also cause serious damage to mine infrastructure. The most common consequence associated with non-entry stope is instability. This may result in a severe financial penalty resulting from the dilution of ore grade and production delays.

Good practices in the design of both entry and non-entry excavations will contribute to reducing rockfall hazards. There are a number of commonly used and recognised approaches for designing underground excavations. As it is often difficult to disassociate the design of excavation and ground reinforcement and support, some of the methods integrate both aspects. The design approaches presented in this manual can be classified as:

- Methods based on numerical modelling (See Section 3.2.1)
- Empirical methods based on rock mass classification systems (See Section 3.2.2)
- Analytical methods (See Section 3.2.3)
- Methods based on ground support demand versus capacity (See Section 3.2.4)
- Rules of thumb (See Section 3.2.5)

The main excavation design parameters to be defined are:

- The size and ground control treatments, reinforcement and support
- The shape
- The orientation

Sections 3.2.1 to 3.2.5 concentrate on good practice methods for designing excavation size and ground control treatments under "static load" (non-rockburst case). Excavations that are likely to be subjected to dynamic loading (rockburst and seismicity) require special considerations. This is

3

discussed in Section 3.2.8. A general discussion on the shape and orientation of excavations follows in Section 3.2.9.

3.2.1 NUMERICAL MODELLING APPROACH

When an excavation advances and rock is extracted from it, the stress that was previously present in the rock mass is re-distributed around the newly created opening. Numerical models can be used to calculate the re-distributed stress component at pre-specified points, both inside the rock mass and at the boundary of excavations (See Figure 13). In this case, the different levels of a stress are calculated on a plane crossing some of the excavations and are displayed using different colours. The high stress is shown in red and grey.

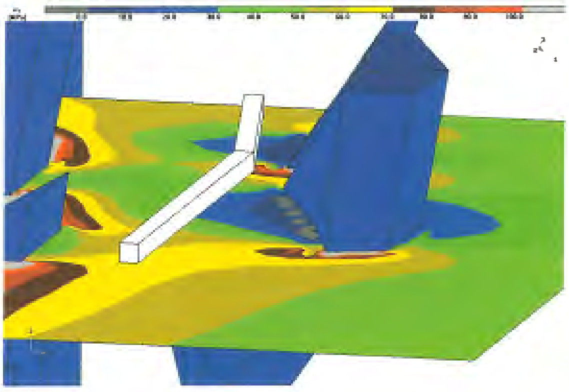


Figure 13: Example of stress distribution around underground excavations estimated from the three-dimensional boundary element analysis program (Map3D)[1]

This theoretical stress solution may then be used in different ways to predict excavation stability. For example, when modelling a mine pillar, areas where stresses are greater than one third to one half of intact rock strength, as determined by a UCS test, as discussed in Section 1.4, are often prone to stability problems. Another simplistic indicator of a potential stability problem occurs when one of the principal stress components is high and the others are low. In geomechanics terms, this is known as a high deviatoric stress condition. As the confinement stress is low, it may be insufficient to counteract the pressure imposed by the high stress component.

Rock mass failure can be assessed at each point where the model has calculated stresses, using simple rules as suggested above or more sophisticated failure criterion. The locations where the calculated stress exceeds the rock mass strength according to failure criterion can be outlined as "computer generated" zones of failure, as shown in Figure 14. Failure criteria commonly used include the Mohr-Coulomb and the Hoek-Brown criterion. A detailed discussion on failure criterion is beyond the scope of this manual, and can be found in several rock mechanics texts.

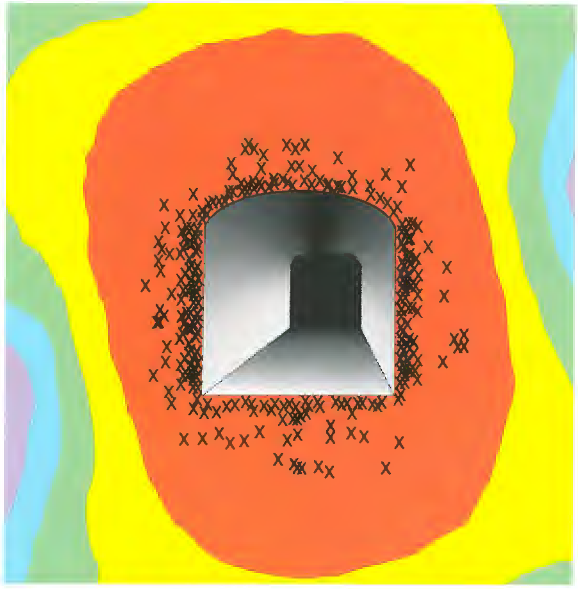


Figure 14: Example of a computer generated zone of failure where the stress estimated by a numerical model exceeds the strength of the rock mass, according to failure criteria. The failed points are shown on the figure by a "x" symbol (Modified after Hoek, Kaiser and Bawden 1995)

Whatever criteria is found to work best in a particular environment, the following considerations should be considered when using numerical modelling:

- The damage criteria should be related to the mechanical damage process. For example, major principal stress versus UCS should have a better correlation where structures are not prominent. Conversely, this criteria is unlikely to correlate with the performance of a highly stressed excavation subjected to shearing displacements on a major structure
- The modelling should be calibrated by a number of observations
- Until adequate calibration is achieved, extreme caution should be exercised when interpreting the results
- The applications and the assessment of the model performance and its value as a tool for risk management (for example) must be kept in the perspective of model limitations. Some stress related fall of ground hazards are unlikely to be perfectly predicted by criteria developed for interpreting pillar performance, shear slip, etc.

[1] *Mine Modelling Pty Ltd*

Another important aspect of interpreting rockfall risks in underground mines is the evolution of hazards as mining progresses. For example, consider a drive adjacent to a stope to be mined. The level of stress surrounding the drive at a certain point will generally increase as production proceeds and the stope void grows closer, but parallel, to the drive. At that point, the rockfall hazard will be driven by elevated compressive stress, crushing, shearing, possibly rockburst. When the stope void, which is parallel to the drive, progresses beyond the drive, the stress at that point will be shadowed by the stope void and therefore will drop to a very low level in at least one direction. The rockfall hazard at the point of interest in the drive will no longer be driven by elevated compressive stress but instead, will now be related to loosening or gravity falls due to the newly created low stress environment. Certain drives can be submitted to cycles of high and low stress conditions. Numerical modelling can assist in understanding the evolution of hazards in drives by looking at stress conditions as a mine evolves.

One of the primary uses of numerical models in mines is to evaluate the stress effect from mining stopes (extraction sequence) not only based on stope stability, but with respect to the entire mine infrastructure. Stope size and shape can be optimised in terms of stability, producing minimum zones of computer generated failure, by trial and error modelling.

Contrary to tunnelling applications in civil engineering, typically dealing with a small number of excavations, where numerical models are recognised design tools, these models are not particularly well suited to the design of mine access ways, such as drives, cross cuts, declines, etc. This is because underground mines often have complex networks of access ways that can be very small compared to stope dimensions. Since large stopes have a much greater effect on re-distributing stresses than small access ways, most numerical model geometry developed for mine sites simply ignores the access ways and only includes the stopes.

Nevertheless, insight on the stability of mine access ways can still be gained from modelling stopes alone. Areas of high stress, high deviatoric stress and/or computer generated zones of failure that are predicted by the model and coincide with the location of access ways, can be identified. Although the access ways are not included in the model, their location compared to stopes are known. Pro-active ground control measures can then be undertaken before stress changes occur. Equally, areas of low stress or "stress shadowing" can be determined. Stress reduction from pre-mining conditions can contribute to instability by removing some of the clamping pressure, or confinement, originally present in the rock mass.

Algorithms exist to simulate the effect of ground reinforcement within numerical models but are not widely used in mining applications. Rules of thumb, wedge analyses and empirical methods are more commonly used to design ground control measures. These approaches are discussed in the following sections.

Experience and caution are required when interpreting the results from numerical models. Rock masses are very complex materials. Since most models cannot precisely replicate the mechanisms involved in rock mass failure, it is good practice to perform extensive calibration of modelled (computer generated) failure. This should be completed using underground observations and/or measurements where possible. This calibration process is discussed further in Section 5.1.6.

Numerical models are particularly useful for comparing different stope sequence scenarios. The inadequacies of models to simulate rock mass behaviour and failure mechanisms with precision are not essential in comparative studies as the rock mass remains the same from one scenario to the other.

More details on numerical modelling can be found at: http://www.rocscience.com/roc/Hoek/Hoeknotes2000.htm

3.2.2 EMPIRICAL APPROACH

Empirical methods compile experiences in a systematic way based on a large number of case studies. This can be used for predicting an outcome, e.g. excavation stability, using direct comparison with case studies involving similar conditions such as similar excavation size and rock quality.

Generally, in a given geomechanical setting, the larger an excavation and the more geological structures and weakness planes are exposed, the more intense the ground control treatment that will be required.

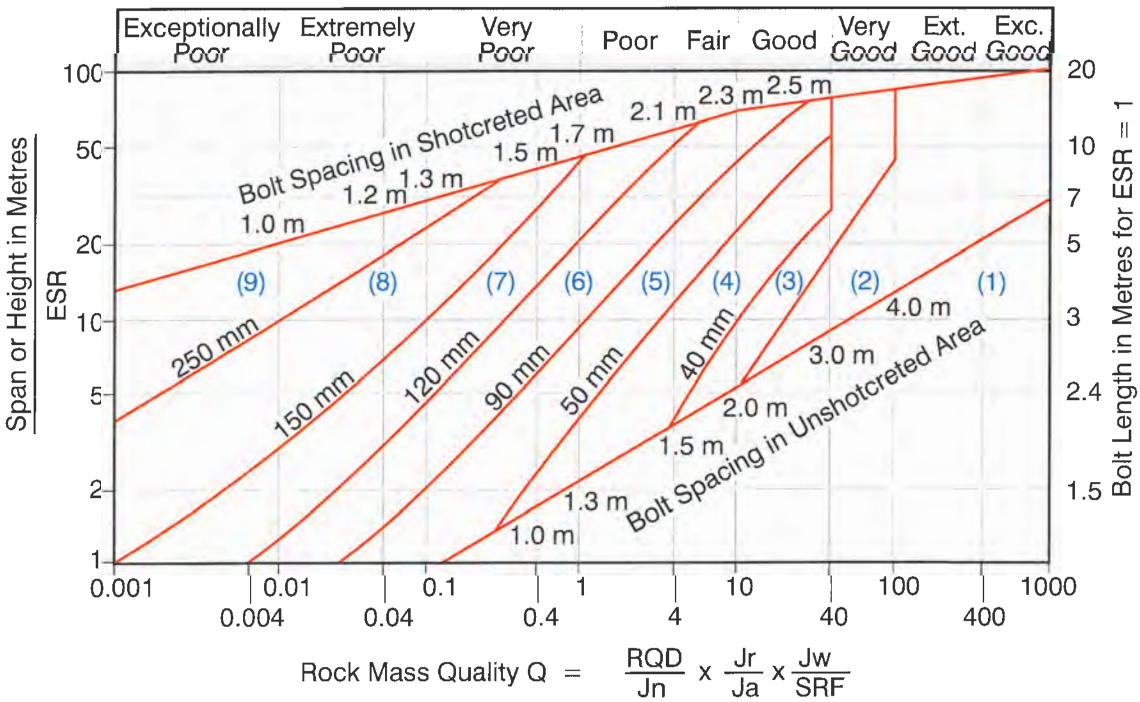
3.2.2.1 Access ways (entry excavations)

The size, height and span, of most mine access ways such as drives, declines, cross-cuts etc., is generally set to safely accommodate the size of mine equipment and associated services, such as pipes, ventilation duct, etc., needed to achieve a target production. In the case of mine access ways, the geomechanics design focuses largely on determining ground control treatments required to ensure a low probability of failure for a pre-set excavation span, considering the expected ground conditions in which they will be driven.

It must be recognised that ground conditions can have a significant influence on excavation stability. The proposed size, location, shape and orientation of development excavations must take appropriate account of ground conditions and their potential variations with time. For example, the location of main access development too close to future stoping areas can have a significant adverse influence on access stability. The long-term use of main access development can be seriously compromised by inappropriate location. This could occur where excavations are too close to stopes, pillars or geological structures.

Intersections, or areas where two or more drives connect, may require special consideration and specific ground control measures. Larger spans are exposed in intersections which can allow large wedges to daylight. Some mines require that all intersections be systematically cable-bolted either during, or immediately after being mined.

Figure 15 shows an empirical graph for excavation design relating the Tunnelling Index "Q" to an equivalent dimension De. De is defined as the span of the excavation divided by the Excavation Support Ratio (ESR). The ESR simply modifies the span to account for different type of excavations, applying more conservatism to situations involving higher consequences of failure. The ESR number for temporary mine openings is between 3 and 5 while for permanent mine openings an ESR of 1.6 – 2.0 is recommended.



Reinforcement Categories

(1) Unsupported
(2) Spot Bolting
(3) Systematic Bolting
(4) Systematic Bolting with 40-100 mm Unreinforced Shotcrete
(5) Fibre Reinforced Shotcrete, 50-90 mm and Bolting
(6) Fibre Reinforced Shotcrete, 90-120 mm, and Bolting
(7) Fibre Reinforced Shotcrete, 120-150 mm, and Bolting
(8) Fibre Reinforced Shotcrete, > 150 mm, with Reinforced Ribs of Shotcrete and Bolting
(9) Cast Concrete Lining

Figure 15: Graphs delineating regions of recommended ground support and reinforcement according to the span and the rock mass quality under Q (Reproduced after Grimstad and Barton 1993)

The graph is sub divided into nine regions corresponding to different ground control regimes. Although this method attempts to account for a variety of civil, mining and nuclear storage applications using the ESR factor, the ground reinforcement and support guidelines are not necessarily well suited to Australian mining applications and should be viewed as an initial guide only. For example, the only surface support recommended is fibre-reinforced shotcrete whilst in reality, mesh is the most popular surface support treatment used in mines. Furthermore, region 1 of the graph recommends no ground support or reinforcement. This is no longer an acceptable practice for access ways in Australian mines.

The other widely used classification system, Rock Mass Rating (RMR) also offers guidelines for ground support but is only applicable to 10 m wide horseshoe-shaped tunnels. This is therefore not applicable to most mining access ways or stopes.

Laubscher (1990) proposed empirical guidelines for ground reinforcement and support based on the MRMR classification and on mining experience in Southern Africa. Although more relevant than the previous empirical guidelines based on Q and RMR, users must bear in mind the differences in ground support practices between Australia and the African region before following the guideline. The MRMR guideline for ground support commonly used in access ways of caving mines is summarised in Table 11.

3.2.2.2 Non-entry stopes

The size of non-entry stopes, when designed empirically, is expressed using the term hydraulic radius. Tunnels typically have an elongated shape and their width or span is generally sufficient to describe their size. Stopes can take various shapes and if a single parameter is to describe their dimensions, it must account not only for the size, but also for the shape of the excavation.

The hydraulic radius of a stope surface, for the hangingwall or the backs, is calculated by dividing the area by the perimeter of the stope surface.

Hydraulic Radius = Area / Perimeter

The concept of hydraulic radius is illustrated in Figure 16.

Laubscher (1976) proposed an empirical method for designing the hydraulic radius of block caving undercuts, based on the MRMR system. Figure 17 shows Laubscher's empirical graph identifying some data points from block caving mines.

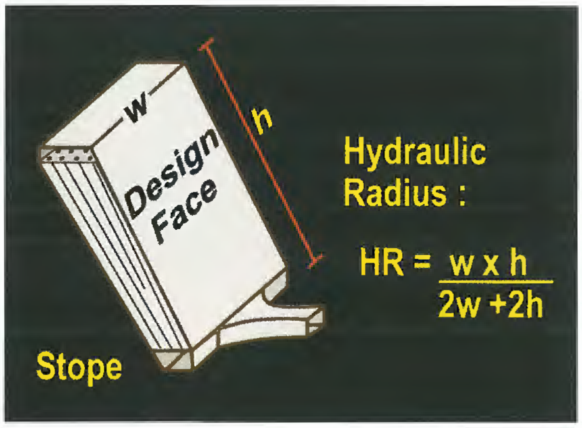


Figure 16: Illustration of the concept of hydraulic radius applied to the hangingwall of a stope

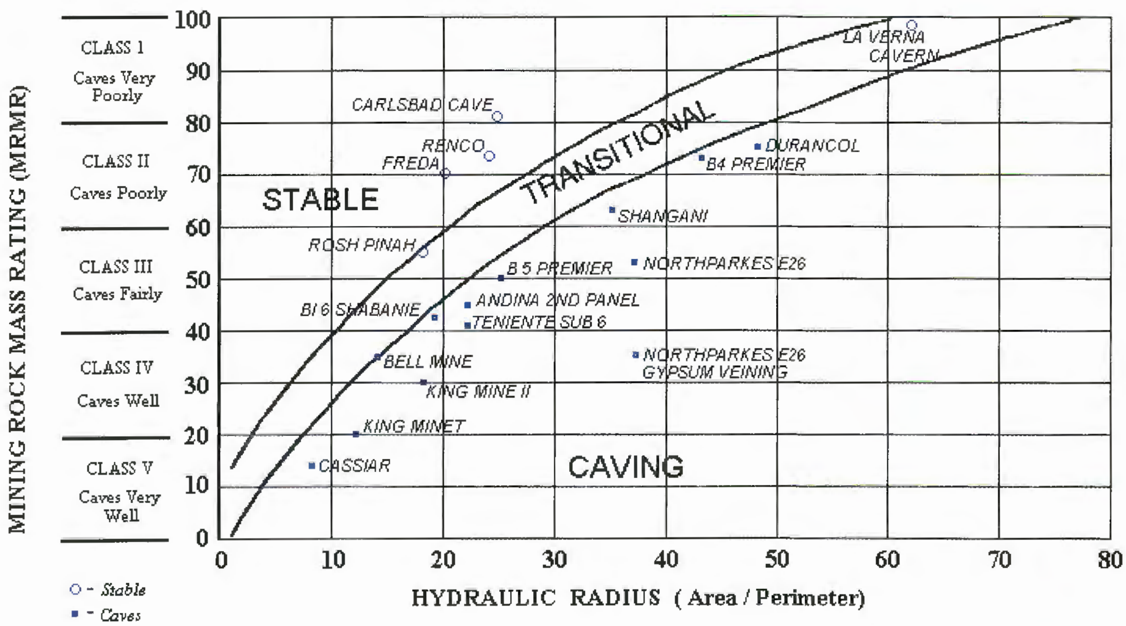


Figure 17: Empirical graphs relating to the Mining Rock Mass Rating (MRMR) to the hydraulic radius for the design of block caving undercuts (Reproduced after Laubscher 1990)

SUPPORT* PRESSURE FOR DECREASING MRMR

	RMR									
MRMR	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
	← Rock reinforcement – plastic deformation →									
1A										
1B										
2A										
2B	a	a								
3A	b	b	a	a						
3B	b	b	b	b	b	c				
4A	r	r	c	c	c	d	d			
4B				d	e	f	f	c+1		
5A						f/p	h+f/p	h+f/1	h+f/1	
5B							h+f/p	f/p	t	t

* The codes for the various support techniques are given below.

SUPPORT TECHNIQUES

Rock reinforcement

a	Local bolting at joint intersection
b	Bolts at 1 m spacing
c	b and straps and mesh if rock is finely joined
d	b and mesh / steel-fibre reinforced shotcrete bolts as lateral restraint
e	d and straps in contact with or shotcreted in
f	e and cable bolts as reinforcing and lateral restraint
g	f and pinning
h	Spilling
i	Grouting

RIGID LINING

j	Timber	Low deformation
k	Rigid steel sets	Low deformation
l	Massive concrete	Low deformation
m	k and concrete	Low deformation
n	Structurally reinforced concrete	

YIELDING LINING, REPAIR TECHNIQUE, HIGH DEFORMATION

o	Yielding steel arches
p	Yielding steel arches set in concrete or shotcrete

FILL

q	Fill

SPALLING CONTROL

r	Bolts and rope-laced mesh

ROCK REPLACEMENT

s	Rock replaced by stronger material
t	Development avoided if possible

Table 11: Support and reinforcement recommendation based on MRMR index (Reproduced after Laubscher 1990)

A similar empirical approach was developed for open stope surfaces design by Mathews et al (1981), later modified by Potvin (1988), by Nickson (1992), and by a number of other authors. This empirical method modifies the Q′ index to better reflect factors affecting the stability of open stopes, including stress induced by mining (Factor A), joint orientation (Factor B) and the inclination of the stope surface (Factor C). A stability number "N" is calculated for each stope surface by combining Q′ with factors A, B and C. A high stability number reflects a very stable surface and allows for large hydraulic radii. A number of empirical relationships, called the stability graph, between hydraulic radius and the stability number "N" have seen ongoing development since the early 1980s. The version developed by Nickson is shown in Figure 18.

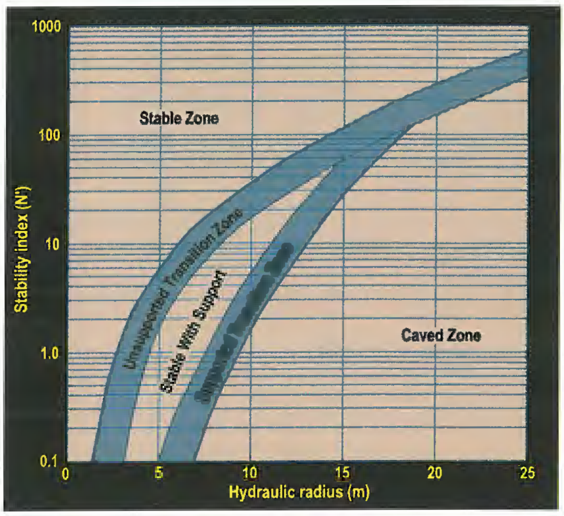


Figure 18: Stability graph for open stope design (After Nickson 1992)

Cable bolt reinforcement is commonly used to provide stability for larger, stable stopes for a specific set of ground conditions. This is reflected in most stability graphs by a zone illustrating "stable with support". When a "non-entry" stope design plots in this zone, it suggests that reinforcement in the form of cable bolts will be required to stabilise the designed stope surface. Potvin (1988) proposed empirical relationships to assist in selecting adequate patterns of cable bolts (Figure 19).

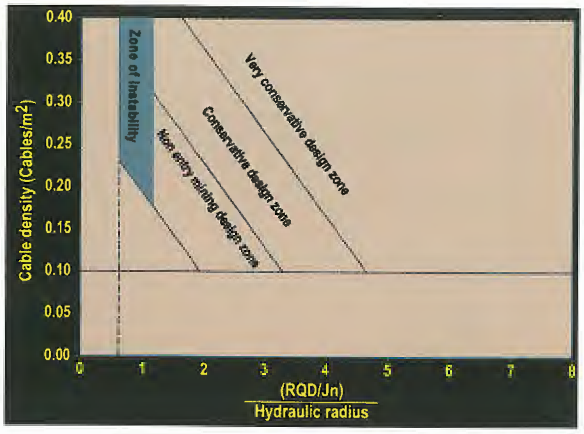


Figure 19: Cable bolt density design chart for non-entry excavations (After Potvin 1988)

Further information on the application of empirical non-entry stope and reinforcement design techniques can be found in Hoek, Kaiser and Bawden (1995), and Hutchinson and Diederichs (1996).

3.2.3 ANALYTICAL METHODS

3.2.3.1 Voussoir arch

Voussoir arch theory has been applied to excavation surfaces parallel to laminated rock mass, where no transecting joints are effecting the stability of the designed surface.

This method is "borrowed" from civil engineering for the design of mortar beams and plates. The main variables are the span and dip of the stope surface (plate), the thickness of the plate (lamination spacing) and the elastic properties of the intact rock.

Design charts have been produced for various plate geometries and can be found in Hutchinson and Diederichs (1996). Caution is required when using this method, as it has numerous assumptions, one of which is that no other transecting joints will affect the stability of the beam or plate. Furthermore, the method is highly sensitive to the value of elastic modulus and thickness of the beam/plate. As a result, the Voussoir arch is not a very commonly used tool for designing mine excavations.

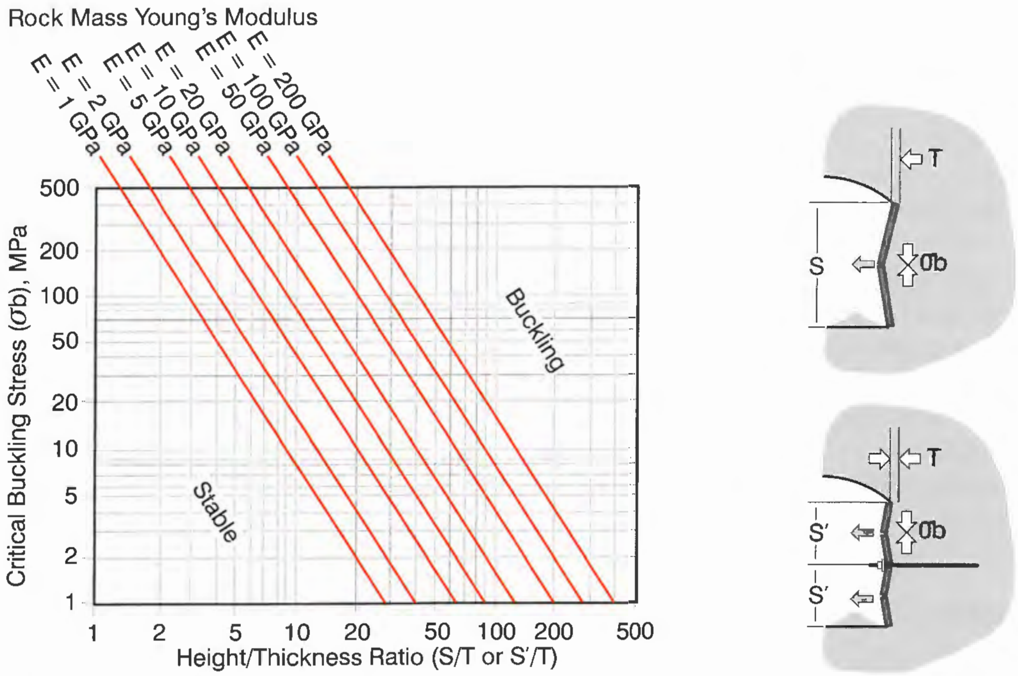


Figure 20: Design chart for buckling analysis (Reproduced after Hutchinson and Diederichs 1996)

3.2.3.2 Buckling analysis (under stress)

This analysis is used where a layered rock mass is subjected to pressure acting parallel to the foliation. The mechanism of failure involves separation of the layers followed by the deflection and collapse, or buckling, of the layer (slab) of rock exposed to the void (See Figure 20). The geometry (thickness of layers and exposed span), the elastic properties of the slab and the pressure acting parallel to the layers are combined into a stability chart. The bolting is accounted for by simply reducing the slab span (S to S' on the right hand side of Figure 20). The critical stress level required to produce buckling of the excavation surface is estimated using the chart above and can be compared to the anticipated stress induced by mining.

3.2.4 APPROACH BASED ON GROUND SUPPORT DEMAND VERSUS CAPACITY

The design approaches described in this section relate to ground reinforcement in mine access ways where the span is pre-determined by production requirements. These approaches share the common basis of defining a potential failure mechanism and calculating the demand on the reinforcement elements to stabilise the potential failure. By comparing the total demand and the capacity of each reinforcement element (rockbolt), the number of elements required to stabilise the potential failure is calculated. Caution is recommended when applying these techniques to ensure that the effect of the anchoring mechanism and the resultant bond strength achieved is fully understood. In addition, the potential influence of stress, whether stabilising or de-stabilising, may not be appropriately accounted for in these methods.

3.2.4.1 Wedge analysis

In theory, at least three intersecting joint sets are required to form a wedge in an excavation. In practice, joint sets may combine with stress-induced fractures to form unstable blocks. A wedge failure can occur if a wedge "daylights" in any of the excavation surfaces (base of the exposed wedge). Potential wedge failure will therefore be a function not only of local structures, but also dependant on how they interact with the geometry and orientation of excavations. Wedges can either slide from a sidewall or free fall under their own gravity from the backs or hangingwall.

Potential wedge failure mechanisms can be identified at a specific location, by structural mapping underground and stereonet analyses as shown in Figure 21.

In such cases, a custom design can be performed to support this potential wedge at the specific location. Wedge analysis can also be performed in a more generic application using any combination of common joint sets present in the mine, evaluating how they could interact with different excavation orientations and dimensions. Generic support patterns can then be designed based on the demand-capacity principle, catering for the largest possible wedge in each excavation and a safety factor to account for errors or installation deficiencies.

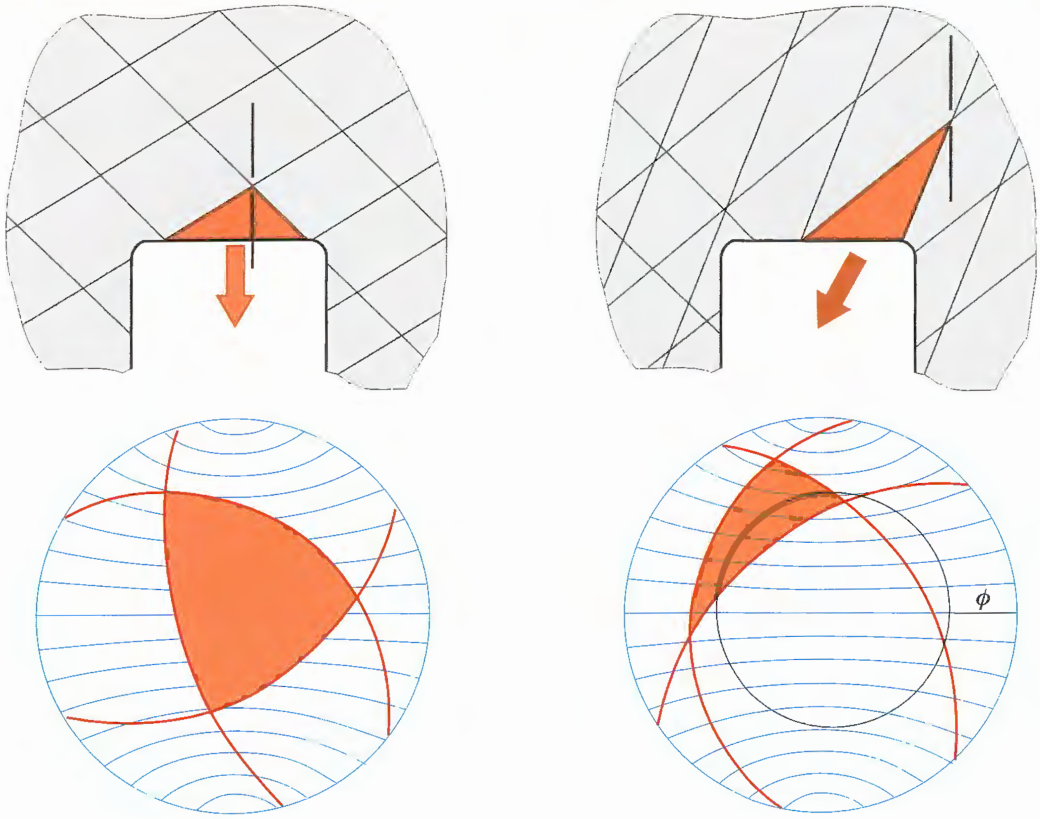


Figure 21: Illustration of single kinematic wedge analysis using stereonet analyses (Reproduced after Hoek and Brown 1980)

More sophisticated computer programs are available to analyse the reinforcement requirements of potential wedge failure. These software packages also offer excellent visualisation tools as shown in Figure 22.

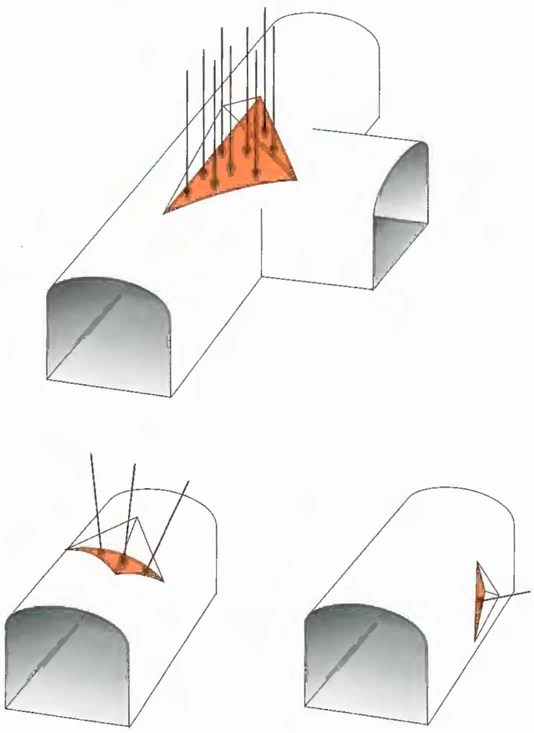


Figure 22: Three-dimensional visualisation of wedges in the back and walls of excavation showing appropriate reinforcement (Reproduced after Hutchinson and Diederichs 1996)

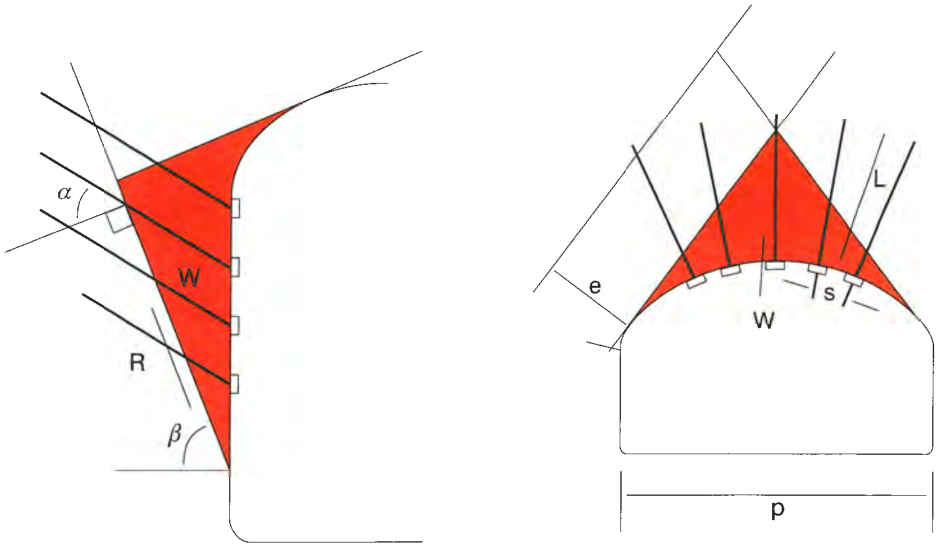
Simple demand-capacity formulae are provided for both sliding and falling wedge analyses in Figure 23.

3.2.4.2 Beam suspension for horizontally layered rock (After Stillborg 1994)

This stabilisation technique assumes that horizontally layered rocks are tied together by the reinforcement and anchored (suspended) to the more competent layers, further up above the backs of an excavation. The beam suspension method and the relevant formulae to estimate the support system are shown in Figure 24. This method may be particularly sensitive to the anchoring mechanism of the support element used and specifically to the bond strength achieved if friction or fully grouted reinforcement is used.

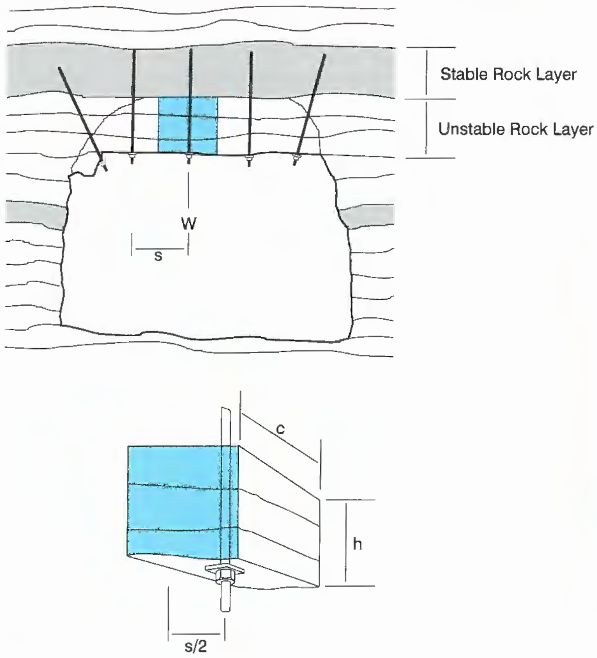
3.2.4.3 The compressive arch method (After Stillborg 1994)

Rock mass has the natural tendency to stabilise itself, taking the shape of an arch. Inside the arch, the rock mass is under compression. The role of the rock reinforcement in this case is to maintain the arch by ensuring that key blocks are not lost. The formulae are therefore developed as a function of the excavation span and joint spacing (See Figure 25).



Reinforcement of a Block Free to Slide Under its Own Weight	Reinforcement of a Block Free to Fall Under its Own Weight
$N = \frac{W(f \sin\beta - \cos\beta \tan\phi) - cA}{B(\cos\alpha \tan\phi + f \sin\alpha)}$ $R = cA + W \cos\beta \tan\phi$	$N = \frac{Wf}{B}$ $s \leq 3e$ $p \geq L + 1.0m$
Where: N is the number of rockbolts R is the resistance to sliding W is the weight of the block f is a safety factor $1.5 \leq f < 3.0$ β is the dip of the sliding surface ϕ is the angle of friction of the sliding surface c is the cohesive strength of the sliding surface A is the base area of the sliding surface B is the load capacity of the bolt α is the angle between the plunge of the bolt and the normal to the sliding surface	Where: N is the number of rockbolts W is the weight of the block f is a safety factor $2 \leq f < 5$ B is the load capacity of the bolt s is the spacing between rockbolts e is the joint spacing p is the excavation span L is the length of rockbolts

Figure 23: Wedge reinforcement in the sidewall and in the back of an underground excavation (Modified after Stillborg 1994, and Choquet and Hadjigeorgiou 1993)



$W = f \times s \times c \times h \times p$	$L > h + 0.75$ m $L - h \geq W/A$

Where:

W is the weight of the block (t)

f is the factor of safety

s is the bolt spacing, in the direction perpendicular to the axis of the excavation (m)

c is the bolt spacing, in the direction along the axis of the drive (m)

h is the thickness of unstable layer of rock (m)

p is the rock density (t/m3)

L is the bolt length (m)

A is the anchoring or bond capacity (t/m)

Figure 24: Reinforcement of a suspension beam in the back of an excavation for horizontally layered rock (Modified after Stillborg 1994, and Charette and Hadjigeorgiou 1995)

3.2.5 RULES OF THUMB FOR EXCAVATION BOLTING PATTERN DESIGN

A number of rules of thumb have been proposed to determine rockbolt patterns for use in civil engineering, tunnelling or mining excavations underground. As these formulae are purely based on empiricism, it is important to understand their origin and limitations.

The following rules of thumb published by Laubscher (1984) are believed to be used frequently as a starting point for reinforcement design in Australian mines. As a result, many drives are approximately 5 m wide and use 2.5 m bolt lengths. The bolt spacing is commonly around 1.2 m.

Minimal bolt length:

- Half of the excavation span
- Double the bolt spacing
- Three times the critical block size
- For spans 18 m to 30 m, bolt length should be one quarter of the roof span

Bolt spacing:

- Half the bolt length
- One and a half times the critical block size

Table 12: Rules of thumb proposed by Laubscher to reinforce the back of underground excavations (Laubscher 1984)

The rules proposed by the U.S. Corps of Engineers (1980) are relevant to excavations widths of 4.5 m to 30 m and heights varying from 4 m to 60 m. The rules shown in Table 13 are used mainly for relatively shallow civil excavation support designs (150 m below surface).

Farmer and Shelton (1980) developed the rules summarised in Table 14 from a synthesis of proposals by other authors. These rules are applicable in rock mass conditions having no more than three sets of unaltered and tight discontinuities.

Charette and Hadjigeorgiou (1999) summarised their observations and experience with both rock bolt and cable bolt lengths used in Canadian mines in the two graphs shown in Figure 26.

PARAMETER	EMPIRICAL RULE
Minimum length and maximum spacing	
Maximum length	Greatest of : (a) 2 x bolt spacing (b) 3 x thickening of critical and potentially unstable rock blocks (Note 1) (c) For elements above springline : spans < 6 m: 0.5 x span spans between 18 and 30 m: 0.25 x span spans between 6 and 18 m: interpolate between 3 and 4.5 m (d) For elements below the springline: height < 18 m: as (c) above height > 18 m: 0.2 x height
Maximum spacing	Least of: (a) 0.5 x bolt length (b) 1.5 x width of critical and potentially unstable rock blocks (Note 1) (c) 2 m (Note 2)
Minimum spacing	0.9 to 1.2 m
Minimum average confining pressure	
Minimum average confining pressure at yield point of elements (Note 3)	Greatest of: (a) Above springline: *either* pressure = vertical rock load of 0.2 x opening width or 40 kN/m^2 (b) Below springline: *either* pressure = vertical rock load of 0.1 x opening height or 40 kN/m^2 (c) At intersections: 2 x confining pressure determined above (Note 4)

Notes:

1. *Where joint spacing is close and span relatively large, the superposition of the two reinforcement patterns may be appropriate (e.g. long heavy elements on wide centres to support the span, and shorter, lighter bolts on closer centres to stabilise the surface against ravelling).*
2. *Greater spacing than 2 m makes attachment of surface support elements (e.g. weld mesh or chain link mesh) difficult.*
3. *Assuming the elements behave in a ductile manner.*
4. *This reinforcement should be installed from the first opening excavated prior to forming the intersection. Stress concentrations are generally higher at intersections and rock blocks are free to move toward both openings.*

Table 13: Rules of thumb proposed by the U.S. Corps of Engineers (Reproduced after U.S. Corps of Engineers 1980)

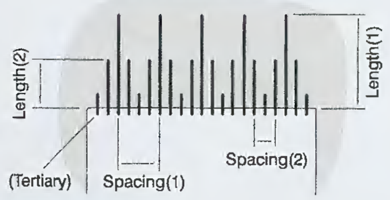
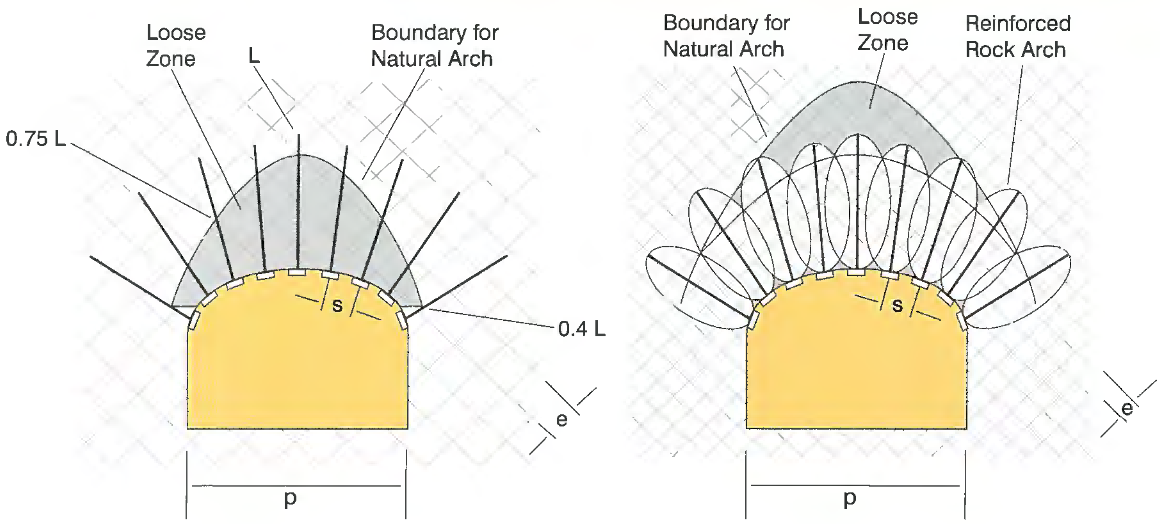
SPAN m	NUMBER & (Dip°) OF JOINT SETS	BOLT RECOMMENDATIONS	COMMENTS (AFTER FARMER AND SHELTON & BY AUTHORS OF THIS MANUAL)
<15	1 to 2 (0 to 45)	Length = 0.3 x Span Spacing < 0.5 x Length Install bolts perpendicular to lamination with mesh to prevent flaking. Decrease spacing in weak strata	Bolting creates load carrying beam over span. Grouted bolts or modified cable strand create higher joint shear stiffness. Tension bolts (plate cables) in weak rock. Angle bolts where joints are vertical
<15	1 to 2 (45 to 90)	For wall bolts: Installed at 90° to lamination *Length > Height x cos (Dip)* Installed horizontally *Length > Height / tan (Dip)* *(Dip = dip of joints)*	Roof bolting as above. Side bolts designed to prevent sliding along planar joints Spacing should be such that bolt capacity is greater than sliding or toppling weight. Tension bolts (plate cables)
<15	>2 with tight and clean surfaces	*Length > 2 x spacing* *Spacing < 3 to 4 x Block Size* Install bolts perpendicular to lamination with mesh to prevent flaking. Decrease spacing in weak strata	Bolts should be installed quickly after excavation to prevent loosening and retain tangential stresses. Tension and plate to improve radial confinement Sidewall bolting where wedge toes daylight into excavation
>15	<2	Alternate Primary (1) and Secondary (2) Bolting: *Length (1) > 0.3 x Span* *Spacing (1) < 0.5 x Length (1)* *Length (2) > 0.3 x Spacing (1)* *Spacing (2) < 0.5 x Length (2)* Mesh to prevent spalling	Primary bolting supports span and major blocks. Secondary bolting retains surface blocks Limit spacings (and provide load capacity) accordingly Bolt or cable lengths should penetrate beyond extent of known discrete wedges
>15	>2 with tight and clean surfaces	Alternate Primary (1) and Secondary (2) Bolting: *Length (1) > 0.3 x Span* *Spacing (1) < 0.5 x Length (1)* *Spacing (2) < 3 to 4 x Blk. Size* *Length (2) > 2 x Spacing (2)* Mesh as required for surface block retention	

Table 14: **Rules of thumb proposed by Farmer and Shelton to reinforce the back of underground excavations in ground conditions containing three tight joint sets with no alterations (Reproduced after Hutchinson and Diederichs 1996)**



Moderately Fractured Rock Mass	Heavily Fractured Rock Mass
Use non-tensioned rockbolts $L = 1.40 + 0.184p$	Use friction or tensioned bolts $L = 1.60 + \sqrt{1.0 + 0.0012p^2}$ To develop a compressive zone: $L/s \geq 2$ $S \leq 3e$ $0.5B < T < 0.8B$ Shotcrete and mesh are required

Where:

L is the bolt length in the centre of the pattern (See diagram) (m)

p is the excavation span (m)

s is the bolts spacing (m)

e is the joints spacing (m)

T is the applied tension to the bolt (kN)

B is the load-bearing capacity of the bolt (kN)

Figure 25: Reinforcement of the back of an excavation based on the compressive arch method (Modified after Stillborg 1994, and Charette and Hadjigeorgiou 1995)

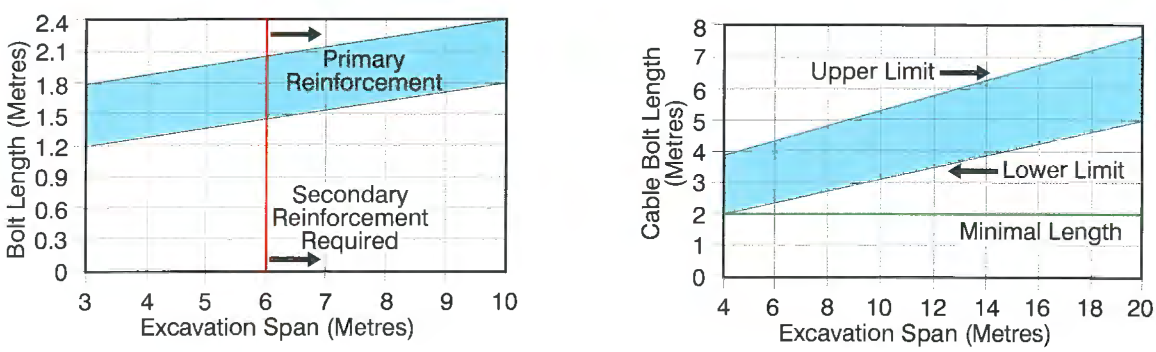


Figure 26: Rules of thumb to reinforce the back of excavation based on Canadian experience proposed by Charette and Hadjigeorgiou (Reproduced after Charette and Hadjigeorgiou 1999)

Extreme care must be taken when using any of the above rules of thumb. The function of reinforcement is to arrest and prevent rock mass failure. Any design methodology that does not directly account for the potential failure mechanisms that it aims to control may be deficient. Rules of thumb are best used as a "first pass" indicative or "ball park" design method only. The implementation of any bolting pattern should also include a process by which the pattern can be modified according to local conditions, as systematic patterns will not necessarily "pin" all key blocks.

3.2.6 EMPIRICAL RULES TO ASSIST WITH SHOTCRETE DESIGN

The interaction between a rock mass and shotcrete is complex and the application of a deterministic approach for designing shotcrete, thickness, strength, etc., can therefore be challenging. Keeping their inherent limitations in mind, empirical rules can be useful as a basis for deciding on shotcrete thickness requirement.

Grimstad and Barton (1993) proposed a graph relating a design thickness of fibre-reinforced shotcrete against the rock quality index "Q", for an excavation span of 10 m (See Figure 27). The graph also shows a range of excavation spans smaller and larger than 10 m. These authors suggest that the bolting pattern can be widened by 20 to 40 percent when shotcrete is applied.

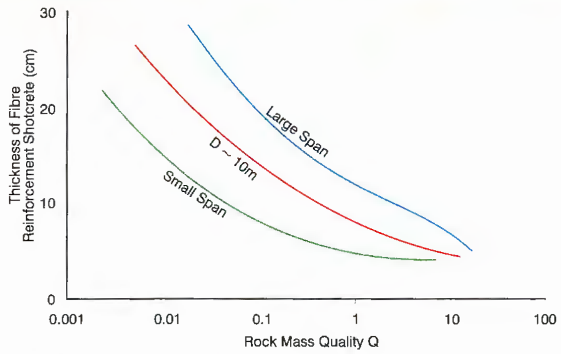
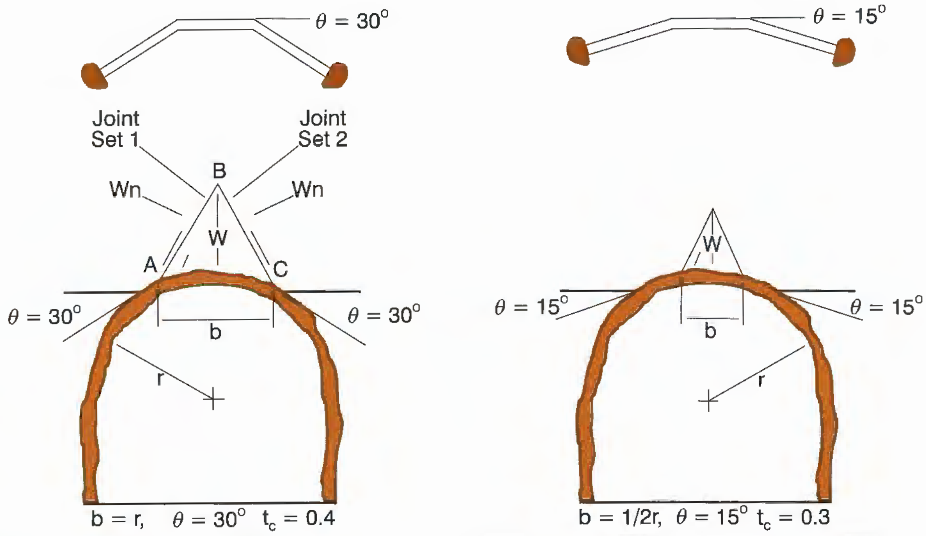


Figure 27: Empirical relationship between the thickness of fibre reinforced shotcrete and the rock mass quality index Q, for different excavation spans (After Grimstad and Barton 1993)

Fernandez-Delgado et al (1979) developed the formula, described in Figure 28, to calculate the shotcrete thickness required to stabilise distinct wedges.

Notwithstanding the above empirical rules, Australian mines often use a reinforced shotcrete layer thickness of approximately 50 mm in temporary excavations where low to moderate ground control problems are expected. In severe conditions, 100 mm to 150 mm layer thicknesses and greater are commonly applied.



$$t = \frac{W}{2t_c (\sin \theta) f_{28} L}$$

t_c = load acting in the axis of the arch/f_{28} / area of section of the shotcrete layer between the removable block and fixed wall

Legend:
- t = shotcrete thickness
- W = weight of the potential wedge
- f_{28} = compressive strength of shotcrete after 28 days
- t_c = a dimensionless thrust coefficient
- L = length of contact between the movable block and fixed wall shown as b in the diagram
- θ = angle as indicated in the diagram

Figure 28: Estimation of shotcrete thickness required to support a wedge in the back of an underground excavation (Reproduced after Fernandez and Delgado 1979, and Charette and Hadjigeorgiou 1999)

3.2.7 GROUND SUPPORT PATTERNS

Reinforcement and support patterns must be designed to accommodate local ground conditions. The orientation and intensity of discontinuities as well as the induced stress will have a significant influence on the bolting pattern. A number of authors have proposed generic patterns to accommodate generic ground conditions.

For example, Figure 29 shows drive reinforcement in a range of rock mass and stress environments. Figure 30 proposes a series of nine cases where the orientation of the bolts is adapted to reinforce specific discontinuities in drives. Since rockbolts are generally stronger in tension than in shear, an attempt is made to maintain the bolt orientation as perpendicular to the dominant discontinuity as practicable, and as parallel to the direction of movement as possible. Hutchinson and Diederichs (1996) have also proposed generic patterns for cable bolts in stopes, brows and drives, as shown in Figure 31.

A detailed process to assist mine operators in developing and implementing ground support standards suitable for their own local conditions is proposed in Section 5.2.2.

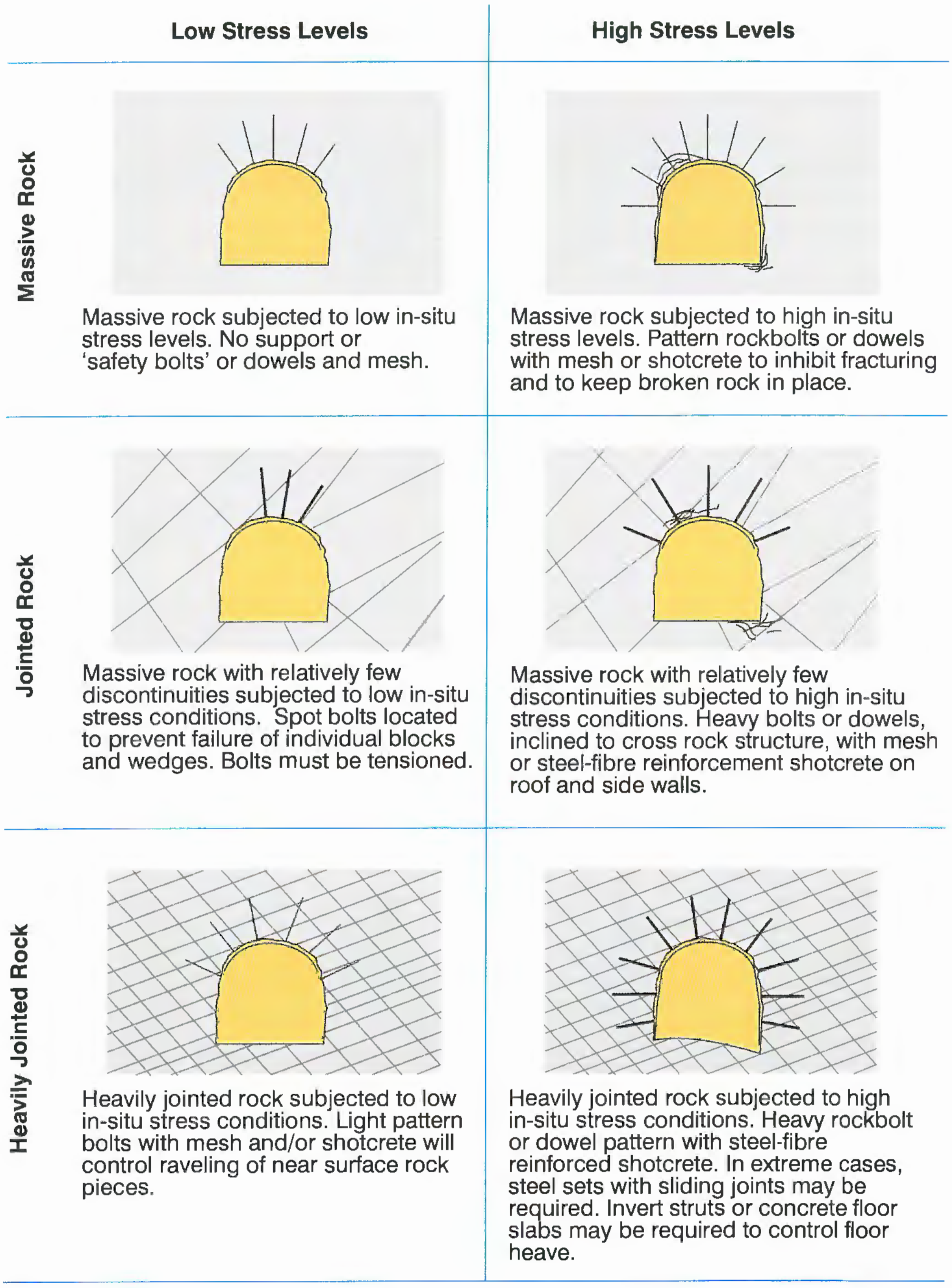


Figure 29: Typical reinforcement approaches to address generic ground conditions (Reproduced after Hoek, Kaiser and Bawden 1995)

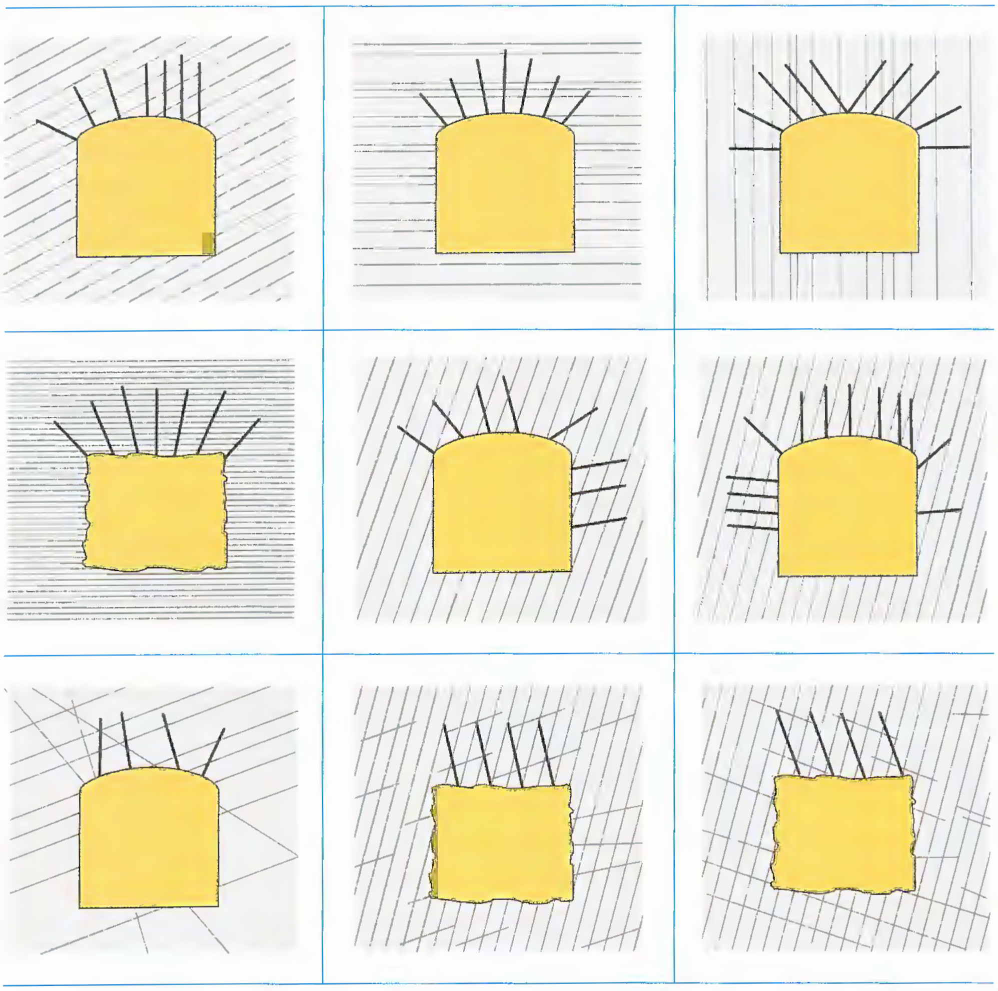


Figure 30: Typical reinforcement approaches emphasising the relative orientation of bolts with respect to the dominant discontinuity (Reproduced after Choquet 1987)

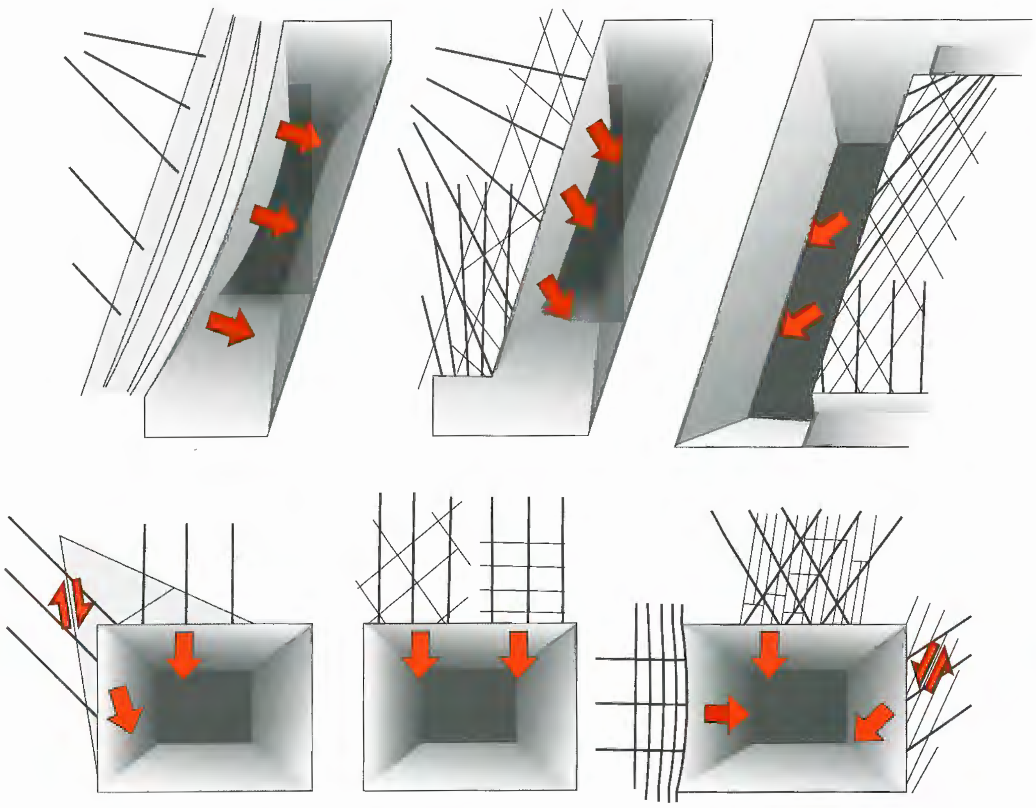


Figure 31: Typical cable bolt reinforcement approaches to be used in stopes, brows and drives (After Hutchinson and Diederichs 1996)

3.2.8 GROUND REINFORCEMENT AND SUPPORT IN SEISMICALLY ACTIVE CONDITIONS

The design of ground reinforcement and support in a seismically active and rockburst-prone environment requires special consideration. The potential loading mechanism acting on the reinforcement and support elements can be dynamic or similar to an impact rather than static load, or dead weight. The reinforcement and support elements must be capable of absorbing the energy produced by the impact of a potential rockburst. Since the energy is better absorbed through deformation of the supported rock mass, the reinforcement elements must be both strong and deformable. Yielding reinforcement elements such as the "cone bolt" for example, have been successfully used in burst-prone conditions. Adequate surface support must also be considered in seismically active conditions as the rock mass may shatter and eject at high velocity under dynamic loads. Strong mesh or mesh reinforced with straps, cable bolts or shotcrete are often used in areas that are most at risk from rockbursts.

It is therefore important to consider some of the key characteristics of reinforcement and surface support elements when dealing with seismically active conditions.

- Reinforcement elements to be used in seismically active conditions require some degree of yieldability. Grouted and/or tensioned bolts tend to break after only modest deformation and are less likely to be successful under dynamic loading conditions. De-bonding a section of a fully encapsulated bolt or using reinforcement specifically designed to deform or yield under load offers a better solution. Plain shotcrete has low yielding characteristics and is generally less suitable to dynamic loading conditions. Mesh and, to a lesser extent, fibre reinforcement, assist in providing the extra yieldability to shotcrete after it cracks.
- Rockbursts can be high-energy events involving heavy displacement at potentially high velocity. The capacity of reinforcement and support to absorb energy is a function of the yieldability and the ultimate strength of the support elements. High-strength, combined with high yieldability results in a support system that can absorb high levels of energy. Mesh-reinforced shotcrete, cable lacing and cone bolts are often used as components of high-energy absorption systems.

Guidelines for reinforcement and support in rockburst conditions shown in Table 15 can be used as a starting point for designing dynamic resistant support according to the anticipated magnitude of rockbursts and failure mechanisms. The table provides indicative values of yieldability (displacement in mm) and energy absorption capacity (kJ /m²).

3.2.9 SHAPE AND ORIENTATION OF UNDERGROUND EXCAVATIONS

The most common profiles for underground excavations are:

- Arched back
- Rectangular (flat back)
- "Shanty" (inclined back)

As a general rule, the excavation shape should be designed to suit the dominant discontinuities. An example of a shanty back accommodating a rock mass dominated by inclined bedding planes is shown in Figure 32. A flat back is not only a good choice in cases where flat discontinuities are prominent, but it is also often used as a default option in low stress conditions, when the network of discontinuities does not exhibit a preferential shape.

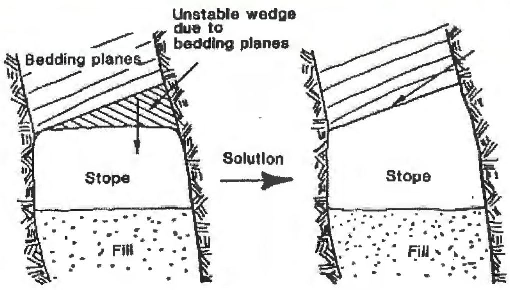


Figure 32: Illustration of how a shanty back can improve ground conditions when regular inclined bedding planes are dominant discontinuities

Photograph courtesy of McArthur River Mining

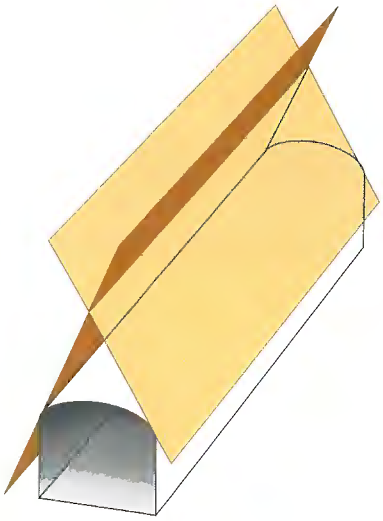
MECHANISM	DAMAGE SEVERITY	LOAD [kN/m²]	DISPLACEMENT [mm]	ENERGY [kJ/m²]	EXAMPLES OF SUGGESTED SUPPORT SYSTEMS*
Bulking without ejection	Minor	50	30	not critical	• mesh with rockbolts or grouted rebars (and shotcrete)
	Moderate	50	75	not critical	• mesh with rockbolts and grouted rebars (and shotcrete)
	Major	100	150	not critical	• mesh and shotcrete panels with yielding bolts and grouted rebars
Bulking causing ejection	Minor	50	100	not critical	• mesh with rockbolts and friction rock stabiliser bolts (and shotcrete)
	Moderate	100	200	20	• mesh and shotcrete panels with rebars and yielding bolts
	Major	150	>300	50	• mesh and shotcrete panels with strong yielding bolts and rebars (and lacing)
Ejection by remote seismic event	Minor	100	150	10	• reinforced shotcrete with rockbolts or friction rock stabiliser bolts
	Moderate	150	300	30	• reinforced shotcrete panels with rockbolts and yielding bolts (and lacing)
	Major	150	>300	>50	• reinforced shotcrete panels with strong yielding bolts and rebars (and lacing)
Rockfall	Minor	100	na	na	• grouted rebars and shotcrete
	Moderate	150	na	na	• grouted rebars and plated cable bolts with mesh and straps or mesh • reinforced shotcrete
	Major	200	na	na	• as above plus higher density cable bolting
Limits (MPSL)		200	300	50	Maximum practical support limit

* Items in brackets are beneficial but optional

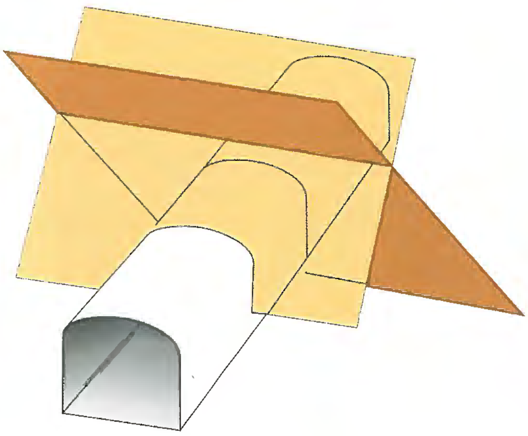
Table 15: Examples of dynamic resistant reinforcement and support as a function of anticipated damage security and rockburst failure mechanisms (After CRRP 1995)

In high stress conditions, an arched back will generally produce more stable excavations. This is because sharp corners tend to act as a stress concentrator and initiate failure. The smooth shape of arched drives promotes a more even flow of stress around the excavation and results in a more stable configuration.

The orientation of excavations can also have a significant influence on their stability. It is generally accepted that in jointed rock, the excavation orientation that will produce the smallest volume of potentially unstable "wedge", as shown in Figure 33, is the preferred orientation from a geomechanics perspective.



Unfavourable Orientation



Optimum Orientation

Figure 33: Underground excavations oriented perpendicular to dominant discontinuities will produce smaller wedges and will be more stable than excavations oriented parallel to discontinuities (Modified after Hoek and Brown 1980)

The relative orientation of excavations with regards to the stress field may also need consideration if the magnitude of the mine-induced stress is significant in comparison to the rock mass strength. Excavations orientated parallel to the maximum stress will better sustain this stress compared to those orientated perpendicular. This is why cross-cuts and drives in similar ground and stress conditions are sometimes observed to behave very differently.

3.2.10 SMOOTH WALL BLASTING

Smooth wall or perimeter blasting techniques are used to protect the surrounding rock mass from damage when developing an excavation. Perimeter blasting assists in creating an environment where the resulting profile of the backs and walls are both stronger and smoother than would otherwise be expected if such techniques were not employed. When well designed perimeter blasting is carried out, it assists in reducing the amount of overbreak as well as the time and cost associated with scaling and supporting an excavation.

The success of smooth wall blasting depends largely on the accuracy of drilling, rock type and explosives used. In ground conditions that are heavily jointed or fractured, smooth wall blasting may not be as successful as in more competent, less fractured rock masses. This is due to explosive gases having a greater number of existing path ways along which to travel.

Smooth blasting reduces disturbance to rock in the excavation perimeter by:

- Reducing the explosives energy yield per metre in perimeter blast holes
- Reducing the spacing of perimeter blast holes used to approximately 75%[2] of the normal spacing designed for a round
- Ensuring that the burden of perimeter holes is approximately 1.1. to 1.42 times the spacing
- Firing perimeter charges on the last delay(s), allowing earlier charges to have created effective free faces
- Drilling 'easer' holes (shoulder and knee holes) inside the line of the perimeter holes to reduce the work done by the perimeter holes

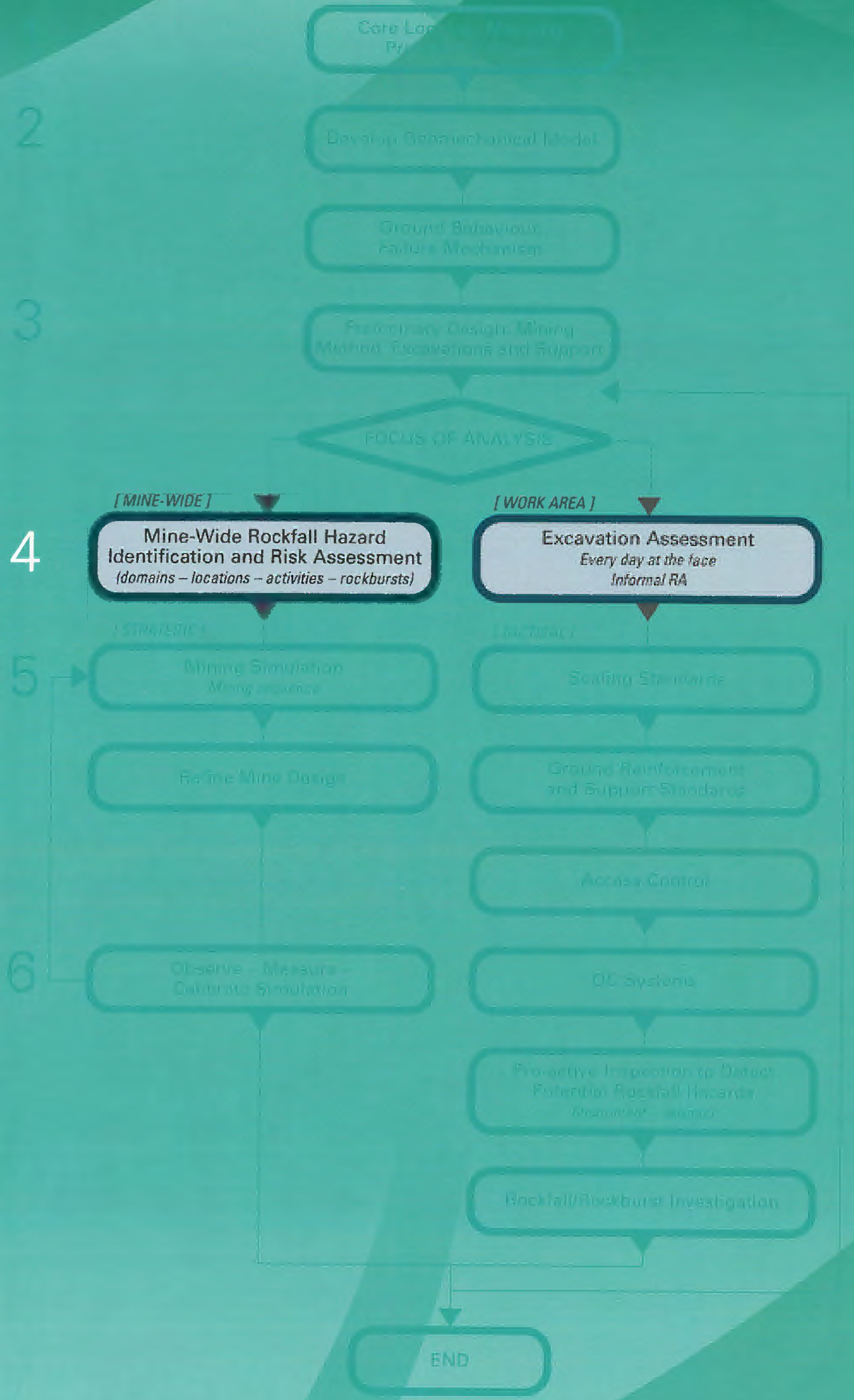
[2] *A guide only. Blasting design should be carried out by experienced consultants or professionals for each mine to ensure that the optimum perimeter blasting results are obtained, as ground conditions at different mines will vary (I.C.I. Explosives, 1991).*

Smooth wall blasting will be most successful in strong massive rocks in which tight bedding planes are normal to the axes of blast holes. In rocks that have closely spaced joints or bedding planes, some overbreak will occur regardless of the steps taken to prevent it. The techniques that are successful in a strong massive rock may be unsuitable in weak, highly fissured rock. As a consequence, blast hole spacings and charge concentrations should be designed to suit each mine site's unique ground conditions.

To achieve the required smooth wall effect, it is usually necessary to charge perimeter blast holes along the backs and walls of the excavation with an explosive that has a relatively low energy yield per metre of charge length. Site conditions will dictate the charge required in perimeter blast holes, depending on the structure, strength and geomechanical characteristics of the rock types being mined.

Perimeter hole charges should be initiated on similar delays after all other holes in the round have been fired. The optimum smooth wall results are obtained when all perimeter charges detonate simultaneously.

4 Assess Rockfall Risks



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4. IDENTIFICATION OF ROCKFALL HAZARDS AND ASSESSMENT OF ROCKFALL RISKS

The assessment of rockfall risks in the management process, shown in Figure 1, is performed globally at the mine-wide scale determining strategic controls, such as the mining method and sequence, automated equipment and mining systems. In each individual work area, tactical controls are established by carrying out scaling and installing ground support.

As described in the previous step of the rockfall management process, the preliminary design provides the main parameters under which the mine intends to operate (mining method, excavation size, ground support, etc.). The risk of rockfalls can be assessed against these parameters. This requires that the anticipated rockfall hazards ensuing from the designed mining environment must be well understood. The risk will be a function of how people and assets are exposed to the rockfall hazards and also of the control measures applied to manage the risk. This analysis needs to be performed at both the mine-wide and specific work area scale.

Rockfall risk assessments at both scales may be repeated periodically as more information and experience are gained and as the preliminary design parameters are refined and modified. This is represented in the process Figure 1, with the right hand side of the loop, starting at the end of Step 6 and feeding back in prior to Step 4. It is intended that risk assessments at the work area scale are repeated more frequently than at the mine-wide scale. Major changes in mining practices or ground conditions and behaviour should trigger a new round of risk assessments for either or both scales.

4.1 A Brief Introduction to Risk Assessment

The material below is taken from the National Minerals Industry Safety and Health Risk Assessment Guideline, commonly referred to as The National Guideline. This guideline can be accessed via the Internet at www.mishc.uq.edu.au. Readers are strongly encouraged to consult the guideline for more information on this subject. The guideline suggests that the following major points be considered when conducting risk assessments:

- Setting **the context**
- **Scoping** or designing the risk assessment
- **Facilitating** /leading a risk assessment team
- **Applying** the risk assessment deliverables

In the case of rockfall risk assessment, **the context** is largely defined as whether the assessment is performed at the mine-wide or at the work area scale. The context will also differ when the assessment is triggered by an event or an operational change compared to the original risk assessment that may have been based on the preliminary design in the early phase of the mine's life.

The success of a risk assessment is dependent on how well it is **scoped** or designed. The National Guideline suggests that a *significant risk assessment* exercise considers nine main areas:

- Defining the objective based on the expected deliverables
- Identifying and describing the system to be reviewed
- Identifying and understanding the potential hazards
- Selecting the risk assessment method – the means of systematically identifying the risks
- Selecting the risk analysis method – the means of calculating and examining the level of risk
- Selecting a facilitator for the risk assessment
- Determining the composition of the team or work group
- Deciding the time required, and venue
- Providing risk assessment results and the desired deliverable

The **facilitating** process must lead the team through a review of the risk assessment scope and in the present case, the mining systems relevant to the risk of rockfalls. This will enable the team to identify and understand the nature and magnitude of rockfall hazards, and clarify any uncertainties related to them. According to the context and the scope, an appropriate method to assess the risk is then applied that takes into account the existing controls already in place.

It is essential that the question of "What constitutes an acceptable risk?" is defined and understood by the team carrying out the assessment. There is no hard criterion on acceptable risks for rockfalls. The way in which assessments are carried out can be influenced by factors such as local regulations, legislation, mining industry standards, corporate policy and mine site culture. New controls may need to be introduced to deal with "unacceptable risks" or where there is a suspected increase in the level of risk.

As all formal risk assessment should be documented, the deliverables from the risk assessment should include a report and an action plan. **Applying** the deliverables encompasses implementing the action plan. It may involve new controls, actions, accountability and target dates.

4.2 Mine-Wide Risk Assessment

The general objective of the risk assessment at the mine-wide scale is to better understand and assess the potential impact of the "macro" mine design issues, largely medium to long term decisions, such as:

- Location of permanent access development, (shafts, declines, etc.), permanent infra-structure, (crusher, workshops, conveyors, etc.) and return airways, lateral and vertical
- Mining methods
- Mining systems and equipment
- Pillar and stope dimensions and locations with respect to ground conditions, geological structures and stress
- Use of backfill and type of backfill
- Extraction sequence, etc.

on the overall risk of rockfalls throughout the mine.

These are "significant" and "formal" risk assessments that will require team input and facilitation and should consider all steps described in the previous section.

4.2.1 OBJECTIVES

The National Guideline lists 11 possible generic objectives for risk assessment. From this list, the following four generic objectives seem the most relevant to the context of mine-wide rockfall risk assessment:

- Formal Safety Assessment development (After National Minerals Industry Safety and Health Risk Assessment Guideline).
  "The term Safety Case (SC) is used to describe a comprehensive integrated and documented risk management system. The objective of a SC is to develop a comprehensive management document specific to that operation detailing what major accident events could occur, quantitatively assessing the risk of those events, and describing how the risk controls are assured through the safety management system.

  The SC is usually designed to demonstrate to a regulator that measures are appropriate and adequate to ensure that risks from potential major accident events have been reduced to a level as low as reasonably practicable (ALARP[3]).

  SC should not be confused with any particular risk assessment method but rather a management methodology based on a rigorous Formal Safety Assessment (FSA) method. The FSA method usually involves a systematic review of the operation, initially using preliminary or broad brush risk assessment methods as well as more detailed techniques to examine major issues in more depth.

  The FSA methodology can be applied at minerals industry sites for comprehensive operational review."
- Risk Acceptability determination (After National Minerals Industry Safety and Health Risk Assessment Guideline).
  "The objective of this deliverable is to decide if risks related to an issue (rockfalls for example), *plan or system are acceptable. Determining risk acceptability involves initially determining the risk acceptance criteria. This is followed by some process of reviewing the issue, plan or system, establishing the relevant risks with controls in place and judging whether relevant risks are or can be reduced to an acceptable level."*
- Information for major or principal hazard plan (After National Minerals Industry Safety and Health Risk Assessment Guideline).
  "When the objective of the intended deliverable is to supply information for Major or Principal Hazard Management Plans, the intention is to analyse and assess risks related to potentially high consequence hazards as well as identify key controls."

  "These plans are intended to be carefully developed documents that outline the management system in place, to ensure the risks related to the specific major hazard are

[3] *ALARP is used in the UK, but terms such as ALAP (as low as practicable) and ALARA (as low as reasonably achievable) are used by other pieces of legislation. It should be noted that these phrases have different meanings and put different responsibilities on the operator of the facility*

acceptable. Originally, these plans were derived for hazards where uncertainty about the nature of the locations of the hazard was high, such as outburst, ground control, inrush, etc."

- Option/Selection Review (After National Minerals Industry Safety and Health Risk Assessment Guideline).
  "Sometimes it is necessary to compare optional designs or methods where one criterion for option selection is risk. The objective of this deliverable is to generate information that identifies the risks in each option and allows comparison. The latter is greatly affected by the risk analysis or calculation method."

4.2.2 PROPOSED RISK ASSESSMENT TOOLS

The National Guideline suggests that the tools summarised in Table 16 below, can be used to assist in fulfilling the generic risk assessment objectives:

4.2.3 RISK ANALYSIS METHODS

Of the three methods for analysing risks, namely:

- Qualitative
- Semi-quantitative
- Quantitative methods

a qualitative approach involving risk ranking probably offers the most practical means of analysing the mine-wide risk of rockfalls. The lack of quantitative data on rockfalls generally precludes the use of quantitative and even semi-quantitative methods.

A guideline based on qualitative analysis of rockfall risks in a mine-wide context has been developed by the Western Australian Ground Control Group and is reproduced in Appendix 1.

4.3 Work Area Risk Assessment

The general objective of the specific work area risk assessment is to assist with the development and implementation of Safe Operating Procedures (SOP) with regard to rockfall risk control.

TOOLS/ OBJECTIVES	EBA	CONSEQ. ANALYSIS	PHA/ HAZAN/ WRAC	HAZOP	FTA	ETA	FMECA	HEA
Formal Safety Assessment	X	X	X	X	X		X	X
Risk Acceptability		X	X		X	X		
Major Hazard Plan	X	X	X		X	X		
Option/ Selection Review			X		X	X		X

WHERE THE RISK ASSESSMENT TOOLS ARE:

Energy Barrier Analysis (EBA) – detailed analysis of determining phases of an event and control mechanisms

Consequence Analysis – general to detailed understanding of the magnitude of unwanted events with potential to apply quantitative analysis

Preliminary Hazard Analysis / Hazard Analysis / Workplace Risk Assessment and Control (PHA/HAZAN/WRAC) – general identification of priority risk issues / events, often to determine the need for further detailed study

Hazard and Operability Study (HAZOP) – systematic identification of hazards in a processing design

Fault Tree Analysis (FTA) – detailed analysis of contributors to major unwanted events, potentially using quantitative methods

Event Tree Analysis (ETA) – detailed analysis of the development of major unwanted events, potentially using quantitative methods

Failure Modes, Effects and Criticality Analysis (FMECA) – general to detailed analysis of component reliability risks

Human Error Analysis (HEA) – general or detailed analysis of human factors or reliability issue

Table 16: Summary of the suitability of risk assessment tools as a function of generic mine-wide risk assessment objectives being pursued (Developed from information provided in the National Minerals Industry Safety and Health Risk Assessment Guideline)

These procedures may or may not involve comprehensive and "formal" risk assessments. For example, the implementation of techniques to fulfil the objective of an "informal" risk awareness on day-to-day tasks will not follow all the steps of a formal risk assessment process.

4.3.1 OBJECTIVES

The National Guideline lists 11 possible generic objectives for risk assessment. From this list, the following three generic objectives seem the most relevant to the context of work area rockfall risk assessment:

- Information for operational guidelines (After National Minerals Industry Safety and Health Risk Assessment Guideline).
  "The objective of this deliverable is to generate information that can be used to help derive guidelines for operating. SOPs provide the detail for specific tasks. Operational guidelines are information involving a group of related task such as... "in the case of rockfall, development mining, ground support installation, etc. As such, it is guidance for a team or group of operators concerning the objective of that work group."
- Information for drafting Standard Operating Procedures (SOPs) (After National Minerals Industry Safety and Health Risk Assessment Guideline).
  "The objective of this deliverable is to produce information on hazards and required controls for inclusion in the drafting of a Standard Operating Procedure (SOP). Once a site has identified a required SOP, risk assessment is done to review the current or planned job steps to identify hazards and controls."

  The two most important standard procedures to control rockfalls are scaling and ground support procedures. These are discussed in details in Sections 5.2.1 and 5.2.2.
- Risk awareness in formal day-to-day tasks (After National Minerals Industry Safety and Health Risk Assessment Guideline).
  "The objective of this deliverable is to create a state of risk awareness in the minds of individuals about to undertake a task or during a task where an unexpected change has occurred. Many mines have adopted "mental models" to prompt people to think about the risks."

4.3.2 PROPOSED RISK ASSESSMENT TOOLS

The National Guideline suggests that the tools shown in Table 17 can be used to assist in fulfilling the generic risk assessment objectives:

TOOLS/OBJECTIVES	INFORMAL RA	JSA/JHA	PHA/ HAZAN/WRAC	HAZOP	HEA
Information for operational guidelines			X	X	X
Information for drafting of SOPs		X	X		X
Informal risk awareness	X				

WHERE:

Informal Risk Assessment (RA) – general identification and communication of hazards and risks in a task by applying a way of thinking, often with no documentation

Job Safety / Hazard Analysis (JSA / JHA) – general identification of hazards and controls in a specific task, usually for determining the basis of a Standard Operating Procedure (SOP)

Preliminary Hazard Analysis / Hazard Analysis / Workplace Risk Assessment and Control (PHA/HAZAN/WRAC) – general identification of priority risk issues / events, often to determine the need for further detailed study

Hazard and Operability Study (HAZOP) – systematic identification of hazards in a processing design

Human Error Analysis (HEA) – general or detailed analysis of human factors or reliability issues

Table 17: Summary of the suitability of risk assessment tools as a function of generic work area risk assessment objectives being pursued (Developed from information provided in the "National Minerals Industry Safety and Health Risk Assessment Guideline")

4.3.3 EXCAVATION ASSESSMENT: EXAMPLES OF INFORMAL RISK ASSESSMENT (RA) METHODS

It is good practice for underground workers to conduct an informal risk assessment when they enter a working area. This informal approach aims to raise risk awareness in day-to-day tasks compared to a formal and structured comprehensive risk assessment. The National Guideline lists some of the RA commonly used in mines:

- 'Plan' (Pause, Look, Act, Note)
- Stop and Think
- 'Hudson's Rule of Three'
- Stepback 5*5
- PASS (Positive Attitude Safety System)
- 'Spend a Minute – Save a Life'

In some mines, rockfall risk awareness is supported with field books that describe rockfall hazards, failure mechanisms and bolting patterns. A sample of such a field book is shown in Figure 34.

Because rockfall is a major hazard with potentially catastrophic consequences, it may be warranted for workers exposed to higher rockfall risk tasks in particular to use an informal risk awareness system that is dedicated to rockfall hazards.

In some mines, jumbo operators and ground support crews are using excavation assessment sheets. An example of such system is given in Figure 35. The sheet in this example has three sections. The top section describes how the system works. The central section is a "tick-a-box" style detachable sheet from a pad that aims to document and assess the risk of geotechnical hazards present in the excavation. This information is then passed on to supervisors and geotechnical personnel at the end of every shift. The bottom section of the sheet is a memory jog of the main rockfall hazards at the mine.

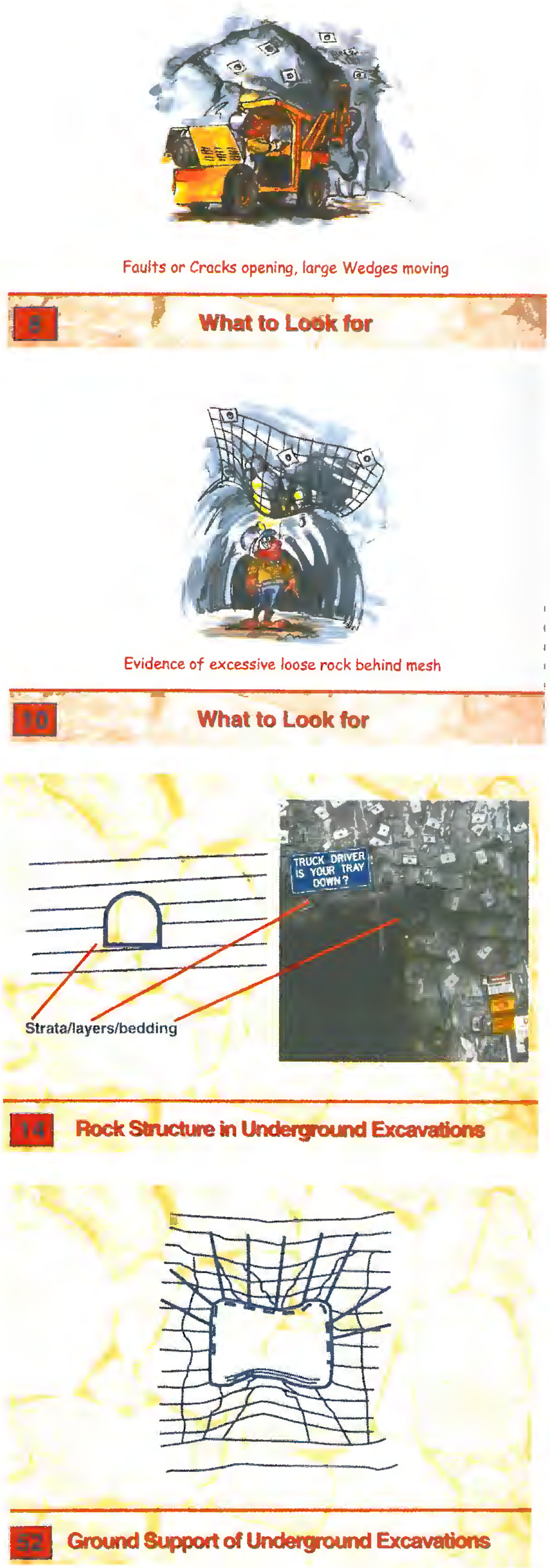


Figure 34: Sample of a fieldbook content to assist all underground personnel to assess the risk of rockfalls (After Nedin and Potvin 2000)

Excavation Assessment

HOW TO USE THE GROUND CONDITION REPORT SHEET

This sheet aims to help you identify ground conditions that may be a serious hazard or result in an uncontrolled rockfall

STEP 1 – Look for Hazards
check for any of the 5 main types or any other hazards that might be present. Tick box for the different hazards you see in each heading.

STEP 2 – Assess the Risk
Decide if one or more of these hazards is a threat to personal safety or equipment damage is ranking the risk as "high" or "low".

STEP 3 – Take the Appropriate Action
If you are sure that the ground conditions present a low risk, commence work following the Safe Work Procedures that apply to your job.

IF YOU RE UNSURE OF THE RISK – DO NOT COMMENCE WORK!
BARRICADE THE DANGER ZONE & CONTACT YOUR SUPERVISOR

Ground Condition Report Sheet

Name: **Date:**

Shift / Location	D / Bolts	N / Mesh	Small scats	Corroded support	Sliding rock from walls	Large wedges	Signs of stress	Other	Heading high risk? Y	N
1										
2										
3										
4										
5										

Risk Legend: Heading safe for work Heading not safe for work

Follow up required? Y ☐ N ☐ Urgent ☐ Heading No(s) ______________

Other hazards ______________

or comments______________

Small scats or loose rocks

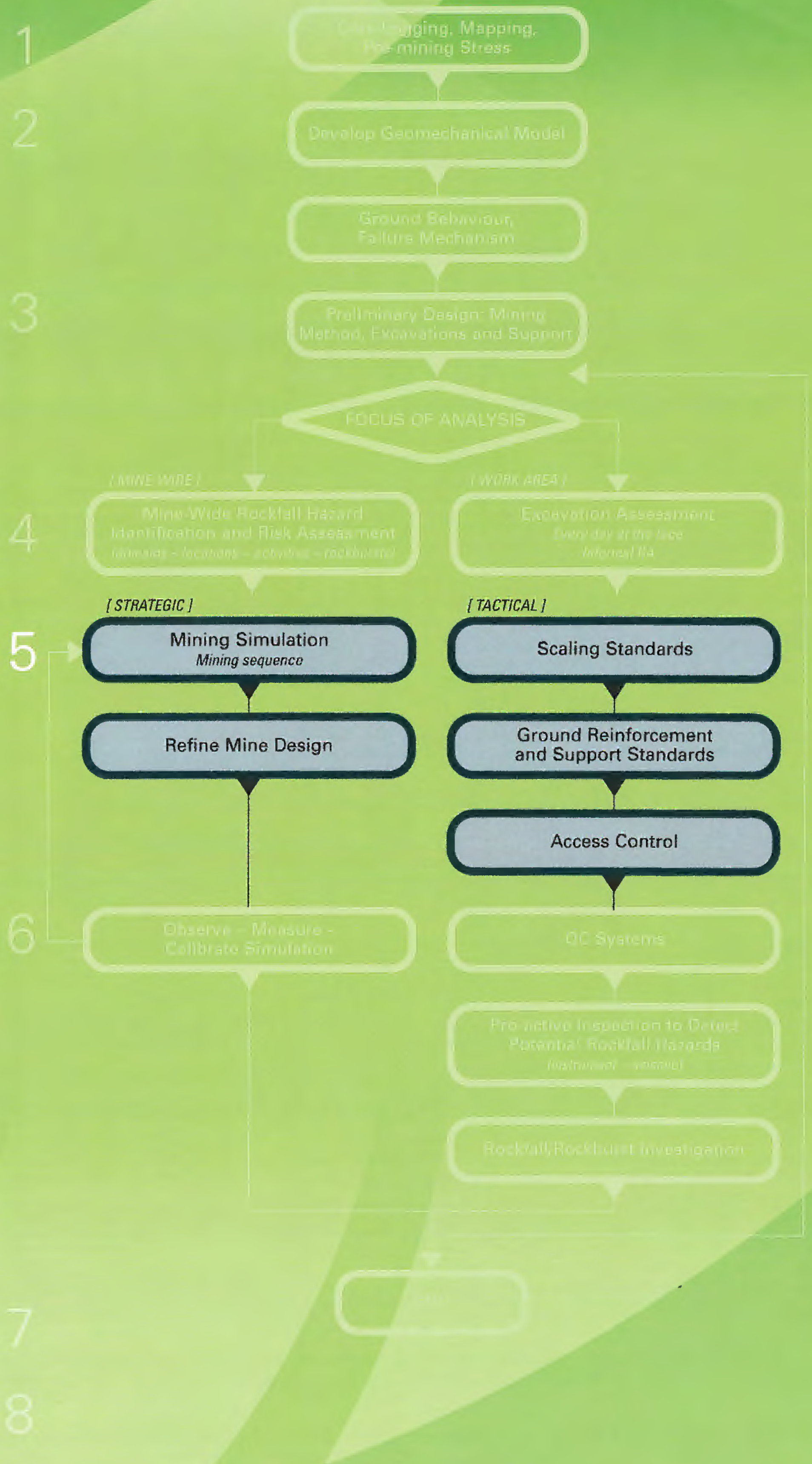
Large wedges

Sliding rocks in walls

Signs of stress

Figure 35: Example of an excavation assessment sheet designed to assist jumbo operators and ground support crews in informal daily rockfall risk assessment

5 Control Rockfall



5. CONTROL OF ROCKFALL RISKS

"ROCKFALL HAZARDS IN UNDERGROUND MINES CANNOT BE ELIMINATED. HOWEVER, THE RISKS TO PERSONNEL AND ASSETS CAN BE REDUCED TO A LEVEL THAT IS TOLERABLE TO AN ORGANISATION USING STRATEGIC CONTROLS AT THE MINE-WIDE SCALE AND TACTICAL CONTROLS AT THE WORK AREA SCALE. THE CONTROL MEASURES CAN EITHER AIM AT REDUCING THE LIKELIHOOD OF ROCKFALLS OCCURRING, OR REDUCING THE EXPOSURE OF PEOPLE AND ASSETS TO ROCKFALLS."

5.1 Strategic Controls

Strategic controls address the risk of rockfalls in a global way rather than at a specific location or in a specific situation. The probability of rockfalls may be reduced or increased by adjusting mine design strategies such as:

- Mining method (blasting, backfill, mine equipment)
- Mine infrastructure and access layout
- Mining sequence

5.1.1 MINING METHODS AND ROCKFALL RISKS

The selection of a mining method is largely a function of the geometry of the orebody and the geomechanical environment. Mining methods can be classified as either "entry" or "non-entry" extraction sequences. In entry methods such as cut and fill, shrinkage and room and pillar, the mine production activities, drilling, blasting, mucking, etc., are all performed from within the stopes (See Figure 36).

In most cases, this translates to an elevated exposure of workers to freshly blasted ground, which are areas that have an intrinsically higher likelihood of rockfalls. Scaling, ground reinforcement and surface support must be integrated into the production cycle to control local conditions. However, when operating in a high stress environment or in areas where large volumes of rock are extracted, the stability of stopes in entry methods, and therefore the safety of production miners, becomes highly dependant on strategic control measures. These may include

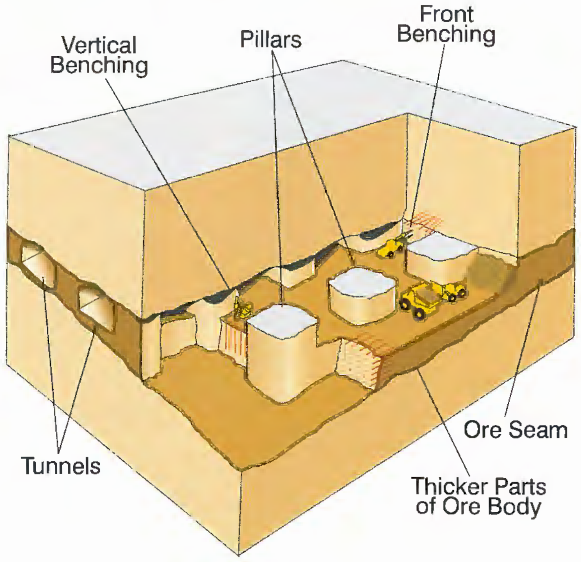


Figure 36: Illustration of a generic room and pillar operation showing mine production activities within the stope (Reproduced after Hamrin 2001)

an extraction sequence that manages stress concentration and the appropriate use of pillars and fill. Such controls are discussed in the following sections.

In general, entry-mining methods have lower productivity, which has caused their popularity worldwide and in Australia to decrease during the last two decades. Exceptions to this rule include rich, narrow vein deposits often extracted using some form of hand held mining technique and flat-lying orebodies mainly mined by room and pillar methods (or longwall in South Africa).

Non-entry mining, which includes variations of open stope and cave mining methods, are in general less labour intensive and do not allow personnel to enter the stopes. All production activities, such as drilling, blasting and mucking, are performed from the stope's periphery as shown in Figure 37. This provides an opportunity to secure the ground prior to the commencement of production in areas surrounding the mining blocks, instead of having to repeat the support process during production cycle, as is the case in entry mining. Open stope mining also facilitates the use of remote control equipment as most

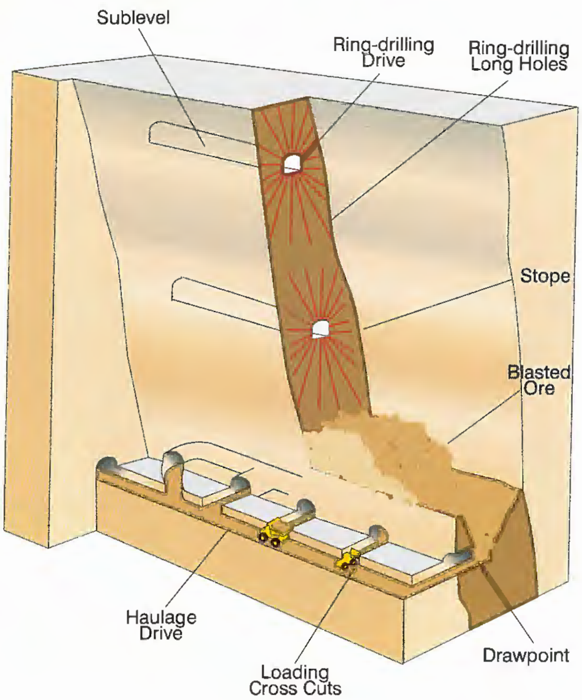


Figure 37: Illustration of a typical open stope operation. Most production activities are performed from the periphery of the stope (Reproduced after Hamrin 2001)

activities are confined to specific areas, draw points, drilling drives, etc.

Although it could be inferred from the previous discussion that non-entry methods have a reduced risk of rockfalls compared to entry methods, the conclusion can only be drawn based on how well the risk of rockfalls is managed at each mine site regardless of the mining method employed.

In general, the more underground workers exposed to areas of a higher probability of rockfalls, the higher the rockfall risk. A wide range of variables applicable to all mining methods may impact on the likelihood of rockfalls and the exposure of personnel. For example, methods relying on intense development mining and low mechanisation will have many workers carrying out tasks at the mine face, an area of higher probability of rockfalls, on a near continuous basis.

Methods relying on large blasts may generate more blast vibrations and localised damage as well as larger instantaneous stress and energy changes. On the other hand, the drilling, charging and mucking operations are generally more efficient and often performed using large and well-protected drill-rigs and mobile equipment including trucks, load haul dump units and others.

Methods requiring large openings may also cause greater stress changes, while the large spans may create greater potential for large rockfalls to occur. These can contribute to increasing the overall probability and severity of rockfalls. This may be compensated by increased mechanisation, where most activities are confined to a smaller number of well-secured areas, resulting in a reduction in personnel exposure.

Mining methods using backfill may offer better regional control of stope closure (lower convergence of hangingwall to footwall) and fewer large voids left open at any time, or for a long period of time. Mine fill can control the risk of uncontrolled collapses and unwanted caving or subsidence. There have been a number of well-documented cases where fill was not used and crown pillars have failed up to surface with a variety of consequences.

The use of mine fill also allows greater flexibility in the extraction sequence and often results in increased or complete recovery of orebodies. The location of voids (stopes in production) and pillars can be strategically controlled to minimise stress-induced problems. In many ways, mine fill can reduce potential sources of instability and the likelihood of a rockfall occurring.

However, other risks associated with fill operations need to be considered. Hydraulic fill in large stopes can introduce the risk of bulkhead failure and flooding. Dry fill reticulated with mobile equipment will increase underground traffic and the risks associated with it.

The selection of mine equipment can also influence the likelihood of rockfalls. Large equipment requires suitably sized excavations that may be prone to substantial falls of ground. High excavations can also be more difficult to manage in terms of scaling, visual identification of structures, loose material, etc.

The equipment itself can provide a degree of protection against small rockfalls, with enclosed cabs, Rollover Protective Structure (ROPs) or Falling Object Protective Structure (FOPs).

The level of mechanisation and automation of mining equipment can also reduce the exposure of personnel to rockfalls. For example, mechanised bolting machines minimise the need for operators to spend time at the mine face, outside the cab.

Tasks such as drilling, mucking or charging are commonly done by remote control equipment, while tele-remote and even fully automated mining equipment are gradually gaining acceptance in the industry. These emerging technologies all contribute to removing mine operators from the areas most at risk. However, new technologies may introduce new risks such as people being struck and injured by remotely controlled equipment.

The selection of mining methods and associated parameters will influence the likelihood of rockfalls and the exposure of the workforce. The risk of rockfalls is however a function of how well the hazard is mitigated and managed.

5.1.2 MINE INFRASTRUCTURE AND ACCESS LAYOUT

The stability of mine infrastructure is time dependant. Even the typical anecdotal story of the drive that remained stable "forever" without any ground support must be put into perspective. Almost every hole in the ground will eventually close. The closure rate can be extremely fast (seconds) or extremely slow (millions of years).

For a given stress condition, the rate of closure is a function of the rock mass quality. Although there is limited flexibility in the selection of locations for the different components of the mine infrastructure, having a good geomechanical model, as referred to in Section 2, will provide the knowledge that can help mine planners to locate the infrastructure in the more competent rock masses and as much as possible, away from major discontinuities.

The stability of underground openings can also be influenced by a number of in-situ factors; like earthquakes, tectonic activities or ground water, while others are induced by mining activities.

The close proximity of mine infrastructure and accesses to the stoping areas (or caving fronts) will reduce mine development and transportation costs but will increase the level of blast vibration and stress changes acting on the infrastructure, thereby increasing the likelihood of rockfalls. Ground control measures may sometimes compensate for the close proximity of the infrastructure but in such cases, the financial gain must be weighed against the increased risk. It is common for mine infrastructure, located relatively close to stopes, to be submitted to one or more cycles of stress increase and stress decrease. The stress increase will contribute to create new cracks and induce slipping along joints followed by a stress decrease, resulting in a general loosening of the rock mass. In such cases, the ground support design must be flexible and account for stress change cycle(s) and elevated blast vibrations. The ground support itself may have time-dependant behaviour, especially if the environment is corrosive. The use of hydraulic fill can also expose ground support in the vicinity of the stope being filled, to a period of intense corrosiveness. All these factors need to be accounted for at the design stage.

Production management and mine planners can sometimes increase the flexibility of their operation by having the infrastructure developed well ahead of time. This is particularly attractive for mines enjoying a surplus in developing infrastructure capability. This strategy is not so desirable however, where an excavation's closure rate is rapid due to weak rock masses or high stresses conditions, or if it results in exposing the infrastructure to an increased number of stress change cycles.

Therefore, in addition to the normal excavation design considerations (size, shape, orientation, ground support) described in Section 3, mine infrastructure design, including ground support, must account for its location relative to stoping activities and the expected service life of the excavations. The timing of developing the infrastructure also becomes critical where rapid closure rates exist.

5.1.3 MINING SEQUENCES

The mining sequence determines the order each stope and mining block will be extracted. Economically, the extraction sequence will often prioritise the stopes having the best combination of high grade and low cost, to maximise the Net Present Value (NPV) of the operation. However, the maximum NPV will only be realised if the following objectives are also met:

- Target production rate is maintained or exceeded
- Stability of the infrastructure is maintained (shafts, orepasses, declines, major accesses, conveyor drives, crusher station, etc.)
- Ore reserves are not sterilised

Consequently, rock mechanics and stress management strategies may overrule the grade and cost considerations in developing the mining sequence, especially when operating in a high stress environment.

For steep deposits, one of the primary considerations and fundamental decisions relates to the direction of mining retreat. Mining may commence towards the top of the orebody progressing downwards (top-down mining). Alternatively, extraction can begin at depth progressing upwards (bottom-up mining).

Top-down mining offers a distinct financial advantage in terms of the lower requirement for infrastructure and capital investment before production starts. The geomechanics issues resulting from this approach include the mining progression towards deeper and higher stress levels coupled with higher extraction ratios. This invariably means gradual worsening of ground conditions, which may lead to loss of ore reserves. Unless a sublevel caving method is employed, whereby empty stopes are filled progressively by caving the hangingwall, as shown in Figure 38, crown pillars will often be required at regular vertical intervals to limit the span of the total opening and control the convergence of the hangingwall/footwall. The convergence can also be controlled with the use of backfill. The top-down progression implies that mining activities will continually have to be performed under fill masses, caved rock or voids.

Bottom-up mining requires significant capital development to reach deeper parts of the orebody which often delays the start of production. It may lower the risk of losing ore reserves towards the end of the mine life, as the extraction progresses towards the lower stress environment in the upper levels of the mine. In general, this approach increases the flexibility in the extraction sequence with the option of using cemented or uncemented fill, in either "pillarless" or primary/secondary extraction scenarios.

When orebodies extend at depth but have limited horizontal extension, it is common to undertake bottom-up mining on multiple horizons to increase the productivity of the mine. This creates a series of stacked mining blocks, separated by crown or sill pillars. The recovery of these crown pillars

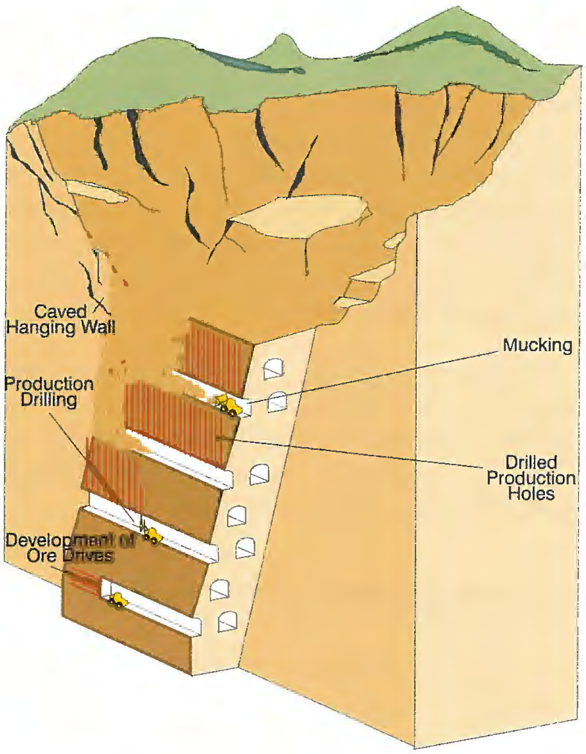


Figure 38: Illustration of a generic sublevel caving operation (Reproduced after Brady and Brown 1985)

generally becomes more difficult at depth and in high stress environments as the stress within the pillar increases with the progressive extraction of the mining blocks above and below.

For top-down or bottom-up mining strategies, the selection of a stope extraction sequence within a mining block can assist in managing areas of high stress concentrations and thereby reduce the likelihood of rockfalls. The following discussion outlines a number of rules and guidelines to be considered when designing mining sequences.

Stress analyses and mining experiences have clearly demonstrated that avoiding significant sized pillars is the best way of minimising areas of high stress concentration, rockburst and rockfall-related problems. In a steep tabular orebody, ideal sequences will have no pillars and may involve starting with one stope centrally located whilst progressing adjacent stopes in a way that allows the total excavation to expand outwards in an inverted "V" shape in bottom-up mining (See Figure 39) or a "V" in top-down mining.

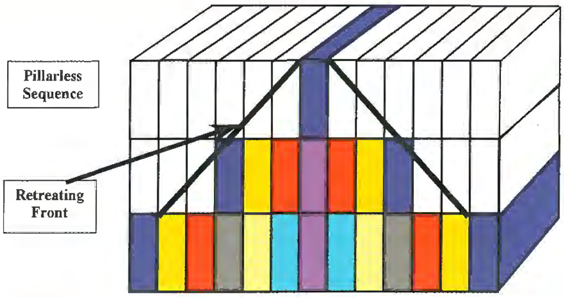


Figure 39: Schematic of a bottom-up pillarless mining retreat with a "V" shape extraction sequence (After Langille 1999)

The angle of the "V" created by the extracted stopes can also affect the stress re-distribution. In general, a very flat or open "V" is more conducive to stress problems than a sharp angled "V". However, a sharp "V" implies that mining must take place on numerous sub levels simultaneously and this may generate production and scheduling problems.

Alternatively, the initial stope could be located at one of the "corners" of the orebody, progressing the extraction by mining adjacent stopes diagonally, which also results in the elimination of in-situ pillars.

"Pillarless" mining using a continuous retreat sequence has the added advantage of pushing stress concentrations out towards the stope boundaries. This results in the stress distribution being relatively uniform across most excavations and reduces the possibility of high stress concentrations occurring.

Unfortunately, there are some practical limitations that make this ideal sequence difficult to achieve. Production rates may require several stopes to be extracted at different stages of production at the same time to ensure that mining schedules retain a degree of flexibility. In the "pillarless" open stope sequence, a stope cannot be blasted until the previously mined adjacent stope is filled. When cemented fill is used, enough time must be left for the fill to cure. It may take several years before the total area excavated provides enough stoping fronts in continuous retreat sequence to satisfy production requirements.

As a result, the general principle of a continuous retreat mining sequence is often applied with some modifications. In the majority of such cases, pillars cannot be totally avoided.

It is possible to use a combination of primary stopes and secondary pillars that expand in a triangular or inverted "V" shape (See Figure 40), or

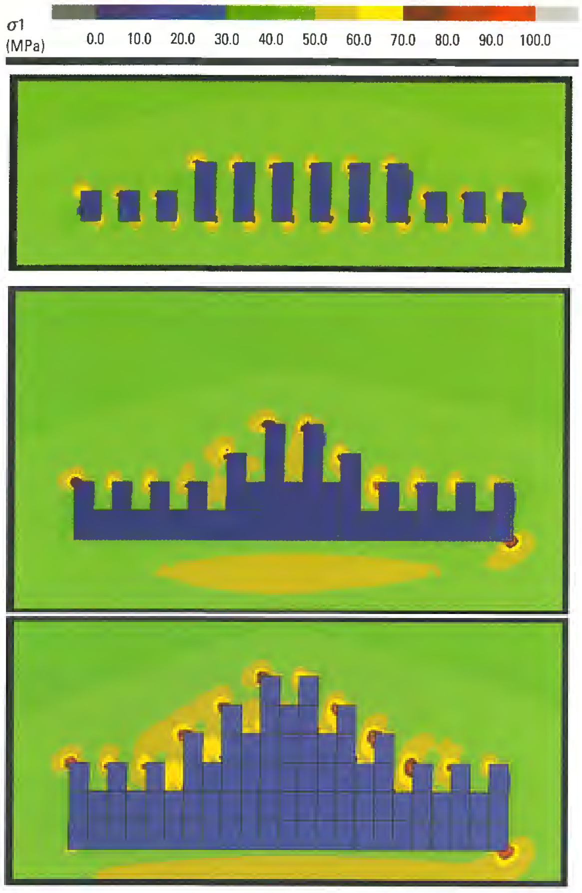


Figure 40: Series of computer model outputs showing stress redistribution around a triangular stope and pillar retreat

alternatively along a diagonal line. This will allow the production rate to be increased whilst managing increases in stress. The secondary pillars are then recovered as early as possible in a continuous retreat sequence, following a similar geometry "V" shape or diagonal. The stresses concentrated in the secondary pillars are then progressively shed towards the abutments.

Pillar recovery remains an area that can cause potential problems. The following rules could be applied to minimise some of the adverse effects:

- Pillars should be recovered as early as possible before they become highly stressed or deteriorate
- The mining of pillars should not result in "slender" shapes being formed. It is preferable to try to keep the dimensions "square or equal (squat shape)"
- Take major geological structures (faults) into account in the recovery strategy (i.e., one may use numerical modelling to verify that stress changes during pillar recovery do not cause large increases in the shear stress acting on faults)

- Focus on mining poor ground conditions early. If pillars in poor ground conditions are extracted late in the mining sequence, they may become difficult to recover safely

Mining sequences that promote the extraction of stopes converging towards a common point or a remnant (central) pillar (See Figure 41) are undesirable in elevated stress environments, as they progressively concentrate the stress in the shrinking pillar. This approach offers an economic incentive as the extraction can proceed using a single access towards the centre of the ore-zone. Extraction starts at both extremities of the orebody providing two mining fronts, retreating towards the central cross-cut connecting to a centrally located decline.

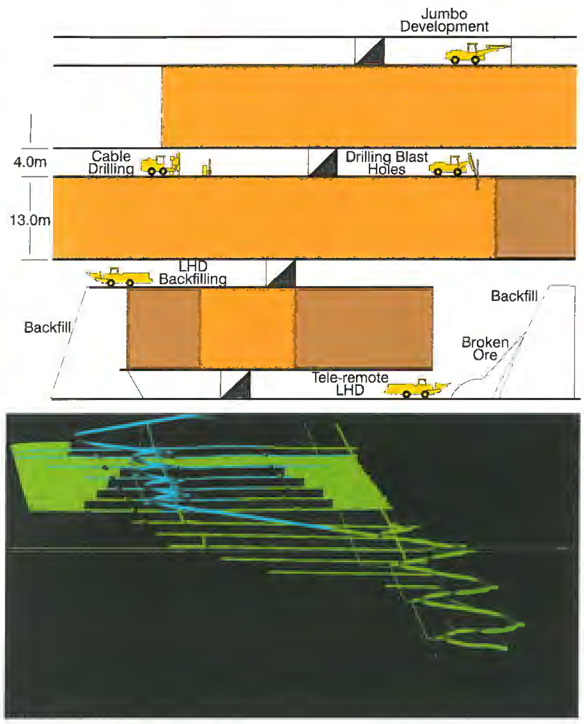


Figure 41: Illustration of a mining sequence resulting in a shrinking pillar towards a central access (After Sweby 2002)

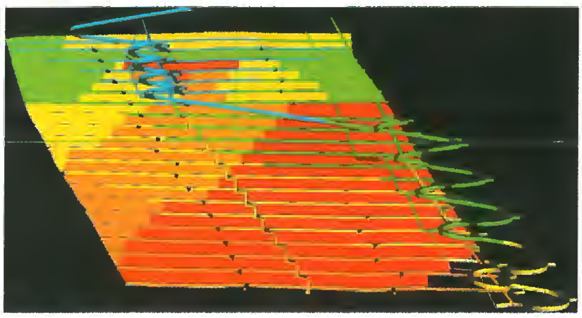


Figure 42: Conceptual top-down mining sequence showing a shrinking pillar in the upper levels and a diagonal retreat in the lower levels

Illustrations courtesy of Placer Dome Asia Pacific

A more appropriate approach in high stress conditions is to retreat diagonally from one end of the orebody towards the other, as shown in Figure 42. This requires that the decline and access be located at one extremity of the orebody. This also leads to a less productive mining sequence, as only one retreating face is available per level. Initially the long haulage distance between the retreating face and the decline can also slow down production. However, an orepass can be developed near the centre of the orebody to reduce the tramming distance during the development phase. The sequence displayed in the lower diagram of Figure 41 shows a shrinking central pillar approach at shallow depth where the stresses are low. A diagonal retreat has been adopted at depth to manage stress induced by mining (See Figure 42).

A number of more productive and flexible sequences could be engineered using footwall (or hangingwall) development and a number of cross-cuts to access the orebody. However, this would result in the establishment of mining horizons with higher development mining costs being incurred.

Extraction sequences should be designed to account for the following general rules as far as is practicable:

- Mining direction should advance towards solid ground rather than towards active or previously extracted areas
- Mining should retreat away from potentially "unstable" geological structures
- When a mining front approaches a potentially "unstable" structure, it should ideally be developed perpendicular to the structure. If this is not possible, an angle of at least 30 degrees between the advancing front and the structure should be maintained

5.1.4 MINING SIMULATIONS

The previous section described general rules for designing extraction sequences as a control measure to reduce the likelihood of rockfalls by minimising areas where stress may concentrate. The detailed analysis of the sequence is however better achieved using numerical modelling. Background on numerical modelling can be found in Section 3.2.1.

The sequence of extraction can be simulated on a stope-by-stope basis, or mining blocks basis, or by using snap-shots of the anticipated mine geometry (extracted stopes) at regular time intervals. This should be carried out annually or biannually. In most cases, the presence of backfill is ignored by the model as it is generally not stiff enough to influence the stress regime.

A number of mining scenarios can be modelled and the preferred sequence of extraction is determined on a modelled trial and error process. Figure 43 shows the model of a complex pillarless mining sequence. From these simulations, areas of high stress can be determined and anticipated stability problems can be assessed using the relevant failure criteria.

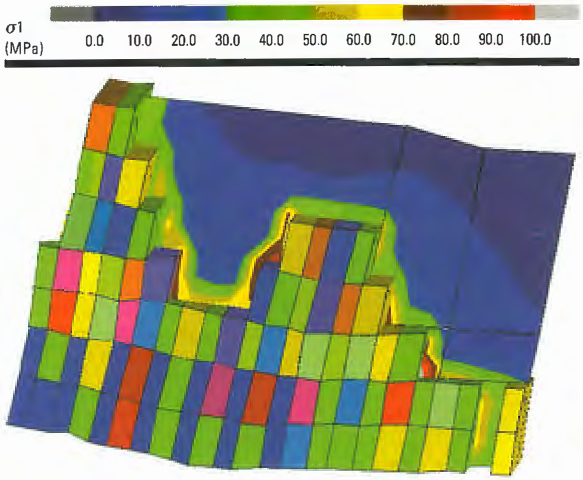


Figure 43: Computer model output showing stress redistribution around a complex pillarless mining sequence

The interpretation of such models remains intricate. However, the focus should be maintained on the relative difference between various mining scenarios rather than examining in detail the result of a particular model in anticipation of future field behaviour.

Strategies for improving safety (reducing rockfall risks) and productivity can be developed using mining simulations of a different nature than stress modelling. For example, the selection of different equipment with various degrees of automation and their effect on safety and productivity can be evaluated using mining systems simulations (Hall 2000). Commercial software such as "@ Risk[4]" can also be applied to evaluate the impact of changing mine design parameters on specific risks such as rockfalls. Finally, work by Owen (2003) can assist in tracking personal exposure to geotechnical risks and integrating this important data into risk models. These areas of mining simulations are relatively new to the mining industry and not widely used at present. Most of the discussions on modelling in this manual will therefore focus on the more widely used stress simulations.

5.1.5 REFINING MINE DESIGN

The mining simulation step of the rockfall management process (See Figure 1) aims to refine the preliminary design established in Step 3. This step occurs when optimising the design as a continuous refinement process throughout the mine life. This is shown by the "small loop" (simulate – refine – observe) in Figure 1. If a major change in the design, or in mine operations takes place, the refinement process "loops-back" to the risk analysis (Step 4).

5.1.6 MONITORING AND MODEL CALIBRATION

This section outlines the use of monitoring as a tool to optimise mine design strategies and control "mine-wide" risks of rockfall. It may involve underground observations and/or measurements of rock mass behaviour with the intent of verifying the validity of simulations.

Monitoring instruments in mines are sometimes used as a surveillance system to provide warning of incumbent hazards. In this application, monitoring is a tactical risk control measure addressing rockfalls within a specific area. This is discussed in Section 6.

A close match between observations/ measurements and the predicted behaviour from simulations will increase the confidence in the models used. Once confidence has been established, calibrated models become powerful tools for optimising mine design strategies. This may require some time to achieve as well as investment in instrumentation programs. When a poor correlation between monitoring data and model results is obtained, this can be interpreted in two ways. Either the model is not appropriate for the application, or the input data is incorrect and needs further adjustment. Decisions based on a poorly calibrated model can lead to flawed mine design strategies and may increase the overall geomechanical risks.

There are a number of monitoring tools used in underground mines with a range of capabilities, sophistication and costs. Systematic and well-documented underground observations can be one of the most powerful means of monitoring, yet it is perhaps one of the less sophisticated tools.

For example, experienced operators and staff can easily recognise signs of elevated and low stresses in underground excavations. The deformation of boreholes, the crushing of drive corners and rock noises are typical indications of high stress (See Figure 44).

[4] *Palisade Corporation*

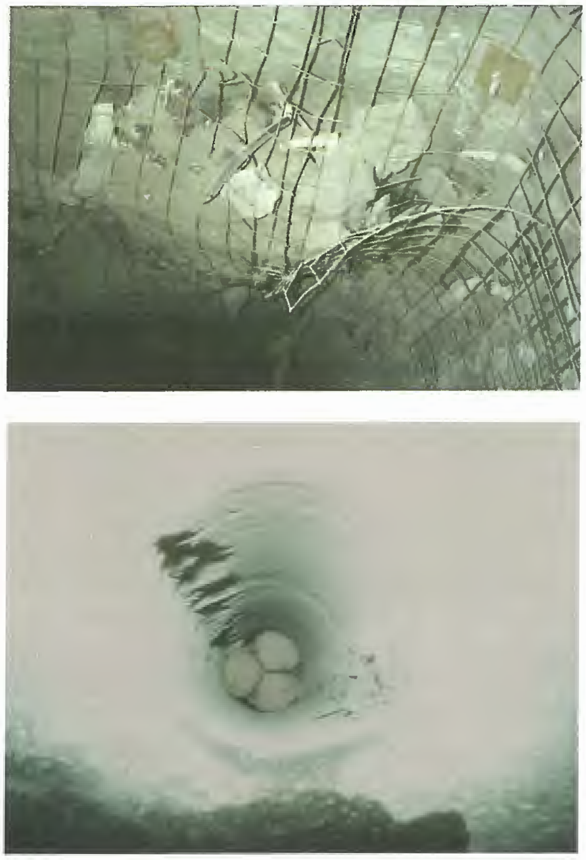


Figure 44: Photographs demonstrating observable signs of elevated stresses (Photographs courtesy of Chris Langille)

Relatively large blocks falling or sliding under gravity or cracks opening may be signs of a low stress environment (See Figure 45).

An efficient use of observational data will rely on systems to collect this information from the workforce, store it in a filing and/or computerised database system to allow retrieval and collation by location, time or mine geometry, level name, cross-cuts, stope name, etc. This can provide a wealth of "calibrating points" for numerical models as it would be expected that areas of high and low stress predicted by models generally match underground observations.

The coverage of underground observations as a monitoring/calibrating tool can be extensive if the workforce is trained and committed to observe and report. However, it remains limited to what occurs at or near the surface of excavations. Furthermore, most observations become noticeable only at the late stages of the rock mass failure process. Having a means of observing the early stages of failure could provide valuable information. Therefore, relying on more sophisticated monitoring systems, in addition to underground observations, is often a more effective way of managing risk.

The rock mass behaviour most often measured is deformation. This can be done at the surface of a drive using rudimentary instruments such as wooden wedges, pins, tape measurements and glass monitors. When cracks are opening, wedges are moving or discontinuities are sliding. These simple measurements enhance visual observations.

Rock mass deformation away from excavations can be measured from boreholes using various types of extensometers. Although extensometers measure only the relative movement between points attached to the rock mass (point measurements), they can provide an indication of what is happening beyond the surface of an excavation. Long extensometers can reach well beyond 100 metres from their installation point, although the installation can sometimes be challenging. More information on the different extensometers and data collection systems are readily available from commercial providers and are not discussed here.

Figure 45: Photograph and sketch demonstrating observable signs of low stress failure (Photograph courtesy of Mount Isa Mines Ltd)

One of the difficulties in using extensometer data for calibrating numerical models is that models simulate stress changes while extensometers measure deformation. The relationship between stress and deformation can be described using the elastic modulus. This is easily obtained from a small piece of core in the laboratory, but for in-situ rock masses, a number of factors need to be taken into account such as different rock types (lithology), the minor and major discontinuities, areas of failed rock masses, etc. It can be assumed that the in-situ elastic modulus describing the stress-deformation relationship of rock masses in the field is not only difficult to assess but is also quite variable according to location, orientation, etc.

Numerical models can easily calculate deformation from the modelled stresses. However, it is important to understand that the in-situ elastic modulus used in this calculation is only a very approximate estimation of reality, as it is difficult to account for lithology, discontinuities, etc. and therefore may require extensive calibration.

The so-called stress cells measure stress or stress changes in the field and can provide direct comparisons with model results. In fact, these instruments, which provide point measurement, also measure deformation rather than stress, but they do it on a very small scale. It is then assumed that at this small scale, the influence of discontinuities, lithology, etc., can be ignored and that the laboratory properties of the local rock surrounding the instrument can be used to calculate the stress from the small-scale deformation measurements. Stress cells are not widely used. They can be difficult to install, the readings can also be "unstable" and the interpretation of the results may sometimes be complicated. More information on the different stress cells and data collection systems are readily available from commercial providers and are discussed here.

Microseismic monitoring is an emerging monitoring technology rapidly gaining popularity, particularly with mines facing high stress and seismically active conditions. It has the distinct advantage of being able to monitor a complete volume of rock rather than a single point, providing a three-dimensional monitoring program.

Microseismic monitoring offers a totally different but complementary approach from that of traditional displacement based instruments. The design of microseismic systems aims at surrounding the area to be monitored, up to several million cubic metres, with an array of sensors (geophones or accelerometers). In principle, these sensors capture vibrations emitted as a result of the rock mass failing. More specifically, microseismic systems have the capability to be tuned to capture a range of vibration. This range can vary from small noises characteristic of early signs of rock mass failure occurring long before any displacement is exhibited, to the large rockburst registering on the Richter scale that may produce extensive damage.

Microseismic systems are capable of estimating the position of an event, rock mass failure, using triangulation techniques from the multiple sensors recording the event. They can also estimate the magnitude of an event from the analysis of the seismograms recorded by each sensor. Figure 46 shows a typical plot of seismic monitoring. Clusters of events clearly depict areas where the rock mass is failing due to elevated stress. The hazard generated by seismicity is classified from low to very high according to the nature of the seismicity.

Microseismic monitoring may become a powerful model calibration tool if this type of output is regularly compared with the results from stress simulations. It is expected that as the model calibration improves, areas of high stress will coincide with areas of intense seismic activities.

Microseismic monitoring involves sophisticated equipment. The purchase and installation cost of the equipment can be relatively onerous; several hundred thousand dollars for a mine-wide system. The system also requires regular maintenance and tuning. Although the operation of the system can be automated, a significant and dedicated effort is required to analyse seismic monitoring data for the purpose of calibrating numerical models.

Cavity Monitoring System (CMS) instruments can be used to reproduce an accurate outline of voids where safe access to personnel may not be available (non-entry stopes, rises, orepasses etc.) by using reflective laser technology to calculate distances to the boundaries of the respective excavation. The data collected by the CMS allows a comparison to be made between the design and actual excavation outlines. This can then be used to take pro-active steps to manage blasting practices, highlight structural overbreak, identify high stress concentrations, etc.

Figure 46: Seismic events displayed on a mine plan indicating areas where the rock mass is failing

5.2 Tactical Control

The tactical control of rockfalls at the mine face or at individual work areas is generally achieved by reducing the likelihood of an occurrence through scaling the area or installing ground reinforcement and support. In certain circumstances, access restriction will be required to reduce the exposure of personnel to rockfall hazards to an acceptable level. Access restriction would apply where the likelihood of rockfalls remains higher than would be experienced in normal operating conditions.

If scaling procedures are not successful in removing wedges or large blocks that are still potentially unstable, other procedures developed by the mine, such as drilling holes into or behind the unstable rocks and firing them, may have to be used.

5.2.1 SCALING STANDARDS

Accident statistics show that scaling is one of the most dangerous activities underground. The development and implementation of safe operating procedures for scaling is an essential step in the management of rockfall risks. The following series of tables suggests responsibilities that could be assigned to key personnel for implementing scaling standards and safe operating procedures at mine sites. However, these suggested responsibilities should not take precedence over any Australian State or Territory regulations, guidelines or legislation.

The following material was referenced to develop the scaling standards:

- Mount Isa Mines Ltd – Copper Mine (2002), "Manual Scaling"
- Western Australian Department of Minerals and Energy (1997), "Guidelines for Underground Barring Down and Scaling"

MANAGERS
• Each underground excavation where personnel travel is scaled and maintained in a safe condition
• All staff and employees under the manager's control are suitably experienced, trained, assessed and deemed competent to comply with their responsibilities in maintaining the scaling standard
• Appropriate mining and personal protective equipment is available to carry out scaling tasks
• Any production and development schedule considers making an allowance for the time required to carry out an ongoing mine-wide check scaling program
• The scaling practices and standards comply with all legislative requirements

Table 18: Proposed list of manager's responsibilities for the implementation of scaling standards

GEOTECHNICAL PERSONNEL
Sufficient information is provided that ensures practical and effective scaling management procedures can be developed/ implemented for all excavations, including: • Identifying structures (joints, faults, shears, etc.) that may intersect or combine to form wedges, large unstable blocks or planes of weakness • Interpreting the influence of any measured or induced stress or seismic activity • Providing information on the optimal excavation design profile to minimise scaling • Monitoring the impact of excavation size mining sequence on stability and productivity • Modelling and monitoring the effect of large voids on adjacent excavations or travel ways • Interpreting the results of updated modelling or simulations and assessing any potential hazards or hazardous areas that may impact on scaling, safe work practices and procedures within the mine
Providing assistance to develop methods of assessing whether excavations have been adequately scaled and the scaling management program is effective by: • Documenting observations • Reviewing daily excavation risk assessments completed by underground personnel • Undertaking formal inspections/audits (weekly, monthly etc.) • Having regular discussions and reviews with supervisors and managers of ground conditions in all working areas
Support for supervisors and operations personnel including: • Communicating any effects or hazards that may be encountered (what to look for when scaling) by changing mining methods, changing stress conditions, mining in undeveloped areas, or near existing stoping areas, or in new rock types or if any changes to the mining sequence are made • Consulting with and providing guidance for workplace trainers on the geotechnical content of training material for employees carrying out scaling duties (ground or stress conditions, restricted access areas etc.)

Table 19: Proposed list of geotechnical personnel responsibilities for the implementation of scaling standards

SUPERVISORS
• Scaling is undertaken in all areas in accordance with workplace risk assessments, site practices and procedures • Only employees trained and deemed competent to carry out scaling are allowed to do so • Employees are provided with on the job assistance to understand ground conditions and scale correctly as required • The mine-wide scaling plan and associated record of check scaling activities are updated as soon as practicable after completion of any such work • Geotechnical engineers, supervisors and/or managers are notified when excessive scaling identifies a rockfall hazard that may warrant a re-evaluation of ground conditions or support requirements • Unsafe areas are identified and barricaded to prohibit entry

Table 20: Proposed list of supervisor's responsibilities for the implementation of scaling standards

WORKPLACE TRAINERS
• All underground personnel are capable of assessing ground conditions, recognising loose rock hazards and scaling in their normal place of work. Competence can be defined as trained and assessed by practical and theory training to carry out the scaling duties they will be required to perform • Scaling procedures are updated as directed by management. This may be a function of periodic review, discussions with geotechnical personnel, accident/incident investigations, or as a result of changing ground conditions • Training material standards and competencies for scaling are current with respect to approved industry practice (national training standards etc.), government guidelines, regulations, legislation and site conditions

Table 21: Proposed list of workplace trainer's responsibilities for the implementation of scaling standards

MINE WORKERS
• Only undertake activities they are trained for in ground conditions they feel capable of assessing and scaling safely • Scale in accordance with the site's standard practices and procedures • Regularly check their work areas for loose rock and scale as required • Report any hazardous ground conditions that cannot be scaled safely or requires "excessive" scaling to the relevant supervisors, geotechnical personnel or managers and, as soon as possible, barricade the hazardous area to prohibit entry to all personnel

Table 22: Proposed list of mine worker's responsibilities for the implementation of scaling standards

A process to assist with the task of developing and implementing scaling standards is illustrated in Figure 47 and described in the following sections.

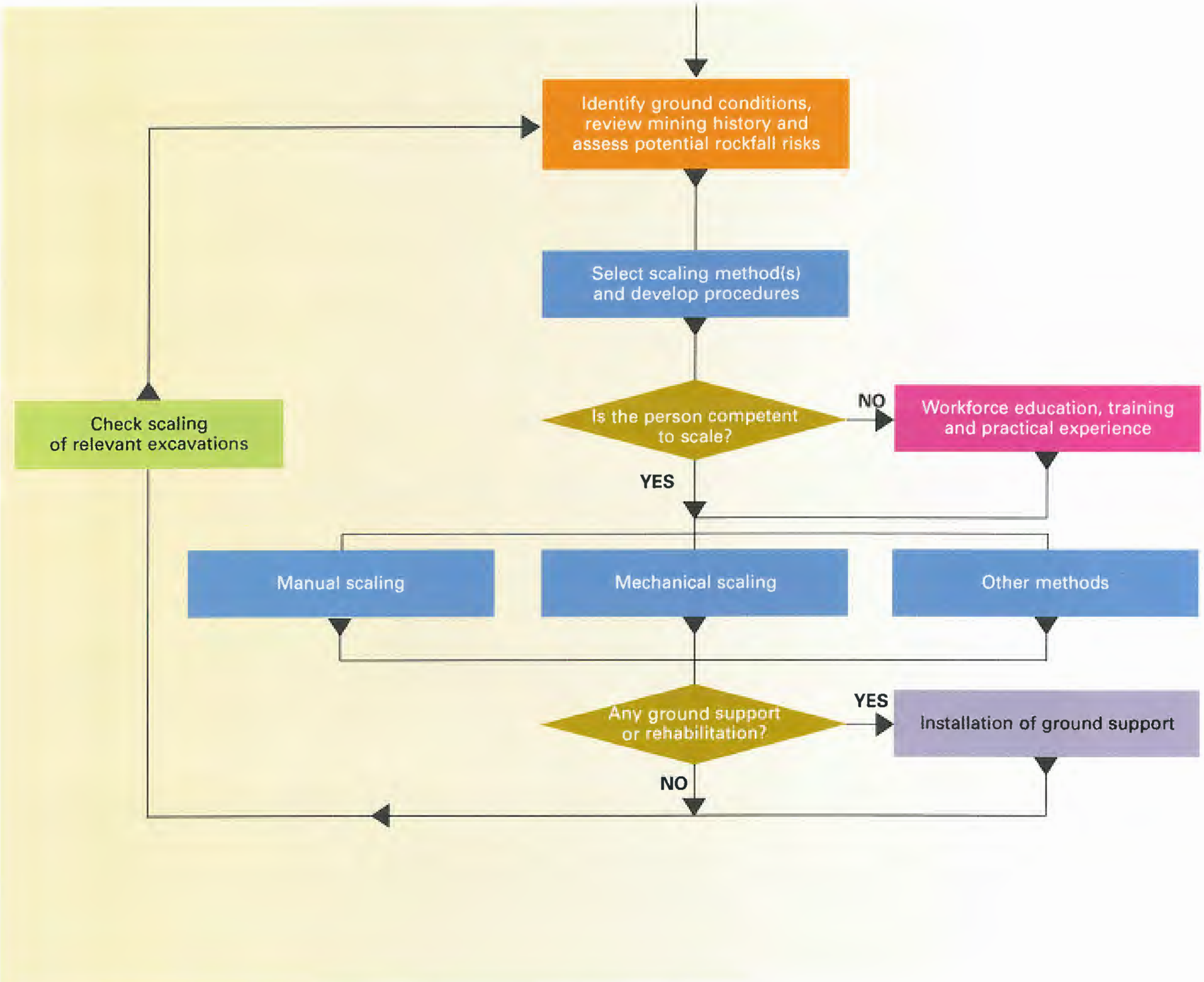
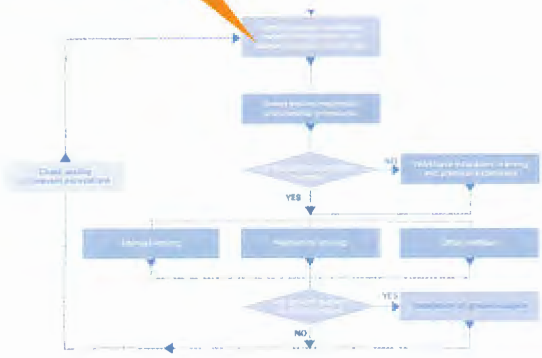


Figure 47: Flowchart describing the process for the development and implementation of scaling standards

Identify ground conditions, review mining history and assess potential rockfall risks



5.2.1.1 Identify ground conditions and assess potential rockfall risks

Ground conditions and the potential risk of rockfalls can be effectively assessed using the techniques outlined below. Procedures can then be developed to cater for different ground conditions and levels of risk.

Observe

The presence of any, or a combination of the following conditions that may cause instability:

- Faults/ cracks
- Intersecting joints that may form large wedges
- Large, shallow dipping joints
- Zones of weakness
- Signs of stress – this may include continuous splitting or spalling of small rocks
- Evidence of weathering or large inflows of water
- A large change in the excavation profile (from the last section of excavation advance)
- Excessive blast damage
- Excessive loose rock behind mesh or other types of surface support
- Signs of movement or slip between opposite sides of joints faults, etc.
- fresh rocks on floor of excavations that have recently fallen from backs, walls, faces
- Recent appearance or disappearance of water or wet surfaces

Listen

Listening to determine whether there is any instability, or if a rockfall could be imminent, is an important part of the scaling process. This could include any, or a combination of the following:

- Rock noise caused by high stress
- Unusual rock noise – any sound that is not usually heard when re-entering an excavation, either after blasting or when travelling in established areas
- Striking a rock surface with the tip of a:
  - scaling bar
  - drill rod (jumbo, robolter, production drill, etc.) or
  - the moil tip of a scaling tool on a purpose-built scaling machine

  will provide a means of determining whether the rock is loose or solid.

A drummy or hollow sound means the rock could be loose. A high pitched or ringing sound means the rock could be solid. Scaling alone should never be relied upon to decide whether the ground is safe or secure. Any sounding of ground should be carried out as part of a thorough inspection process to ensure scaling minimises the risk of personal injury from rockfalls.

It is difficult to listen for rock noises whilst using mechanised scaling methods due to the noise generated by the equipment. Pausing equipment operation periodically can help to overcome this problem.

Clean Surface

Washing the walls, backs and face of an excavation using a water supply of adequate volume and pressure can assist in the rapid removal of:

- Dust which may be trapped in cracks/joints, allowing cracks/joints to be more easily observed
- Very loose rock
- Keystones that may be preventing much larger rocks from falling
- Any rocks which may be loosened but partially trapped at the edge of the last section/row of surface support
- Surface support loosened and/or damaged by blasting (shotcrete, liners, mesh, etc.).

It should be noted that the application of water in certain ground conditions (e.g. high stress), can cause rocks to fall off backs and walls more readily than may normally be expected in lower stress areas. Under such circumstances, entry into the area that has been washed may have to be restricted for a defined period to minimise any such exposure of personnel and equipment.

Look for Planes of Weakness

Natural planes of weakness or structures such as joints or faults are important components in the formation of slabs, blocks and wedges that could be unstable and require scaling. It is also important that persons carrying out any scaling activities can recognise and take the time to observe the:

- Gap or joint opening
- Strike and dip
- Length
- Spacing
- Roughness

of structures that are exposed in the backs, walls and face of an excavation. This will assist in locating loose material to be scaled and identify any combination of weakness planes that may cause a more serious hazard.

Look for prominent joint sets that could have a significant influence on potential rockfalls.

Look for the lie of the ground by making visual observations from different directions. Sometimes, rock masses can look stable from one direction and exhibit blocky appearance, movement and open joints from the opposite direction.

Look for Intersecting Joints/Structures

Where three or more joints or structures intersect in an excavation, slabs, blocks or wedges can form that may become unstable. It is important to understand and consider these possible failure mechanisms that may occur or be present in the different ground conditions within the mine. This will also assist in developing the most effective scaling procedures and determine whether manual, mechanical, or other scaling methods are undertaken.

The main failure mechanisms observed in underground excavations are shown in Table 23.

STRUCTURALLY CONTROLLED/ GRAVITY DRIVEN	STRESS INDUCED/ GRAVITY-ASSISTED
Sliding	Ejection (rockburst)
Gravity broken bedding	Continuous spalling, crushing, squeezing
Gravity wedge	Relaxation

Table 23: Common underground failure mechanisms classified as structurally controlled or stress induced

Look for Unstable Rock

Unstable material can usually be identified by sounding the ground with a scaling tool. However, in some cases, rock that may be deemed stable when initially scaled, could fall or be ejected at some later stage due to stress changes. This can be caused by factors such as the natural redistribution of stress which may take place after blasting or induced stress from extraction in adjacent areas. This is a key consideration in defining re-entry times after blasting/prior to scaling.

Look for Keystones

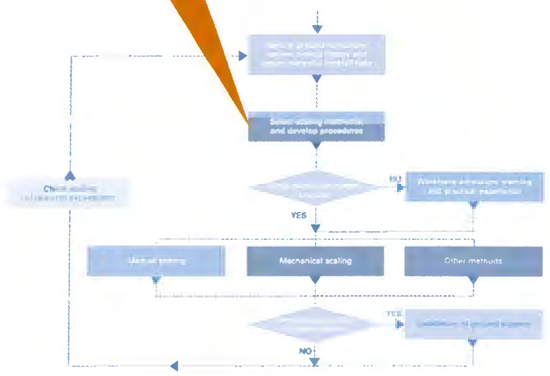
Keystones that hold other rocks in place should be identified during the inspection process where possible to determine whether there is potential for a larger fall if the keystone is removed. Early identification of keystones is important to ensure that personnel remain remote from the danger area when they are dislodged.

Use Adequate Lighting

High-powered lighting should be used to properly inspect the backs, walls and face of an excavation. This will more clearly allow potentially unstable rocks to be identified before and during the scaling process.

Lighting of this type fitted to mobile equipment will also improve visibility when scaling in high excavations.

Select scaling method(s) and develop procedures



5.2.1.2 Select scaling method(s) and develop procedures

When deciding whether to scale manually, mechanically or using other methods and developing the relevant procedures, careful consideration should be given to all the available geotechnical information, site-specific conditions and mining methods that will be employed. This may mean a combination of manual scaling and mechanical scaling methods are used in different sections of a mine and/or are co-dependent on a number of other activities.

The selection should also consider the information listed in Table 24.

There will be some common points that apply to all methods of scaling. These include:

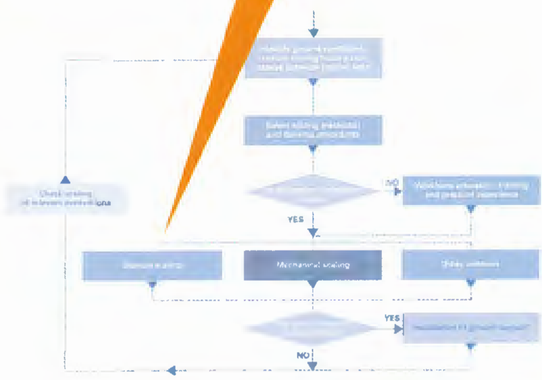
- Conducting a work area risk assessment
- Ensuring adequate ventilation is installed
- Installing appropriate dust suppression controls
- Checking the area for misfires or butts

Once the scaling method(s) has been decided upon, the relevant Safe Operating Procedures (SOPs) can be developed. It is good practice to use risk assessment techniques to assist in the development of SOPs as outlined in Section 4.3.

SCALING METHOD SELECTION PARAMETRES
Ground conditions: The ground may be defined into such categories as good ground, poor ground, very poor ground, highly deformable/sheared ground or other conventions such as geotechnical domains. Any definitions that are created should be clearly understood by all mine employees
Risk: Evaluating risk when scaling should consider: • Task and location (e.g. initial development, check scaling, development or rehabilitation adjacent to existing stopes/ infrastructure) • Rate of advance (with regards to estimated time to scale each advancing excavation) • Excavation dimensions • Mining method • Seismicity (with reference to such issues as re-entry times after blasting and prior to scaling) • Proximity to voids/stopes and interaction with other mining activities (e.g. production blasting) • Working near vertical openings (shafts, rises, orepasses, etc.) • Type of equipment used/selected (eg. purpose-built scaler, jumbo, robolter)
Legislative requirements: These may vary considerably depending on the State or Territory and could include: • Scaling in "high" excavations • Mandatory workplace risk assessments • Workforce training and competency standards • Any relevant Australian Standards

Table 24: Parameters to consider for the selection of a scaling method

Manual scaling



5.2.1.3 Manual scaling

Prior to commencing scaling, the backs, walls and face should be thoroughly washed down with water. This will facilitate inspection of the rock surface. If the area cannot be made safe by manual scaling or cannot be reached safely using the longest scaling bar, an alternative means of scaling will have to be employed. Until the heading has been scaled by an alternative method, it should be barricaded to prohibit entry.

The five main points that must be adhered to when manual scaling are:

THE FIVE MAIN POINTS FOR MANUAL SCALING

Scaling Bar

- Use a scaling bar of correct length and in good condition
- The bar should be straight and have sharp tips
- The bar should be long enough to safely reach the area to be scaled
- Never hold the bar in front of the body when scaling – a sudden fall of rock could result in the bar being pushed in front of the person scaling and cause injury
- Push or pull the bar in an upward direction when scaling – this will reduce the chance of stumbling into the danger area if a rock falls suddenly

Footing and Retreat

- Have a firm footing and a clear safe retreat
- Make sure the area where you are standing is stable and clear of obstacles
- Check that the area behind where you are standing is clear so you can move back quickly in the event of an unexpected fall of ground
- Remember that rocks that have been scaled in front of you may later become obstacles in any retreat path. Continue to check your means of egress

Scale from Good Ground to Bad Ground

- Plan the approach to the area to be scaled to ensure that you are working under ground that has already been scaled/bolted. This will depend on any site procedures in force for working under unsupported ground
- The sequence for scaling surfaces in an excavation should be: back, walls, face (where present)

Watch for Unexpected Falls

- Never assume that an excavation will remain stable after scaling
- Check the area regularly during the course of other tasks
- When ground is exposed to air, water, stress or other activities (drilling, etc.), loosening of the ground can take place. Continue to assess or scale during the course of other activities as required

Drop the Bar if a Rock Falls Towards You

- Rocks can slide down or fall on the scaling bar. Dropping the bar will reduce the possibility of the rock reaching the hands or arms of the person scaling
- Retreat quickly after dropping the bar to avoid any other rocks that may fall into the danger area

Table 25: Key elements of a manual scaling procedure

Manual Scaling in High Excavations

Site management or guidelines (e.g. Underground Barring Down and Scaling Guidelines, Western Australian Department of Minerals and Energy, 1997), can define high excavations. A system for manual scaling in these conditions could be developed which would include a means of elevating persons carrying out these activities to a suitable height.

The equipment and work platforms used to elevate personnel for scaling high excavations should be designed to be strong, safe, effective and able to withstand the impact forces and loads that may be encountered during scaling.

This type of equipment could include, but is not limited to, work platforms for mobile mining equipment on:

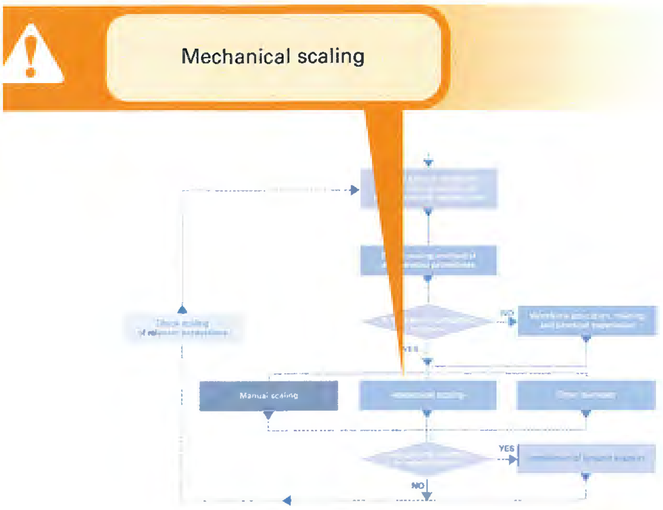
- Scissor lifts
- Integrated tool carriers
- Vehicles fitted with articulating telescopic booms

Note: It is not recommended that personnel scale from the bucket of a loader as there is no safe retreat from the danger area if an unexpected fall of ground occurs.

The following should also be considered in relation to manual scaling from an elevated work platform on mobile equipment:

- Operator training
- An effective means of communication between the vehicle operator and the personnel scaling (where applicable)
- Safety rails around the perimeter of the platform are of a suitable height
- Vehicle hydraulic systems fitted with a system that prevents a rapid, unplanned drop of the platform (AS 1418.10 – 1996)
- A dual raising/lowering control arrangement (operator's cab and work platform)
- A fail-safe locking device to attach the platform to the vehicle (where applicable)
- Engineered to all the relevant Australian standards
- Number of persons permitted on the platform when scaling, tramming (if permitted) etc.
- Condition of the work platform floor
- Development of specific procedures for scaling from an elevated platform

It is important that each mine develops safe operating procedures for manual scaling in high excavations using elevated platforms to take into account all the variables specific to their operation and the type of equipment used.



5.2.1.4 Mechanical scaling

The main points to consider when mechanically scaling are:

- Selection of rig (scaler, robolter, jumbo, etc.)
- Ensure the rig is located under scaled and/or supported ground as per the relevant site standards
- Connect services/power to the rig when required
- Set up the rig using jacks or other devices provided to safely stabilise the machine for scaling operations
- Wash down the area to remove or identify loose rock and suppress dust

Specific instructions related to the type of equipment used for mechanised scaling are suggested below (but not limited to):

EXAMPLE OF SPECIFIC INSTRUCTIONS FOR MECHANISED SCALING

For purpose-built scaling equipment:

- Ensure the correct moil tip is correctly fitted to the scaling head
- Extend the boom and scaling head to the rock to be scaled
- Position the boom so that it is kept out of the potential path of falling rocks
- Insert the moil tip into the cracks or crevices behind the rock, levering off loose material as per equipment manufacturers operating procedures
- Scale as required, removing all loose rock, working the boom from side to side in the backs, walls and face of the excavation
- To replace a moil tip, move the boom under scaled/supported[5] ground, switch off the power/engine and install new parts in line with the manufacturer's specifications

For drilling equipment:

- Use the most appropriate drill rod for scaling as defined by site management
- Fit the correct sized bit to the drill rod
- Extend boom and drill rod to the rock to be scaled starting in the backs
- Position the boom so that it is kept out of the potential path of falling rocks
- Turn water on and run the drifter hammer and rotation as required using site specifications
- Drill into the cracks or on the rock surface to remove loose rock
- Scale as required, removing all loose rock, working the boom from side to side in the backs, walls and face of the excavation
- If the drill bit or rod needs to be changed whilst scaling, the bit and/or rod should be rattled loose, moved under scaled/supported ground[5], the booms shut down and the bit/rod replaced and retightened

Table 26: Work instructions for operating equipment for mechanical scaling

[5] *As per site procedures in force for working under unsupported ground.*

Regardless of general industry practices, all duty of care compliance requirements must be considered by managers in justifying the safety of any such scaling operations. All relevant legislation, regulations, guidelines and Australian standards should also be examined before developing procedures or carrying out any mechanical scaling with non-purpose-built equipment.

Notes:

i. Mechanical scaling procedures should be combined with any other site safety procedures such as working under unsupported ground. This may recommend that personnel or the rig itself are not exposed to the unsupported ground hazard. Most mines in Australia currently employ the "no travelling under unsupported ground" rule.

ii. As drill jumbos, robolters etc. are not purpose built scaling machines, certain precautions should be considered such as damage to the boom(s) of the rig which may occur. The procedure that is developed should therefore take into account all the relevant consequences of personal exposure, mechanical damage and effectiveness of scaling when using such a method.

iii. Some private and public organisations do not encourage the use of drilling equipment as it is not built specifically for scaling. Although not universally endorsed throughout the world, such methods are widely used and accepted within Australia.

5

Other Methods

Installation of ground support

5.2.1.5 Other methods

If the size of the potentially unstable slab, block or wedge is sufficiently large, it may not be practicable to use manual or mechanical scaling methods. In these circumstances, it may be necessary to use drill and blast methods to remove the potentially unstable ground. The issues requiring attention include, but are not limited to:

- Location of potentially unstable ground
- Likely consequences of blasting the unstable ground, for example, potential for triggering further instability
- Access for drilling equipment to be set-up in a safe position
- Number, length, orientation, of stripping holes to be drilled
- Charge weight of explosives required to dislodge unstable ground
- Need for remote charging explosives into drilled holes
- Barricading access ways to areas where potentially unstable ground exists
- Initiation of explosives using safe, recognised, procedures

5.2.1.6 Support or rehabilitation requirements

If being carried out prior to the installation of support, scaling forms an integral part of establishing a safe, stable excavation. Refer to the Support Standards, Section 5.2.2, to view the role of scaling in the process with respect to the installation of ground support. Rehabilitation is discussed in more detail in Section 5.2.2.6.

Check scaling of relevant excavations

5.2.1.7 Check scaling of relevant excavations

Check scaling may be carried out in excavations on a local, as required, or mine-wide basis as part of a defined program. Check scaling is generally relevant where not all exposed rock is surface-supported, or where there is no surface support installed on either the backs or walls of an excavation. The framework and detailed plan of any check scaling program developed for an underground mine should consider the elements shown in Tables 27 and 28.

KEY ELEMENTS OF A FRAMEWORK FOR CHECK SCALING
• Effective integration with the development and production schedules, ensuring enough time and resources are available to carry out check scaling activities. This may involve scheduling check scaling using the same software or methodology employed to create development and/or production schedules • Targeting problem areas identified by regular inspections • All excavations are considered in the process, including escape ways, refuges, shafts, rises and mine infrastructure used for travelling by personnel or equipment, or excavations that accommodate fixed plant, crusher chambers, substations, workshops, etc. • Manual or mechanical check scaling methods used are clearly established in all areas depending on ground conditions, excavation height, type of surface support, proximity to voids, seismicity and any other relevant site specific issues • Detailed inspection and sign-off by geotechnical staff and managers that may be required prior to: – Any check scaling and/or rehabilitation in old workings – Work being carried out in areas that have not been check scaled for long periods – Check scaling adjacent and close to active stoping areas/stope brows – Check scaling where installed ground support is thought to be inadequate for future operations and special procedures may be required prior to commencing any rehabilitation activities • Periodically reviewing all risks associated with check scaling activities as the mine develops, making changes to procedures and practices as required • Regular updates/discussions with the workforce to seek their input and communicate the program status, flag any new hazards or changes associated with the program that will affect check scaling practices or procedures

Table 27: Key elements of a framework for check scaling

KEY ELEMENTS OF A DETAILED PLAN FOR CHECK SCALING
• Be updated on a regular basis to show the current status of check scaling activities • Be displayed in prominent areas so that the workforce, supervisors and managers can easily view the program's status • Show a date-based colour scheme (or similar) highlighting the areas planned to be scaled for the chosen time frame (week, month, period, etc.) • Display and detail any known hazards, caution areas or areas designated "No Unauthorised Entry" • Be updated by supervisors immediately after check scaling activities have been completed • Be maintained in an archive file when completed. This will assist in providing a reference for geotechnical personnel, managers or additional information for design engineers planning future development. It also provides a record for any statutory compliance or audits

Table 28: Key elements for a check scaling plan

5.2.2 Ground Support Standards

Ground support standards aim at standardising the ground control regime within different areas of the mine, generally related to geomechanical domains. The type, length and pattern of reinforcement, the surface support specification, the installation procedure and all other information relevant to the reinforcement and support of excavations may be included in the ground support pattern. An example of a ground support standard implemented at a mine in Australia is shown in Appendix 2.

The ground support standard is generally a minimum requirement and unless otherwise specified by a procedure, operators and supervisors should have the liberty to increase support, according to the particular local conditions.

The ground support standards in this section were developed after reviewing current industry practices and associated documents. The authors would like to acknowledge the following:

Mount Isa Mines Ltd (2002), Ground Support Standards – Copper Mine.

Newmont Australia (2000), Underground Ground Control Health and Safety Management Standard.

Whilst scaling is used to temporarily secure the ground, the installation of ground reinforcement and support is the principal means for reducing the likelihood of rockfalls for the serviceable life of excavations. In this section, material is presented to assist site engineers in the development and implementation of ground support standards. The following series of tables suggests responsibilities that could be assigned to key personnel for implementing ground support standards and safe operating procedures at mine sites. However, these suggested responsibilities should not take precedence over any Australian State or Territory regulations, guidelines or legislation.

MANAGERS
• The standards are developed to provide a safe, stable working environment • The standards comply with all relevant legislative requirements • The standards can or will form part of the ground control management plan developed for the site • All staff and employees under the manager's control are suitably experienced, trained, assessed (where required) and deemed competent to comply with their responsibilities in maintaining the ground support standard and assessing ground related hazards at all times

Table 29: Proposed list of manager's responsibilities for the development and implementation of ground support standards

GEOTECHNICAL PERSONNEL
Ground support design considers and utilises all available and relevant geotechnical data, as well as: • Mining method/extraction sequence • Effect of stress • Effect of voids, voids management and stope filling methods Changing ground conditions are proactively monitored and addressed by: • Frequent excavation inspections and recording of data • Good communication with supervisory staff and employees to ensure hazards are being identified and managed on a daily basis • Periodic risk assessments of current mining practices • A system to modify support standards that will maintain stable excavations in designated work areas as required Provide assistance to develop methods of checking the condition of ground support and ground conditions using such methods as: • Documented observation • Pull testing • Well managed, thorough check scaling procedures and practices • Formal audits Support for supervisors and operations personnel including: • Communicating any effects or hazards that may be encountered (what to look for) by changing mining methods or mining in new areas • Consulting with and providing guidance for workplace trainers on the geotechnical content of training material for employees installing ground support

Table 30: Proposed list of geotechnical personnel responsibilities for the development and implementation of ground support standards

SUPERVISORS
• The ground support standards are maintained • Quality control systems that have been implemented are being adhered to by all employees installing ground support • Geotechnical personnel are notified of ground conditions that may be hazardous to personnel or equipment and work is suspended in the area of concern until an action plan to deal with the hazard is formulated • Work ceases in any area where a significant rockfall or seismic activities takes place, the danger area is barricaded, the incident is reported to geotechnical personnel and the relevant managers as per site operating procedures

Table 31: Proposed list of supervisor's responsibilities for the development and implementation of ground support standards

WORKPLACE TRAINERS
• All personnel installing ground support have been deemed competent to carry out their duties. Competent can be defined as trained, assessed and having received the required "hands-on" experience to install the current ground support designed for their normal places of work • All other personnel working in the mine who are not installing ground support have been trained, assessed and deemed competent to be able to: – Understand ground conditions and failure mechanisms – Recognise and report on the type and location of hazardous ground conditions to carry out their specific duties in a safe manner with respect to their work environment • Ground support installation procedures are updated on a regular basis • Hazard identification and risk assessment materials are provided to assist in the prevention of rockfalls • Training material standards are current with respect to national standards, approved industry practice and the respective State and Territory regulations/legislation

Table 32: Proposed list of workplace trainer's responsibilities for the development and implementation of ground support standards

MINE WORKERS
• Ground conditions are assessed as per the site's procedures • Appropriate action is taken to ensure a safe workplace • Any ground condition hazards that present, or are perceived to present a safety risk that the employees deem outside their ability to control are to be reported to the relevant supervisors, geotechnical personnel or managers in a timely fashion consistent with site and regulatory standards

Table 33: Proposed list of mine worker's responsibilities for the development and implementation of ground support standards

A process to assist the task of developing and implementing ground support standards is illustrated in Figure 48 and described in the following sections. It should be noted that the proposed process has many common elements with the overall rockfall risk management process shown in Figure 1. Many of these common elements are only briefly discussed here as more details can be found in other sections of this manual.

The basis for ground support standards, including the bolting patterns and the type of bolts, are often laid out at the feasibility study stage. The details and refinement of the standard evolves as more information on in-situ ground condition is gained. The refinement of the ground support standards is more effective if all steps of the process described in the following sections are well documented.

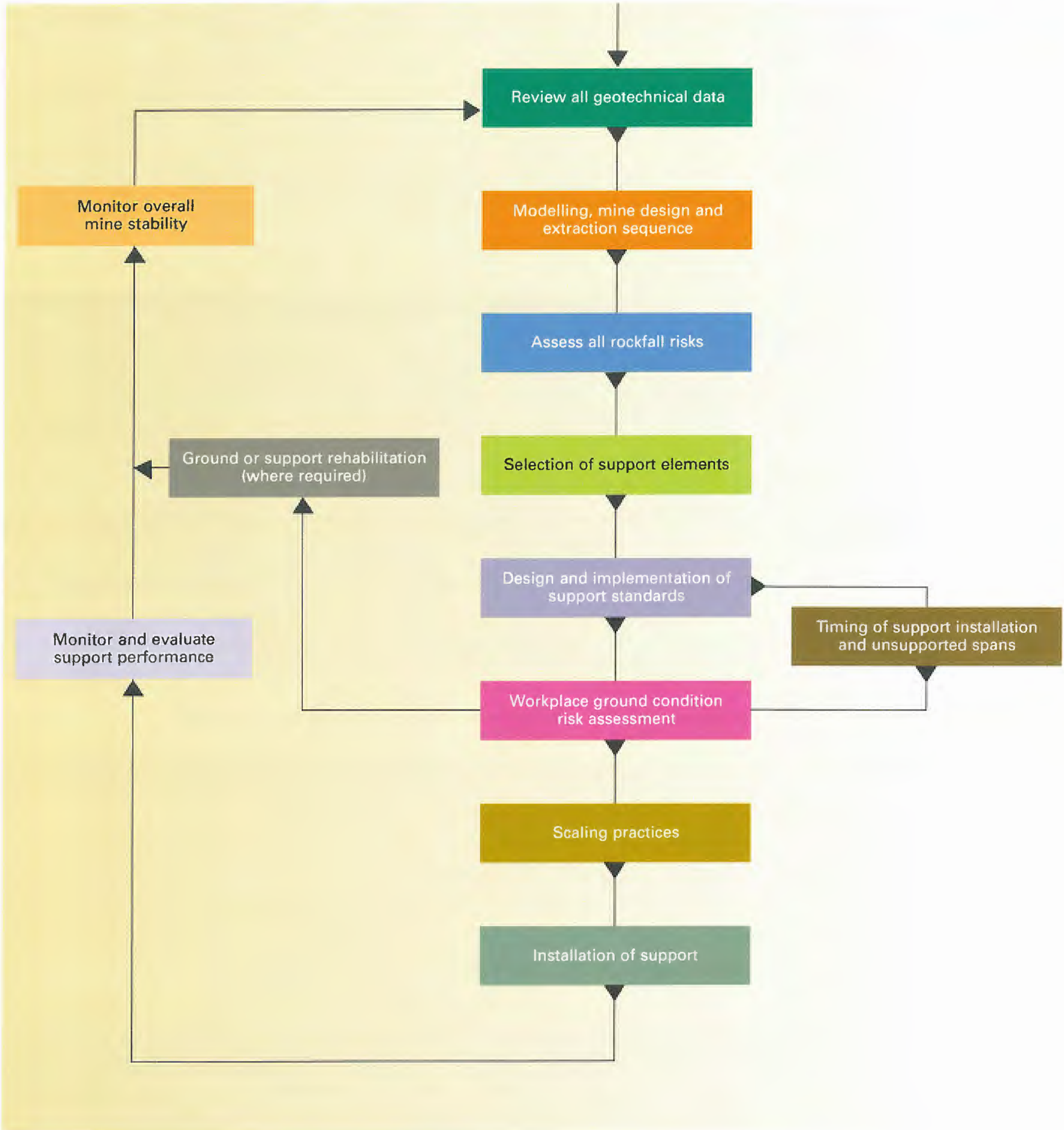


Figure 48: Process for the development and implementation strategy of ground support standards

Review all geotechnical data

5.2.2.1 Review all geotechnical data

This would involve the gathering of information from a number of sources or databases which could include:

TYPE AND SOURCES OF GEOTECHNICAL DATA	
• Structural data	• In-situ stress field
• Logged diamond drill core	• Void data (where relevant)
• Borehole logging (using a borehole camera)	• Materials properties
• Face mapping	• Hydrogeological studies

Table 34: List of geotechnical data and their relevant sources that could be reviewed as a step in the development of a ground support standards process

More specifically, some of the rock mass properties and indexes (See Sections 1 and 2 of this manual), to be determined could include, but are not limited to:

ROCK MASS PROPERTIES AND INDEXES			
Intact rock properties	UCS	E	v
Rock mass classification	RQD	Q'	RMR
Structural data	Dip	Orientation	Spacing, length infilling
In-situ stresses (magnitude orientation, dip)	Sigma 1	Sigma 2	Sigma 3

Table 35: List of rock mass properties that could be reviewed as a step in the development of a ground support standards process

This data will serve as input parameters in excavation design analysis.

Modelling, mine design and extraction sequence

5.2.2.2 Excavation design, modelling and extraction sequence analyses

It is important to undertake detailed excavation and support design analyses with some knowledge, or at least a "feel" for the potential failure mechanisms that may develop in the different domains of the mine. The process described in Figure 49 may assist in identifying potential failure modes.

The ground support specifications should briefly summarise the design intent and would include, but not be limited to:

a) Reinforcement elements (rockbolts, cable bolts, etc.)
   - Type of element
   - Length
   - Diameter
   - Yield load (in KN)
   - Failure load (in KN)
   - Elongation % at yield (elastic)
   - Elongation % at failure
   - Steel grade (relevant Australian standard)
   - Thread type (if applicable)

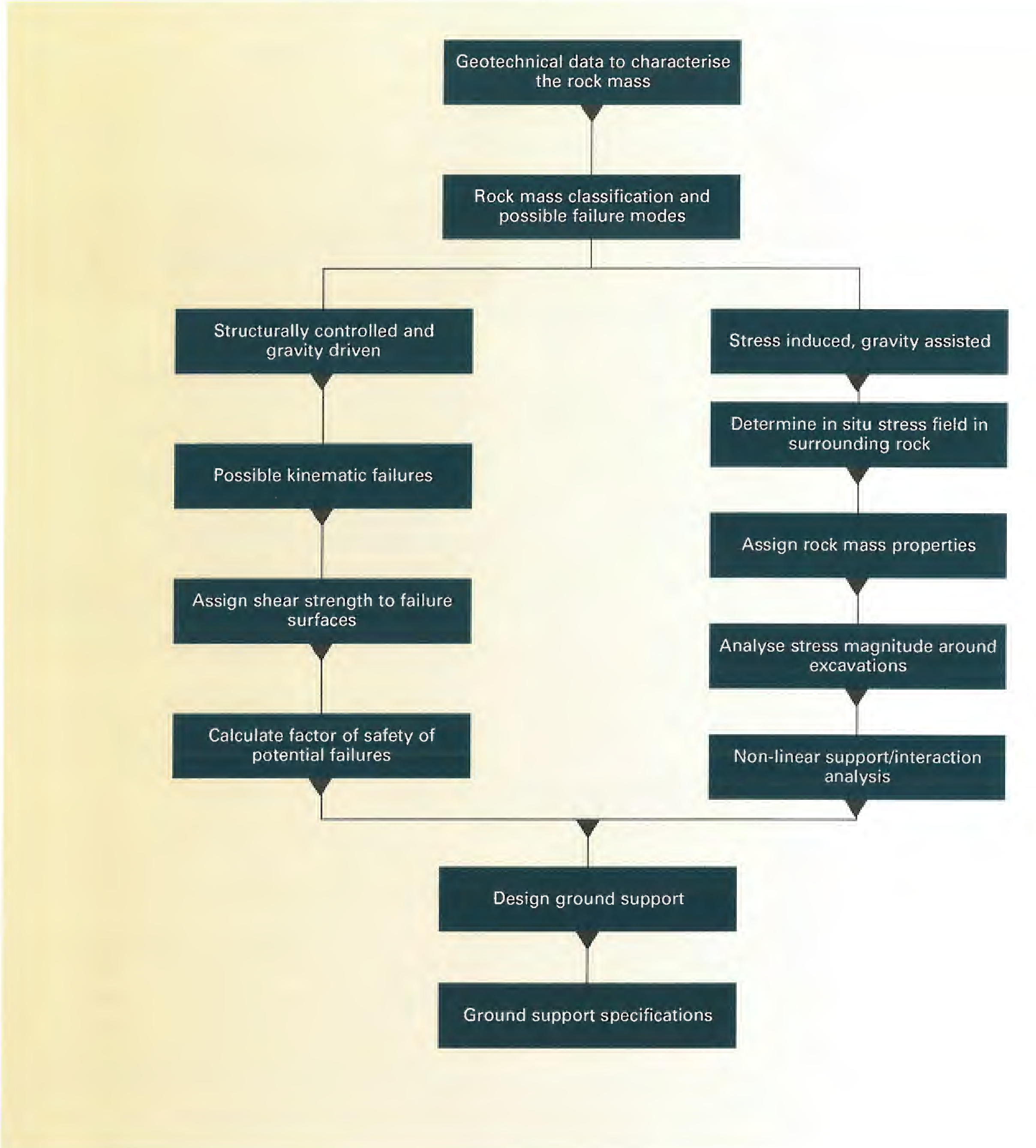


Figure 49: Flowchart describing a process for designing ground support (Modified after Hoek, Kaiser and and Bawden 1995)

- Corrosion protection (if applicable)
- Anchorage method and details (expansion shell, grout, resin, etc.)

b) Surface support elements

Mesh

- Mesh grade/type
- Wire diameter and tensile strength
- Mesh aperture
- Sheet size (m x m) and weight (kg)
- Corrosion protection

Plates and straps

- Size and type
- Thickness
- Hole diameter and tolerance
- Steel grade (relevant Australian standard)
- Corrosion protection (if applicable)
- Shape or cross section (if applicable)

Shotcrete

- Mix type (wet or dry, fibre, plain, etc.)
- Mix specification (cement type, fibre type and dosage, additives, etc.)
- Minimum UCS
- Applied thickness
- Curing requirement and duration

A number of recognised tools and techniques to determine dimensions and support regimes for entry and non-entry excavations, including ground reinforcement and support, are described in Section 3. These include:

EXCAVATION DESIGN
Numerical models:
• Boundary elements
• Finite elements
• Hybrid method
• Finite difference
• Particle flow codes
Empirical methods:
Access ways:
• Barton and Grimstad (Q system)
• Laubscher MRMR
Stopes:
• Stability graph method
• Laubscher
Analytical methods:
• Voussoir arch
• Buckling analysis

GROUND SUPPORT DESIGN
Demand vs capacity approaches:
• Wedge analysis
• Beam suspension
• Rock mass unit reinforcement
• Compressive arch method
Rules of thumb:
• U.S. Corp of Engineers
• Farmer and Shelton
• Laubscher
• Charette and Hadjigeorgiou
Shotcrete empirical rules:
• Grimstad and Barton
• Fernandez-Delgado

Table 36: Summary of tools and techniques commonly used to design underground excavations and ground support

All design methods have limitations in terms of how well they represent what happens in reality and what factors they fail to account for. The following table lists some of these factors that may require further consideration when developing ground support standards.

OTHER DESIGN CONSIDERATIONS
Intended life of excavations (impact of ground water and corrosion and time related behaviour of rock)
Induced stress by mining and potential cycles of loading (high stress) and unloading (low stress)
Blast vibrations during development mining and from surrounding stopes
Potential impact of voids and voids management (stope filling)
Tolerance for stability problems and rehabilitation
Potential for rockburst events
Equipment and supply availability, workforce skills, etc.
Integration with mine design and mining operation activities

Table 37: Other considerations for the design of ground reinforcement and support

Assess all rockfall risks

5.2.2.3 Risk assessment

As ground support aims at controlling rockfall-related risks, performing a formal risk assessment is seen as an essential step in the development of ground support standards. This will facilitate a systematic and comprehensive examination of all aspects covered by the standard, from the conception and installation of reinforcement and support to the quality control and audits schemes. A formal risk assessment will involve the following nine main steps:

NINE MAIN AREAS OF A FORMAL RISK ASSESSMENT
Defining the objective based on the expected deliverables
Identifying and describing the system to be reviewed
Identifying and understanding the potential hazards
Selecting risk assessment method – the means of systematically identifying the risks
Selecting risk analysis method – the means of calculating and examining the level of risk
Selecting a facilitator for the risk assessment
Determining the composition of the team or work group
Deciding the time and venue required
Providing risk assessment results and the desired deliverable

Table 38: Summary of the main steps of a formal risk assessment (After National Guidelines, MISHC 2002)

Performing a formal risk assessment gathers perspective from a number of areas including:

- Geotechnical
- Design, planning and scheduling
- Operation and production
- Management
- Operators and contractors
- Equipment
- Supply and logistics

These perspectives are then amalgamated to create a documented standard that promotes a safe and stable working environment by minimising the likelihood of a rockfall occurring, minimising the exposure of all personnel to rockfalls and by implementing systems to manage the residual risks.

The implementation of the risk assessment outcome will involve an action plan with possibly new controls, tasks, accountability and target dates.

Selection of support elements

5.2.2.4 Selection of support elements

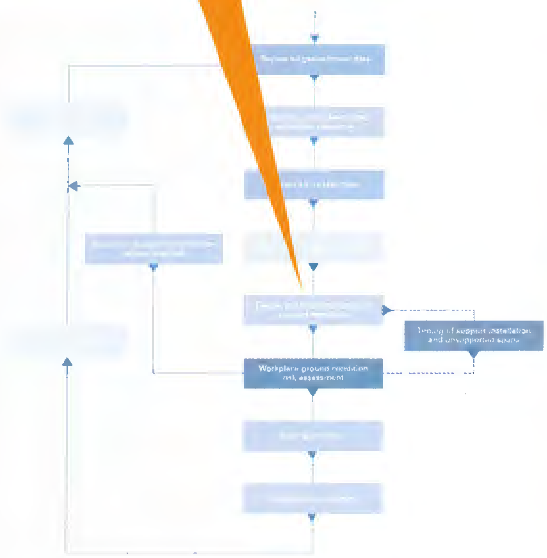
Some of the considerations with the selection of a suitable ground reinforcement and support system are summarised in Table 39:

SELECTION OF GROUND SUPPORT
• Carried out by personnel suitably trained and experienced in the design of rock reinforcement in the conditions that exist at the site • Compatible with ground behaviour (i.e. high/low deformation, burst prone, large/small wedges, etc.) and environment (water/corrosion, other chemical, temperature, etc.) • Capable of supporting all design excavation spans where they are installed, with an acceptable factor of safety • Compatible with installing equipment capability and dimensions with respect to excavation size (i.e. is the equipment capable of safely and effectively installing the chosen support elements?) • Compatible with other reinforcement or support elements • Mindful of both reinforcement and surface support with respect to: – Legislative requirements – Reduction of repetitive scaling activities that may impact on both safety and production in the mining cycle – Supply and storage issues – New and improved products – Ease of installation and adequate quality control – Any relevant Australian standards – Productivity targets

Table 39: Some considerations for the selection of ground reinforcement and support systems

5

Design and implementation of support standards



5.2.2.5 Design and implementation of support standards

By this step of the process, the type of reinforcement and support systems have been selected and suitable bolt lengths and patterns are designed. The ground support standard is formalised with documentation that may outline, but is not limited to, some of the following points (See Table 40):

PROPOSED CONTENT OF GROUND SUPPORT STANDARDS DOCUMENT
• The design life of the excavation
• Definitions of ground conditions in which the standards will be applied, which may include rock types and/or geomechanical domains
• Any potential hazards such as increased stress, relaxation or rockburst that may be associated with working in the types of ground where the standard will be applied
• Any geological features that are persistent in the area where the excavation is being mined (e.g. faults, water courses, joints)
• Bolt type, length, diameter and chemical treatment (e.g. black steel, galvanising)
• Correct angles at which bolts should be installed relative to the rock surface
• Surface fixtures such as bearing plates
• Spacing between bolts in a row
• Spacing between rows of bolts
• Type of surface support, chemical treatment and method of installation (e.g. how should mesh sheets be orientated and connected to adequately cover backs and/or walls, how far down walls should shotcrete be sprayed etc.)
• Required physical properties or chemical additives for surface support (e.g. strength of shotcrete, accelerator or fibre addition, cable bolt grout water:cement ratios/admixture requirements etc.)
• Curing times required before entry to a recently supported area is permitted (shotcrete, liners, cable bolts, seismicity related issues etc.)
• Reference to Australian standards or any internal or external documents that were used or are related to the development or implementation of the ground support standards
• Diagrams

Table 40: Items that could be included in the documentation of ground support standards

Diagrams that show the ground support to be installed and are given to operators and supervisors should show or describe clearly, but not be limited to (See Table 41):

GROUND SUPPORT STANDARDS DIAGRAM
• Excavation profile, shape and dimensions • Length of time for which the excavation will be used (e.g. short/medium/long term) • Ground conditions and/or location of development within the mine sequence (ore drive, decline, hanging wall, ventilation drive etc.) • All equipment used for installation • Bolt types, lengths, diameters and surface treatments (e.g. galvanising) • Spacing between bolts in a row • Spacing between rows of bolts • Correct cable tensioning and exposed tail length (cables) • Grouting information (method, type, curing time, admixes, mixing residence times) • Correct bolt installation angles • Surface fixture (e.g. bearing plates for both bolts and overlapping sheets of mesh, barrels and wedges for cable bolts etc.) • Surface support detail which could include: - Plan and section views of mesh orientation and overlap - Rock preparation prior to application of surface liners or shotcrete - Shotcrete strength and/or fibre dosage for fibrecrete - Liner thickness - Application limit points on walls

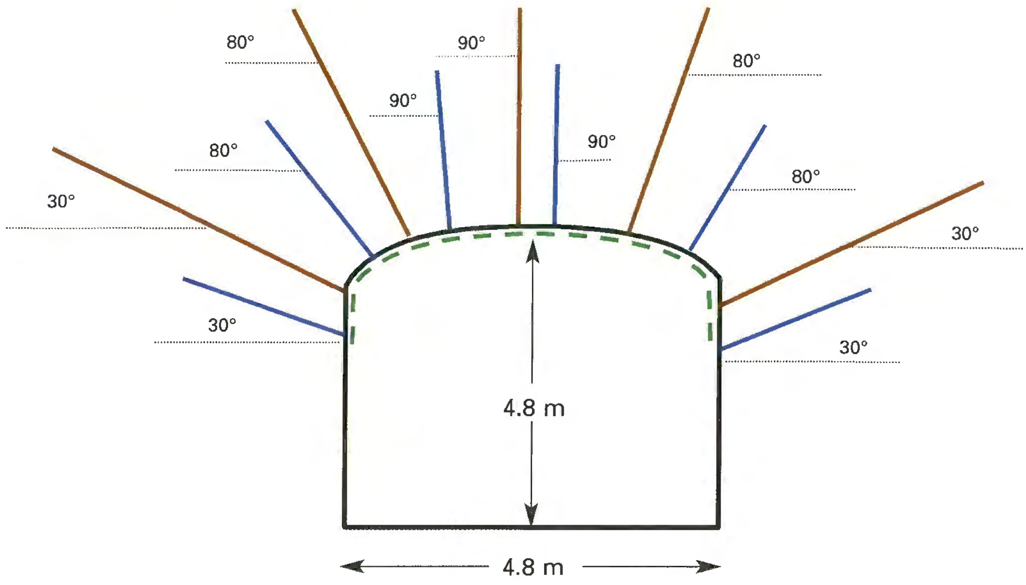
Table 41: Elements that could be included in a ground support standards diagram

An example of a ground support standards diagram is given in Figure 50.

Ground conditions in mines can vary greatly and unforeseen conditions may be encountered at any time. The standard should account for this and have provision for variations on standard patterns. Any variations in the level of ground support installed should be carried out according to well-defined site procedures. Such procedures should consider:

- All available geotechnical information
- Any increase or reduction in risk that may result from the unforeseen ground conditions
- The input of a competent person, preferably the designated geotechnical staff
- The experience of the operator installing the support and his/her ability and level of training that allows a competent assessment of conditions and installation of support on an "as–required" basis, e.g. spot bolting
- A system to communicate to all relevant personnel (management, geotechnical, supervisor), that a variation from a ground support standard is required

Decline – Long Term Support Good Ground Conditions

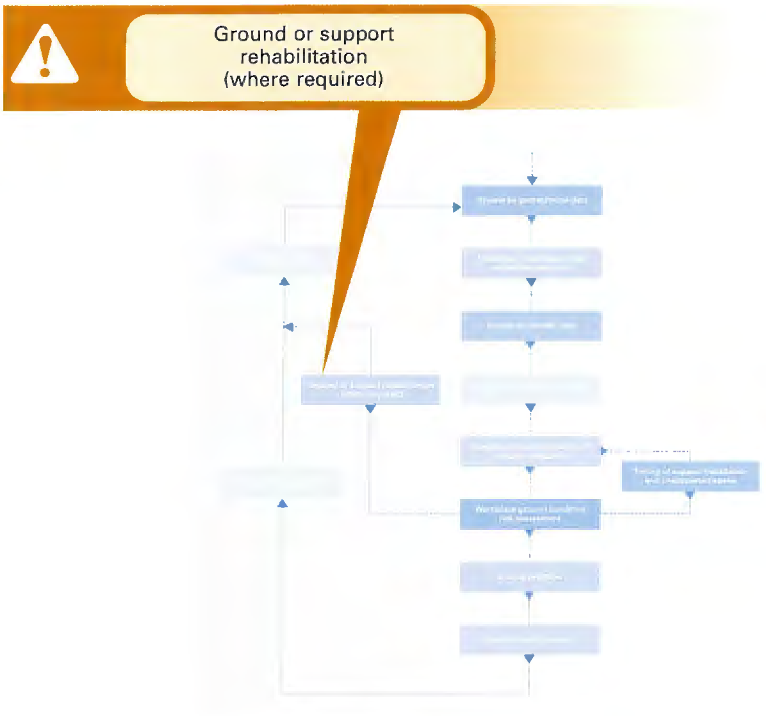


Installation Sequence

1	1	2
Standard Bolts • Type = Split Set • Diameter = 47 mm • Length = 2.4 m • Treatment = galvanized • Plate = (1) friction rock stabiliser dome • Hole diameter = 43 – 45 mm • Install angles = see diagram • Bolts per row = 7 • Spacing in row = 1.2 m • Spacing - rows = 1.4 – 1.5 m	**Mesh** • Type = 5.1 mm, 100 mm x 100 mm • Sheet size = 3.2 m x 2.1 m • Position = Long side across drive • Fasten with – Standard bolts • Overlap sheets by – 300 mm • Pin overlap with – 1.2 m long, 32 mm diameter split sets installed in bolts in last sheet • Mesh to extend down wall = 1 m	**Cable Bolts** • Type = Single strand bulbed • Length = 3 m • No of cables/hole = 2 • Hole diameter = 64 mm • Plate = 150 mm x 150 mm x 6 mm • Fastener – ball and washer with barrel and wedge • Grout type = standard • Curing time = 12 hours • Bolts per row = 5 • Ring spacing = 2.4 m • Tension to = 3 – 5 tonnes • Trim cables to = 100 mm after jacking

Safety Issues/Other Instructions ______________________________

Figure 50: Example of a typical diagram and information to be included in ground support standards



5.2.2.6 Ground reinforcement or support rehabilitation

The need for rehabilitation can be identified at a number of steps of the rockfall risk management process, including during: the work area excavation assessment (Section 4.3), the pro-active inspection of excavation (Section 6.2.1), the quality control on reinforcement and support (Section 6.1), the check scaling (Section 5.2.1.7). Once ground conditions and/or ground reinforcement and support deteriorate, it is important to assess the severity of the conditions as well as the level of risk associated with possible rehabilitation work. Existing site procedures may apply for some rehabilitation work or specific rehabilitation plans may need to be developed to suit a specific situation or set of conditions. It is important that a cross-section of relevant personnel provide input into the rehabilitation plan. The following table is a list of possible issues to be considered during the development of a rehabilitation plan, modified after Mount Isa Mines Ltd "High Risk Rehabilitation Checklist – MIM procedure PRO-45-03-01 (2003)".

GEOTECHNICAL ENGINEER

- Why does the area in question require rehabilitation?
- Where is the rehabilitation required (walls/back/HW/FW)?
- Is the actual geological mapping available (rather than interpreted)?
- Is there a plan of the rehabilitation area showing the actual geological mapping?
- Are there any major structures within the area requiring rehabilitation and, if yes, where do they intersect the area requiring rehabilitation?
- Does ground deterioration exist within the major structures? If so, how has the ground failed?
- Are slippery/greasy joints (graphite/talc/clay) present within the area to be rehabilitated?
- What was the stress regime prior to the need for rehabilitation?
- Has the stress regime changed recently? Is it expected to change in the future?
- Has ground support and/or reinforcement previously been installed in the area requiring rehabilitation?
- Is the ground support and reinforcement corroded?
- Is ground water present in the area requiring rehabilitation?
- Does the area requiring rehabilitation need mechanical scaling?
- Is there potential for excessive scaling and possible undercutting of structures?
- Are there any cases where areas, under similar conditions, have been successfully rehabilitated?
- What are the perceived contributing factors behind the need for rehabilitation?
- What support and reinforcement is required for rehabilitation?
- Will future geotechnical inspections during or after the rehabilitation work be required?

PLANNING ENGINEER

- Have alternative plans or options been investigated?
- Can all the required elements be designed and implemented?
- Can all the material required be sourced?
- Does the plan achieve the aims?
- Is the plan practical?
- Is the area ready for work to commence?
- Any other hazards?

PRODUCTION ENGINEER

- Are there other hazards not yet identified?

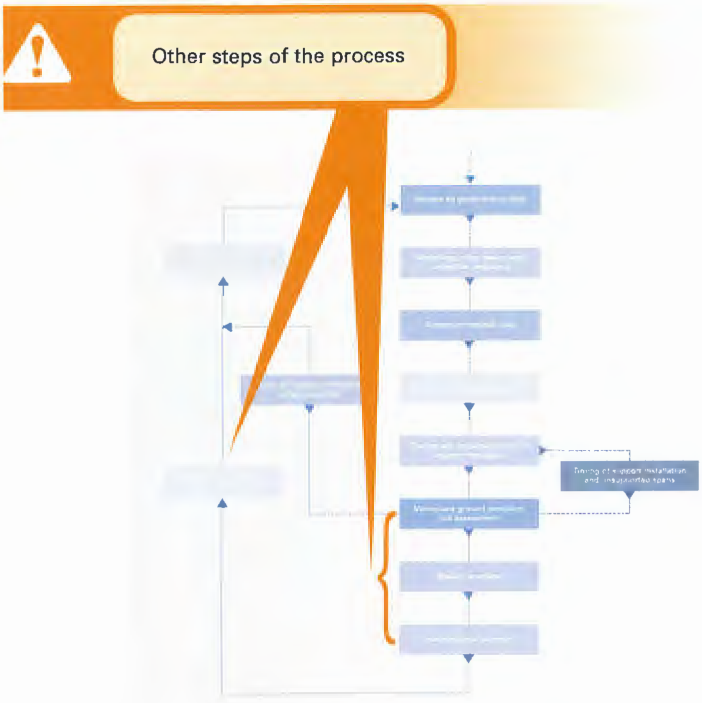
DEVELOPMENT SUPERINTENDENT

- Are there other hazards not yet identified?

UNDERGROUND MANAGER

- Are there other hazards not yet identified?

Table 42: List of possible issues to be considered for rehabilitation work



5.2.2.7 Other steps of the process

Other steps of the process for development and implementation strategy of ground support standards such as scaling, installation, monitoring and quality control, are covered in detail in previous and subsequent sections and are not repeated here.

5.3 Access Control

Access control can be used as an effective means of reducing the risk of personnel being exposed to rockfall hazards by developing a systematic approach that prevents unplanned or unauthorised entry to all areas of the mine.

Control levels can be developed prior to the commencement of mining or as a result of incidents/accidents occuring, where geotechnical modelling predicts the possibility of adverse conditions or if new hazards are encountered as the mine develops.

The level of access control required will vary from mine to mine. Each site may choose to develop their level of control according to corporate or site safety standards, or specific mine conditions. These may also require compliance with the relevant Australian State and Territory regulations, legislation or guidelines.

Factors that may need to be considered in the creation of access control standards may include, but are not limited to:

- Effects of stoping on excavation stability
- Presence, location and magnitude of natural or induced stress
- Amount of old development that may no longer be used for production purposes but is utilised for regular travel, e.g., ventilation drives, old level accesses, declines, etc.)
- Ongoing ground support rehabilitation programs
- Tasks where rockfall hazards may change as a result of the work being carried out, e.g. charge-up, raise drilling, rising, remote mucking, check scaling
- Remnant mining operations outside of "normal" production areas

Signage and barricades are normally used in most mines to control access to any hazardous area. All personnel travelling into a mine must have a thorough understanding of the meaning of all signs and understand who is authorised to travel in signposted or barricaded areas.

Examples of signs and barricades that could be used for access control and their defining levels are shown in Figure 51. It should be noted that the example shown is purely generic. Any access control system practices and procedures should be carefully developed by management and rigorously discussed with supervisors and geotechnical personnel. It should also take into account all relevant site-specific factors that may impact on the way in which potentially hazardous ground conditions are controlled.

DECREASING PERSONAL EXPOSURE

INCREASING POTENTIAL RISK

LEVEL 1

DANGER

NO ENTRY

BAD GROUND

A serious rockfall hazard or a fall of ground has been identified. Only the mine manager, or persons accompanying the manager, are permitted to enter the area.

Written permission must be obtained from the manager before any other person is permitted to enter the area for any purpose (if not under the manager's direct supervision).

LEVEL 2

DANGER

NO TRAVEL UNLESS AUTHORISED

ROCKFALL HAZARD AHEAD

A rockfall hazard has been identified within the barricaded area. Management should consider developing authorisation levels that permit supervisors to enter and assess the area.

This will ensure potential rockfall risks can be readily assessed and a plan for remedial action or permanent barring of access to the area can be determined.

No personnel are allowed to enter the barricaded area without the appropriate authorisation from the designated supervisor or manager.

LEVEL 3

DANGER

TASK IN PROGRESS.

CONTACT OPERATOR OR SUPERVISOR BEFORE ENTERING AREA

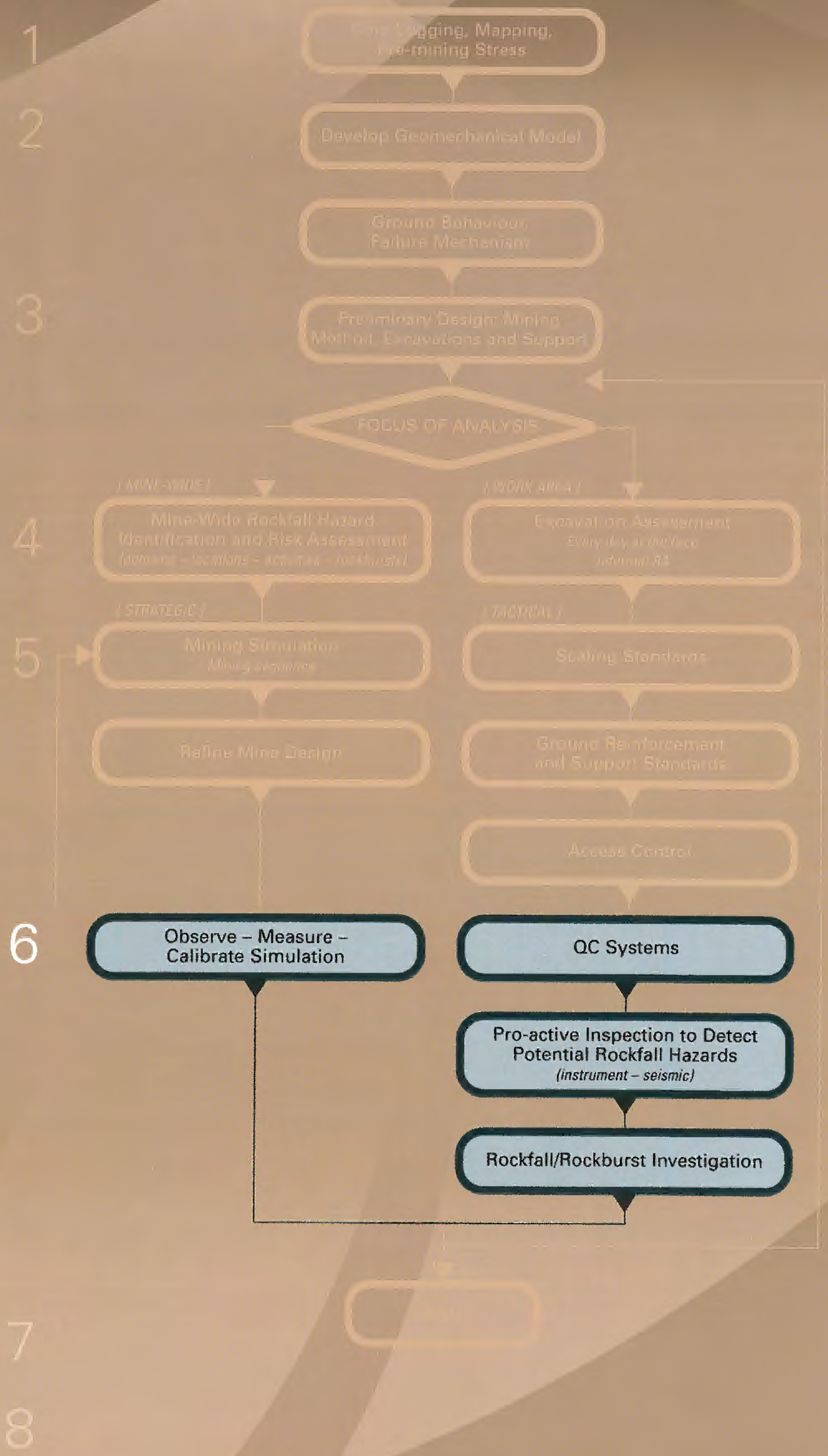
Used for situations where rockfall hazards may be frequently changing as a result of the task being carried out.

The person in charge of the task should be contacted to ensure any rockfall hazards are clearly communicated to the person prior to their passing the barricade.

Site procedures should detail the appropriate course of action for personnel entering/permitted to enter areas and detail how supervisors should monitor conditions or restrict access if required.

Figure 51: Example of signage to control access to areas of elevated rockfall hazards

6 Monitoring Rockfall Risks



6. MONITORING ROCKFALL RISKS

"ONCE ROCKFALL CONTROL MEASURES HAVE BEEN IMPLEMENTED AND THE RISK IS JUDGED ACCEPTABLE, MONITORING SYSTEMS ARE REQUIRED TO ASSESS THE PERFORMANCE OF THESE CONTROLS AND TO ENSURE THAT IF CHANGES IN CONDITIONS OCCUR, THEY ARE DETECTED IN TIME AND CORRECTIVE ACTION IS TAKEN.

GROUND SUPPORT PERFORMANCE IS HIGHLY DEPENDANT ON THE QUALITY OF ITS INSTALLATION (AMONGST OTHER THINGS). QUALITY CONTROL (QC) SYSTEMS APPLIED TO GROUND SUPPORT ARE DESIGNED TO ENSURE THAT THE INSTALLATION METHODS PROVIDED BY MANUFACTURERS AND SITE SPECIFIC STANDARDS DESCRIBED IN SECTION 5.2.2 ARE ENFORCED AT ALL STAGES OF THE INSTALLATION PROCESS.

A NUMBER OF TECHNIQUES FOR DETECTING HOW ROCKFALL HAZARDS MAY CHANGE WITH TIME AND/OR MINING ACTIVITIES ARE DESCRIBED IN THE FOLLOWING SECTIONS. THE SELECTION OF APPROPRIATE MONITORING TECHNIQUES IS DEPENDANT ON LOCAL CONDITIONS AND SITE-SPECIFIC REQUIREMENTS. FOR EXAMPLE, ROCKBURSTING CONDITIONS ARE A SUB-SET OF ROCKFALL HAZARDS WITH UNIQUE CHARACTERISTICS AND THEREFORE THEY MAY REQUIRE SPECIAL MONITORING CONSIDERATIONS".

6.1 Quality Control for Ground Support

Quality Control (QC) standards and procedures used for the installation of ground support are an integral part of a systematic approach to rockfall prevention. The development of a QC system should consider all relevant aspects prior to, during and after the installation of support.

The compilation of information contained in this section has been sourced from the following:

Hutchinson, D.J. & Diederichs, M.S. (1996). Cablebolting in Underground Mines.

Hadjigeorgiou, J. & Potvin, Y. (2002). Ground Control Training for Underground Mine Workers.

Canadian Mines and Aggregates Safety and Health Association (MASHA) (1998).

Yoggy, G. (1995). Shotcrete Nozzleman Training Course.

Knight, B.W., et al (1998). Implementation, Application and Quality Control Aspects of Steel Fibre Reinforced Shotcrete at Inco's Stobie Mine.

6.1.1 OBJECTIVE AND METHODOLOGY OF A QC SYSTEM

The objective of a QC system can be defined as the combined control measures used to ensure the ground reinforcement and support:

- Is installed in line with the manufacturer's specifications or recommendations
- Achieves geotechnical design goals
- Complies with all site-specific procedures related to the installation, training competency of employees for equipment, understanding ground conditions, etc.
- Complies with Australian standards or International Organisation for Standardisation (ISO), where relevant
- Is checked, tested, maintained or rehabilitated, where required, to ensure ongoing excavation stability

It should be noted that ground reinforcement and support design issues in this document are not considered part of QC practices. Qualifying or verifying the design assumptions for the type of support required at a mine is addressed as part of the ground support design process (See Section 3.2), prior to the development of any QC documentation.

Quality control for ground reinforcement and support should consider a broad range of issues including:

- Purchasing – product and delivery standards established with the ground support manufacturer
- Storage – locating the bolts and chemicals, where required, surface support materials and associated equipment needed for installation in suitable areas that minimise the effect of exposure to conditions which may adversely affect product performance
- Installation – developing standards containing key information necessary to ensure that the ground support elements or products are installed to the manufacturer's (or supplier) and the mine's design standards

6

- Criteria for rejection – these would be developed to verify whether the installed support meets the established standards, who is responsible for checking the support, what is done with the results, by what means is the work inspected and/or tested (where possible) and the remedial action to be taken to correct a defective situation
- Frequency of inspection and monitoring – this will be based on the type of support used, where there are specific factors identified after installation that affect the performance of the support over time

The quality control methodology for the various stages of the installation process is shown in Figure 52.

6.1.2 PRE-INSTALLATION

The quality control process starts long before the installation of reinforcement and support takes place. The manufacturer is generally responsible for delivering ground control products that meet ground support specifications. The mining operation must then ensure that products do not deteriorate from the time the products arrive on site to the time they are installed underground.

6.1.2.1 Quality control on supply

From a mining operation's perspective, ensuring that all ground reinforcement and support elements and associated materials are delivered to site in a condition that meets all the site's requirements is the first step in the quality control process. A number of issues to be considered include:

- Ongoing assessment, or audits, of ground support products delivered to site by regular client inspections if a contractor has the responsibility for the supply and delivery of all ground support products
- Agreed acceptance/rejection policy with the product manufacturer or supplier of any special packaging, transport and storage conditions of ground support products. This may include the suppliers providing conformance certification to the relevant Australian standards for each load or batch of bulk products delivered to site for shotcreting such as cement, admixtures, silica fume, accelerator, or quality assurance inspection sheets for rock bolts, cable bolts, resin cartridges, shell anchors, MSDS for chemicals where required, etc.

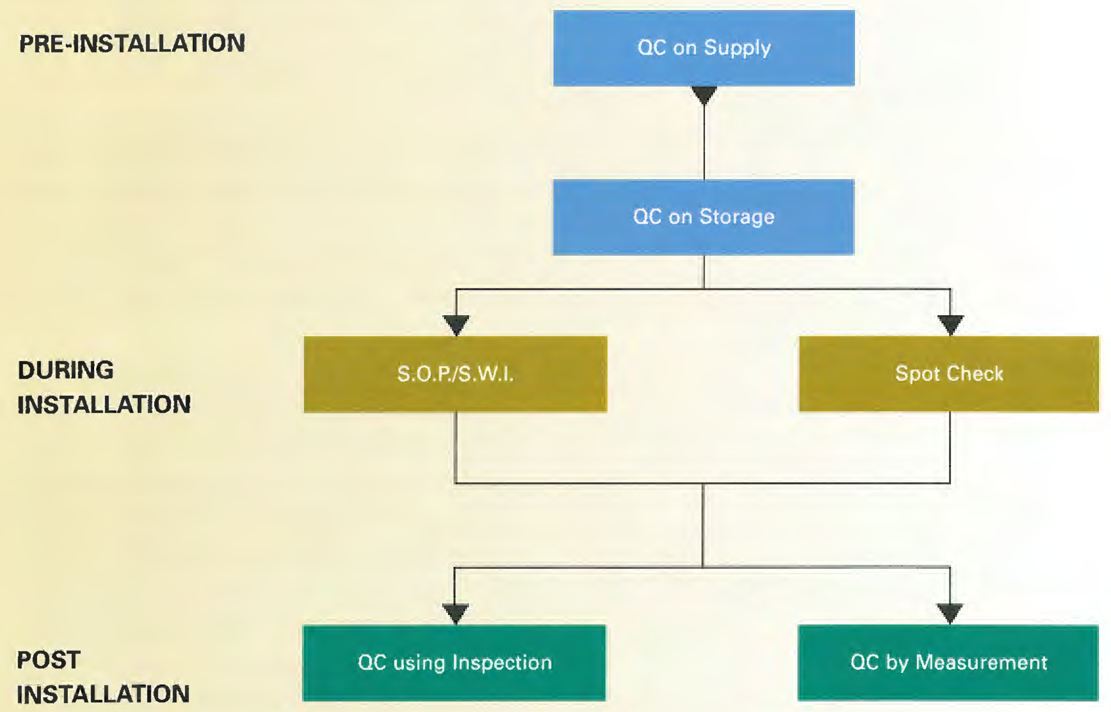


Figure 52: Methodology for the application of quality control techniques at different stages of ground reinforcement and support timeline

- Making supply personnel on the mine site aware of the aforementioned criteria and any special requirements (storing selected items such as cable bolts and bagged cement on pallets, maintaining temperature for chemicals used for resin bolts within the specified range and away from direct sunlight immediately after delivery, storage requirements, etc.)
- An agreement could be developed between the supply and mining departments at the mine site to decide who will be responsible for delivering the ground reinforcement and support products to the specified location once they have been received at the main store's delivery point, or
- The relevant mining department personnel are advised shortly after ground reinforcement and support products have arrived on site and are available for collection from the delivery point, to allow timely arrangement of transport to the mine's storage areas

6.1.2.2 Quality control of storage

Choosing the correct areas to store ground support materials once they have arrived at the mine site requires careful consideration and will also assist in reducing the possibility of installing defective products or the cost of replacing reinforcement and support products rendered defective by improper storage. It can also minimise the chance of causing potential shortages of supply.

A number of factors that should be considered for storage of ground reinforcement and support are shown in Tables 43 and 44. It should be noted that the information provided below are examples of good practices and not a comprehensive list of all possible control measures. All site-related storage issues must be based on the support types used and the mine-specific operating conditions and requirements that may impact on product storage.

GROUND REINFORCEMENT AND SUPPORT STORAGE ON SURFACE
• Area should be located in reasonable proximity to underground where possible
• Well draining floor area elevated above any potential flood level
• Ease of access for stock rotation. Consider lighting storage area for access at night
• Providing adequately sized cabinets/boxes of solid construction to accommodate small items such as barrels, wedges, shells, nuts, pull rings etc.
• Refrigerated storage should be provided if storage temperatures exceed manufacturer's recommendations for long periods *Notes:* *1. Where resin bolts are used, the shelf life of resin cartridges can be adversely affected by high temperatures but are not adversely affected by low temperatures* *2. Resin cartridges should also be stored away from direct sunlight*
• Providing a covered area for aggregates, grouts, cements and other products which can deteriorate or be adversely affected in high rainfall areas

Table 43: Examples of ground reinforcement and support storage considerations on surface

GROUND REINFORCEMENT AND SUPPORT STORAGE FOR UNDERGROUND
• Area should be located in reasonable proximity to active mining horizons
• Clean, dry, well ventilated (low humidity if possible) area. If ground water is present, it should be directed away from any stored material
• Ease of access for stock rotation. Consider installing lights to make product identification quicker and easier
• Excavation is adequately supported for the design life
• Shelving or other suitable means of storage is provided for small items such as barrels, wedges, shells, nuts, plates, pull rings, etc.
• Resin cartridges should be stored in a dry, cool place. Refrigeration may be required if there are products such as resin cartridges that will be stored underground for long periods at temperatures that exceed manufacturer's recommendations
• If refrigerated storage is used, chemicals should be moved to a location at least two days prior to use where temperatures are between 12 – 30°C
• Providing a separate, well drained excavation available for aggregates, cement, fibres and additives if shotcrete is batched underground

Table 44: Examples of ground reinforcement and support storage considerations for underground

6.1.3 DURING INSTALLATION

Quality control during installation can be achieved using procedures that provide the operator installing the support with all the relevant information and/or by creating a list of visual spot checks for the different support types that are used at a mine.

6.1.3.1 Safe Work Instructions (SWIs)

Written procedures for ground reinforcement and support (SOPs or Safe Work Procedures) are developed to ensure that the installation process:

- Complies with the manufacturer's recommendations
- Details the equipment used
- Considers the mine's geotechnical conditions and design requirements
- Maintains local and regional stability
- Outlines any other criteria specific to the mine that may impact on the way in which support is installed

The procedures are the final stage of the process used to design, develop and achieve a high standard of support installation whilst addressing all statutory compliance issues.

However, the complete version of the procedures may contain too much detail or may be written in a language inappropriate for employees involved in installing support on a day-to-day basis. Considering the importance of conveying the practical requirements of QC for ground support in a "ready reference" format to underground employees creates the requirement to develop a system that is simpler than SOPs, such as Safe Work Instructions (SWIs).

A SWI aims to address this requirement by developing a clear and concise summary of the full procedure for each bolt or support type. A number of mines use SWIs in various formats.

The design of SWIs could include:

- Relevant manufacturer information and mine-specific requirements
- A combination of pictures, text and sketches to clarify each step and capture all the salient points contained within the written procedure
- The hazards associated with the reinforcement and/or support type being installed, highlighting key safety issues for each step
- A facility to revise the documents on a regular basis that ensures relevance to new bolt types, equipment and/or installation methods and site conditions

Two examples of SWIs are shown in Figure 53. They should only be viewed as a guide to creating these types of instructions, as they were originally developed in a generic format for use on a number of mine sites. They may not contain all the pertinent information that needs to be considered at a particular mine site, such as ground conditions, stress conditions, mining method, mining equipment, procedural standards and operating practices.

Figure 53: Example of safe work instruction for the installation of friction rock stabilisers

PREPARE TO INSTALL GROUND SUPPORT

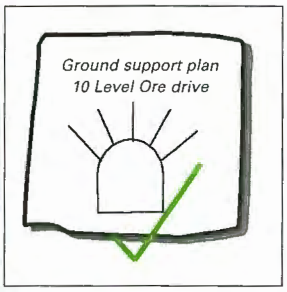
If you do not understand, are unsure of, have not been trained and assessed on, or cannot safely carry out all instructions in this document, Procedure PM 1000 (Prepare to Install Ground Support), or other procedures to be carried out prior to bolting –

DO NOT COMMENCE WORK. CONTACT YOUR SHIFT SUPERVISOR FOR FURTHER INFORMATION AND/OR ALTERNATIVE DUTIES.

Equipment required: Ground support standards, drill bits (correct diameter), spray paint and pole, bit gauge, scaling bar, plod or time sheet.

OPERATOR REQUIREMENTS

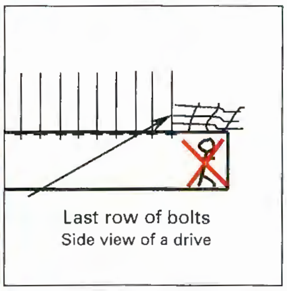
1. Determine ring spacing and bolt hole positions according to the current ground support plan.



KEY POINTS/SAFETY TIPS

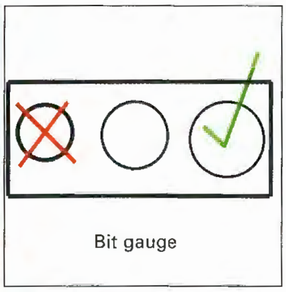
- Use the ground support standards you must have on the jumbo.
- If there is no copy available on your rig, obtain one from your shift supervisor or foreman.

2. Mark distances between rings of bolts on the wall or backs with paint to assist in installing the bolts.



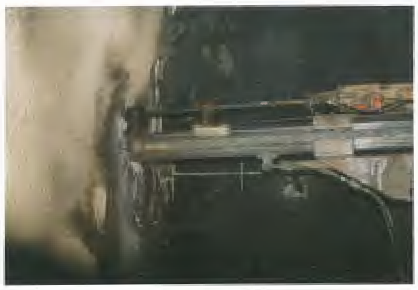
- Do not travel under unsupported ground at any time.
- Mark up rings only where it is safe to do so. Use a paint pole if necessary.
- Do not assume ground you are instructed to re-bolt is safe to walk under.

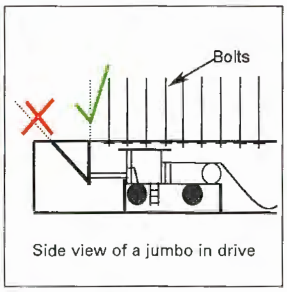
3. Check the drill bit diameter is correct using the bit gauge.



- The bit must not be able to fit through smaller hole on the bit gauge.
- The bit must be able to fit through the larger hole.
- Make sure you have the correct bit and bit gauge for the type of bolt you are planning to install.

4. Attach the bit to the drill steel (unless the ground support standards requires inclined bolts). Position the jumbo boom so that the hole will be drilled at right angles to the rock face.

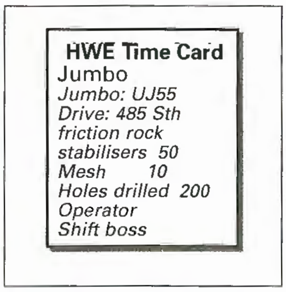




- A bolt installed at a flat angle can result in a 40% reduction in the amount of weight it can support.
- If you cannot install bolts at the correct angle, notify your shift supervisor.

5. On completion of each ring of bolts, record the respective ring number, and bolts installed on your plod.

All bolts that are not installed correctly or are in excess of the original plan must also be recorded.



- Information recorded on your plod is important for the safety of you and your cross shift.
- At the end if each shift, both you and your supervisor must sign off on the work you have completed.

REMOVE ALL BOLTS AND EQUIPMENT FROM THE JOB WHEN YOU HAVE COMPLETED BOLTING
THINK TIDY, WORK SAFE!

6

INSTALLATION OF FRICTION ROCK STABILISERS

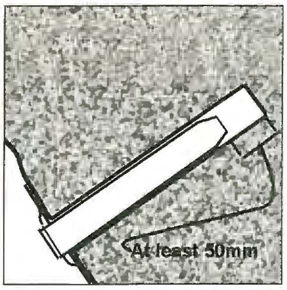
If you do not understand, are unsure of, have not been trained and assessed on, or cannot safely carry out all instructions in this document, procedure PM 934 (Installation of friction rock stabilisers), or other procedures to be carried out prior to bolting -

DO NOT COMMENCE WORK. CONTACT YOUR SHIFT SUPERVISOR FOR FURTHER INFORMATION AND/OR ALTERNATIVE DUTIES.

Equipment required: Jumbo, drill bits (correct diameter), undamaged friction rock stabilisers (correct length and diameter), combination plates, bit gauge, spray paint and pole, rock bolting dolly, scaling bar.

OPERATOR REQUIREMENTS

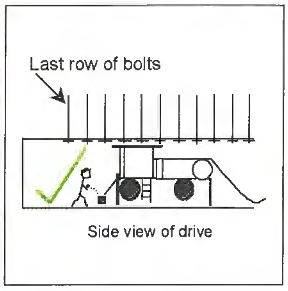
1. Drill the hole at least 50 mm longer than the friction rock stabilisers you are intending to install.



KEY POINTS/SAFETY TIPS

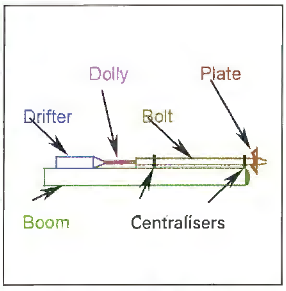
- If you are unable to drill your holes in the correct position (within 250 mm of that shown on the plan), make a record of this on your time card.

2. Attach friction rock stabiliser dolly to bolting boom of jumbo.



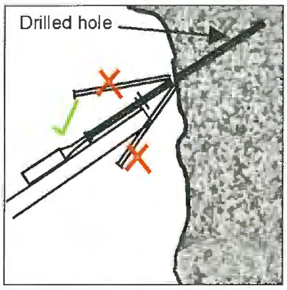
- Position the slides of the jumbo under supported ground before placing the friction rock stabilisers on the bolting boom.
- Fit the bolting sleeves to the centralisers on the bolting boom.

3. Place friction rock stabiliser through bolting centralisers and onto dolly. Place combination plate onto the end of the bolt.



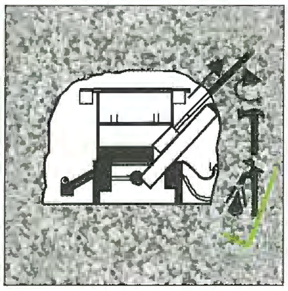
- Place the combination plate on the "rock side" of the centraliser at the end of the boom.

4. Move the bolting boom into position to align the bolt with the drilled hole.



- The boom must be in line with the drilled hole.
- Misalignment will cause damage to the bolt and make it difficult or impossible to install.

5. Drive the friction rock stabiliser into the drilled hole until the combination plate makes firm contact with the rock.



- A 2.4 m friction rock stabiliser should take approx. 30 seconds to install.
- Use hammer, rotation and have flushing water on whilst installing the bolt.
- Do not continue to hammer the bolt after the plate has made contact with the rock surface. This may cause damage to the end of the bolt.

REMOVE ALL BOLTS AND EQUIPMENT FROM THE JOB WHEN YOU HAVE COMPLETED BOLTING
THINK TIDY, WORK SAFE!

6.1.3.2 Spot checks

Spot checks can be used to ascertain the quality of reinforcement and support during and immediately after the installation has taken place. This type of inspection allows defects or inadequacies to be addressed in a timely manner, reducing the possibility that additional ground reinforcement and/or support may need to be installed at a later date.

The tables below show some examples of the checklists that can be developed for the different reinforcement and support types. These tables should be seen as a guide only and not a comprehensive summary of all possible conditions or situations. Developing any such inspection tables or checklists locally, should take into consideration all relevant site-specific safety aspects, such as the support products and installation equipment used, ground/stress conditions along with the risk and consequences of approaching or inspecting support that has recently been installed.

MECHANICAL ANCHOR SPOT CHECK DURING INSTALLATION		
Observation / Test	**Cause**	**Possible Remedial Action**
Bolt length protruding from hole is longer than the threaded bolt length	• Nut was forced onto the bolt shank (may reduce bolt resistance by up to 50%)	• Remove bolt and replace with new unit • Install another bolt close to the original if the existing bolt cannot be removed
Bolt will not stop spinning when rotating nut	• Shell is not expanding enough to touch the side of the hole • Bolt thread is not engaging the wedge • Thread on either wedge or bolt is stripped	• Remove bolt, inspect shell, remove sleeve on bail (if present), adjust or replace shell components or bolt where required • Install another bolt close to the original if any part of the original unit cannot be removed
Bolt is tapped with a spanner or metal object	• Hollow sound indicates low tension	• If tension of bolt tested is below the manufacturer/site specification, re-tension bolts using approved method

Table 45: Checklist to assist in performing spot checks to ascertain the quality of mechanical anchor bolts during installation of the reinforcement

6

FRICTION ROCK STABILISER SPOT CHECK DURING INSTALLATION		
Observation / Test	**Cause**	**Possible Remedial Action**
Face plate can turn freely after installation, or A portion of the bolt protrudes from hole	• Bolt was not fully inserted into hole, or • Hole diameter too small, or • Hole drilled too short (should always be drilled at least 100 mm longer than the bolt)	• Check depth of borehole and drill bit diameter • Check condition of drilling equipment • Attempt to install bolt so that face plate is firmly contacting the rock surface, or • Install another bolt close to the damaged unit if the hole is too short or the diameter is too small
Ring does not make full contact with the bearing plate	• Damaged prior to, or during, installation. Bolt will be ineffective • Bolt is installed at an angle to the hole which prohibits full contact of the ring with the plate	• Install another bolt close to the damaged or inadequate unit
Slot in bolt does not appear to be closed *Note: Slot should not be open more than approximately 6 mm along more than half of the bolt length. Shine light inside bolt to check the gap*	• Hole diameter may be larger than the design specification	• Install another bolt close to the sub-standard unit

Table 46: Checklist to assist in performing spot checks to ascertain the quality of friction rock stabiliser bolts during installation of the reinforcement

RESIN GROUTED BOLT SPOT CHECK DURING INSTALLATION		
Observation / Test	**Cause**	**Possible Remedial Action**
Bolt does not extend far enough into hole	• Hole drilled too short • Resin spun and set before bolt pushed all the way to the back of the hole	• Where threaded bolts are used, attempt to spin the nut up until the plate makes contact with the rock • Redrill hole and install another bolt close to the original
Resin runs out of hole	• Hole diameter too small • Hole drilled too short resulting in an excess of resin • Ground water washes resin from the hole • Rock temperature too high for the standard resin cartridges	• Redrill hole and install another bolt close to the original unit • If a water course is present in the area, try and position the bolt away from cracks or faults where the water is originating. If flow cannot be sufficiently reduced, pressure grouting may be required to stem the ground water flow • If resin too runny, the manufacturer can adjust the viscosity for the specific rock temperature if required
Bolt slides out of hole	• Resin has not set before adapter was removed from the bolt head	• Redrill hole and install another bolt close to the original

Table 47: Checklist to assist in performing spot checks to ascertain the quality of resin grouted bolts during installation of the reinforcement

CABLE BOLT SPOT CHECK DURING INSTALLATION		
Observation / Test	**Cause**	**Possible Remedial Action**
Cable slips through grout	• Dirt, mud or oil on the cable • Grout mix too thin • Cable hanger poorly attached or wrong diameter	• Clean cable and reinstall or replace with clean unit. Check storage conditions for other cables to avoid similar occurrence • Reduce water:cement ratio of grout • Ensure hanger is securely attached and is the correct diameter for the hole in which it will be installed
The cable bolt's circumference is not completely imbedded in the grout	• Part of the cable rests against the edge of the hole *Note: This could affect the load carrying capacity of the cable*	• Remove bolt from hole, attach spacers securely every 1 metre along the length of the bolt, reinstall and grout • If bolt (with spacers set) cannot be centred and regrouted, another bolt may have to be installed at a later date
Grout leaks from hole	• Hole is not properly plugged • Water:cement ratio of grout is too high	• Attempt to stem the flow of grout by re-plugging the hole using the approved method • Reduce the water content of the grout mix and attempt to re-grout • Check the mix to ensure all other ingredients have been added in the correct quantities
Grout cannot be pumped easily through the grout mixer or into the hole	• Grout mix too dry • Not enough additive • Grout not fully mixed	• Thin the mix by gradually adding water without exceeding the recommended water:cement ratio, or • Check the mix to ensure all other ingredients (including additive) have been added in the correct quantities • Check that grout is completely mixed, and contains no lumps or dry patches. If in doubt, pump the grout through a hose on the floor until a consistent, non watery grout is flowing before attempting to grout another cable
Breather/grout tube not fully filled with grout	• Void is present in the column of grout which can affect load carrying capacity	• Ensure that grout travels back along, and flows freely from the breather before bending the end of the tube over and tying it off
Barrel, wedge and plate cannot be fitted to cable	• Free end of cable too short outside the hole	• A replacement cable may need to be installed at a later date with a suitable length tail

Table 48: Checklist to assist in performing spot checks to ascertain the quality of cable bolts during installation of the reinforcement **(continued on page 114)**

6

CABLE BOLT SPOT CHECK DURING INSTALLATION		
Observation / Test	**Cause**	**Possible Remedial Action**
Angle between the bearing plate and the rock less than 90°	• Hole not designed at (approximately) 90° to the rock surface. This can cause a bend in the cable bolt during tensioning	• Cable holes should be designed as perpendicular to the rock surface as practicable. The maximum deviation away from the perpendicular should be 25°
Barrel chips/splits or barrels and wedges do not fit well together	• Barrels and wedges may be mismatched if different sizes and types are used in the mine • Steel barrel or wedges may split due to eccentric loading	• Make sure all matched batches of barrels stay together. If there are a number of different barrel and wedge types in use, make sure that each type is clearly marked
Plate bends excessively when jacking cable	• Plate is too small or thin for the application	• Use plates designed for the job
Barrels and wedges do not appear to tension correctly	• Tension jack is too soft. This will mean that the tension applied by the jack will be lost	• Check the stiffness of the spring in the jack's nose cone. Soft springs should be replaced as soon as possible. The grip's teeth should also be sharp and clean

Table 48: Checklist to assist in performing spot checks to ascertain the quality of cable bolts during installation of the reinforcement **(continued from page 113)**

MESH SPOT CHECK DURING INSTALLATION		
Observation / Test	**Cause**	**Possible Remedial Action**
Mesh not close to, or hard up against, the rock surface	• Bolts not installed correctly • Plates not installed firmly against the rock surface • Irregular rock surface profile. Not enough bolts or bolts not installed in optimum position • Loose accumulates behind mesh causing sagging/loading of mesh	• Spot bolt to pull mesh tight against the rock surface as required • If mesh has become loaded with loose rock, bleed the mesh if the manufacturer's specifications on deformation, or capability, or site standards for acceptable loading are close to being exceeded. Bleed according to the site's approved procedures
Welds broken at point where wires intersect	• Faulty manufacture of mesh sheets • Sheets excessively forced or stretched during installation • Overload due to weight of loose/broken rock behind mesh	• Check other sheets in batch for similar defects, discard, repair or cut away damaged portions if possible • Place additional sheet of mesh on top of damaged area if required
Edge of sheet peeling back or not secured to rock	• Bolts not installed close enough to edge of sheet • Successive sheets do not overlap	• Install additional bolts to secure the edge of the sheet where required, or • Change procedure to define an overlap distance which will ensure both sheets are secured together and excess bolting is avoided

Table 49: Checklist to assist in performing spot checks to ascertain the quality of mesh during installation of the surface support

SHOTCRETE/FIBRECRETE SPOT CHECK DURING INSTALLATION		
Observation / Test	**Cause**	**Possible Remedial Action**
Excessive rebound	• Incorrect nozzle angle or distance from the nozzle to the rock surface • Air pressure may be too high when shooting	• Ensure shotcrete nozzle is at right angles to, and approximately 1-1.5 metres from the surface being sprayed • Reduce air pressure gradually until rebound is minimised
Shotcrete drops off surface shortly after application	• Rock surface has not been cleaned (washed down) properly • Mix is too wet • Water used in shotcrete batch may be adversely affecting product quality	• Ensure walls are thoroughly washed prior to the application of any shotcrete product • Adjust water or carry out slump tests to calculate the correct water/cement ratio • If excessive fall off in backs, additional accelerator may be required to decrease set times • Test water to check for high salt or total dissolved solid levels, which may affect mix. Water used for shotcrete batches should be potable where possible
Shotcrete looks lean or has appearance of dry aggregate when sprayed	• Mix too dry • Distance between spraying nozzle and surface is excessive • Admixtures such as super plastercisers may have to be changed if time between shotcrete batching and spraying is too great • Cement particles in mix may become completely hydrated if a batch undergoes long travel times before spraying. This results in accelerator dosages having an increasing effect of up to four times the design dosage	• Add water • Reduce the distance from the shotcrete nozzle to the surface as required • Consult with the admixture concrete and/or shotcrete suppliers to optimise the shotcrete mix for the specific travel times • Minimise travel time of shotcrete after batching where possible or add accelerator immediately prior to spraying
Rock or mesh protrudes from beneath shotcreted surface	• Shotcrete may be below the design thickness • Irregular surface profile • Mesh not installed close enough to the surface. Shotcrete was sprayed on the rock and built up considerably in an attempt to cover the mesh. This results in an effect called "shadowing"	• Measure shotcrete thickness at regular intervals as spraying is taking place • Special care should be taken when spraying over blocky ground, major structures or changes in rock type to ensure the correct design thickness is achieved • Consider building up the required thickness in two or more passes, or using fibre-reinforced shotcrete as a mesh replacement if large gaps behind the mesh cannot be avoided • Where fibre-reinforced shotcrete is sprayed, the design should consider the loading condition for the specific application *Note: It is not good practice to spray fibre-reinforced shotcrete through or over mesh, especially where large gaps exist between mesh and the rock surface, as it has a greater tendency to form voids and shadows than plain shotcrete*

Table 50: Checklist to assist in performing spot checks to ascertain the quality of shotcrete during installation of the surface support

6.1.4 POST INSTALLATION

The two methods of applying quality control to reinforcement and support that have already been installed are spot checks and instrumentation techniques. By using a combination of these methods, a mine can readily identify problem areas with installation techniques or product quality and verify whether certain support elements are carrying loads at, or close to, their design capacities.

Corrosion warrants special mention as it can have a dramatic affect on the quality of many reinforcement and support types, even those bolts that are fully encapsulated in grout or resin.

Some reinforcement and support elements such as friction rock stabilisers and mesh will corrode over time, even if coated with a protective agent. The corrosion may be easy to see from the portion of the protruding support, but the actual level of corrosion may be difficult to accurately determine on the bolt inside the hole.

In the case of fully encapsulated bolts, corrosion effects may not be visible until the support has failed. Monitoring for corrosion in grouted bolts is not easily achieved. A number of mines have recorded cases of such corrosion-related failures which are thought to have occurred due to ground movement cracking the resin or the grout, thereby exposing the bolt to corrosion effects.

Minimising the effects of corrosion on excavation stability whilst making every effort to maintain reinforcement and support quality should be carefully considered during the design phase and when selecting ground control products. This may include all relevant site-specific factors such as the expected life of excavation, rock types, presence of major structures, natural and induced stress effects, presence and quality of ground water, if known, and relative humidity in ventilated and unventilated excavations.

6.1.4.1 Post installation spot checks

Visual spot checks for established ground support is often standard practice in any mine's ongoing monitoring program. Most mines have some system of regular visual inspections carried out by geotechnical engineers (usually documented) or supervisors (part of inspecting the work during each shift – documented at some mines). These inspections can be taken to the next level in the form of ground support audits that are carried out at specified intervals, weekly, monthly, etc.

Visual spot checks to establish the condition of ground support are also carried out by mine workers in the course of their daily tasks. These may be associated with other workplace inspections used on the site or as part of an excavation hazard assessment that concentrates specifically on ground conditions and support status (See Section 6.2).

The tables on the following pages show some examples of the checklists that can be developed for the different reinforcement and support products. These tables are a guide only and not a comprehensive summary of all possible conditions or situations. Developing any such site-specific inspection tables or checklists should take into account all relevant site-specific safety aspects, such as the support elements and equipment used, ground/stress conditions and the risk and consequences of approaching or inspecting support in excavations which have been open, exposed to blast vibration or have been installed adjacent to stoping areas for long periods of time.

MECHANICAL ANCHOR BOLT SPOT CHECK POST INSTALLATION		
Observation / Test	**Cause**	**Possible Remedial Action**
Loss of contact between the plate and the rock surface	• Shell loosening due to blast vibration or incorrect tensioning during installation	• Re-tension bolts by approved method used on site
Bent rock bolt plate	• Increasing load from surrounding rock	• Check condition of other bolts and overall stability in the area for signs of an increase in bolt loading in the region • Support using bolts with additional load carrying capacity may need to be installed
Bolt is tapped with a spanner or metal object	• Hollow sound indicates low tension *Note: Low tension can be caused by a number of factors including shell slipping, incorrect initial tension, plate bending, blast vibration, rock crumbling under the plate* • Ringing sound indicates high tension *Note: High tension may be caused by ground convergence*	• Re-tension loose bolts by approved method used on site • High tension should be checked using a torque wrench to ensure the reading is within the acceptable range established by the mine site (See QC for instrument testing)
Unbroken bolts have fallen out of their holes	• The bolt has become completely disconnected from the shell • Corrosion has caused damage to any or all of the bolt components • Ground has fallen away from around or behind the shell at the back of the hole causing the support mechanism to be rendered ineffective • One or more bolts failed, causing the load exerted on other bolts in the area to exceed their design capacity	• Install another bolt close to the existing hole • Consider installing a different bolt type that is not as easily affected by localised ground movement in broken or cracked ground • Longer bolts may be required if the rock failed behind the shell. Re-evaluate support requirements in the area
Broken bolts are found on the ground	• The ultimate strength of the bolt has been exceeded ("necking" of the bar) • One or more bolts failed, causing the load exerted on other bolts in the area to exceed their design capacity	• Re-evaluate bolt type and requirements in the area. Consider installing a bolt that has a greater load carrying capacity
A number of intact bolts have fallen on the ground encased in a large rock	• If a shear, fault or major structure was present near the end of the bolt, the anchor may not be located in competent ground. This would result in non-effective anchoring that would reduce the load carrying capacity of the bolts	• Evaluate the ground conditions in the area, redesign and install new reinforcement as required

Table 51: Checklist to assist in performing spot checks to ascertain the quality of mechanical anchor bolts some time after the installation of the reinforcement

FRICTION ROCK STABILISER SPOT CHECK POST INSTALLATION		
Observation / Test	**Cause**	**Possible Remedial Action**
Face plate can turn freely A portion of the bolt protrudes from hole	• Bolt was not fully inserted into hole, or • Hole diameter too small or • Hole drilled too short (should always be drilled at least 100 mm longer than the bolt)	• Consider installing another bolt close to the damaged unit if required • If the hole has been drilled to the correct length (+ 100 mm in excess of bolt length) attempt to push the bolt further into the hole until the plate touches the rock surface)
Ring does not make full contact with the bearing plate, or Ring has partially broken away from the end of the bolt	• Damaged prior to, or during, installation. Can occur due to poor storage practices or overdriving the bolt after the bearing plate has made contact with the rock. Bolt will be ineffective • Bolt is installed at an angle to the hole which prohibits the ring making full contact with the plate	• Consider installing another bolt close to the damaged unit if required • Check other bolts in the area for similar installation defects. Area may need rebolting if a significant number of bolts are not installed at the correct angle *Note: The load carrying capacity of bolts decreases dramatically as the angle of installation increases away from perpendicular (to the rock surface)*
Slot in bolt does not appear to be closed, or Bolt is installed into the hole significantly quicker and easier than a standard installation	• Hole diameter may be above specification *Note: Slot should not be open more than approximately 6 mm along more than half of the bolt length. Shine light inside bolt to check the gap*	• Another bolt may need to be installed close to the defective unit
Face plate has become completely detached from the bolt and is on the ground	• Corrosion of the bolt which results in the ring breaking away • Increased load breaks ring away from bolt, allowing the plate to fall • Redistribution or an increase in stress around the excavation	• Check the area for similar occurrences on other bolts. Re-bolt or rehabilitate as required. Consider using fully encapsulated or other bolts that are not as susceptible to corrosion effects • Consider re-evaluating length and type of support used to control any increased load or stress changes
Slot in bolt closes up completely but ring stays intact	• Ground movement (shearing) or increasing stress	• Friction stabilisers can fail without showing any sign of change at the hole collar. Consider re-evaluating length and type of support used to control increases in stress
A large number of bolts have fallen from an area encased in a single block of rock. The ends of the bolts are visible	• Bolts not generating enough friction to carry the total weight of failed rock • Shear, fault or other major structure was present behind or near the end of the support. Not enough of the bolts were imbedded in solid ground • One or more bolts failed, causing the load exerted on other bolts in the area to exceed their design capacity	• Evaluate the ground conditions in the area, re-bolt or rehabilitate as required

Table 52: Checklist to assist in performing spot checks to ascertain the quality of friction rock stabiliser bolts some time after the installation of the reinforcement

RESIN GROUTED BOLT SPOT CHECK POST INSTALLATION		
Observation / Test	**Cause**	**Possible Remedial Action**
Plate not in contact with the rock surface	• Hole originally drilled too short • Resin spun and set before bolt pushed all the way to the back of the hole • Rock has fallen away from around the hole collar	• Where threaded bolts are used, attempt to spin the nut up until the plate makes contact with the rock • Reinstall another bolt close to the original unit • If rock is falling away from around the collar of other bolts in the area, where there is no surface support, consideration should be given to installing surface support to prevent spalling
A number of intact bolts have fallen out of their holes	• The bond between the resin and the bolt has been broken along its full length. This could be due to a number of issues including improperly mixed resin, poor resin quality etc.	• Redrill hole and install another bolt close to the original • Install bolts in the area to replace any suspected defective after reviewing spin and set times being used. Also check spin and set times on the cartridge boxes to validate installation practices • Check resin batch for use by date
A number of intact or broken bolts have fallen from the surface partially encased in rock	• Bolts not long enough to carry the total weight of failed rock • Shear, fault or other major structure was present behind or near the end of the support. Not enough of bolts were imbedded in solid ground. This results in a reduction in the bolts load carrying capacity • One or more bolts failed, causing the load exerted on other bolts in the area to exceed their design capacity	• Evaluate the ground conditions in the area, redesign and install new reinforcement as required

Table 53: Checklist to assist in performing spot checks to ascertain the quality of resin grouted bolts some time after the installation of the reinforcement

6

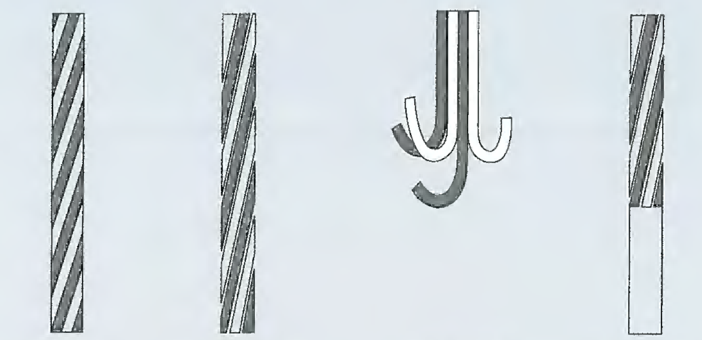
CABLE BOLT SPOT CHECK POST INSTALLATION	
Observation / Test	**Cause**
Grout quality	Look at the grout splashed onto the floor or walls of the excavation that was cable bolted. If the grout seems more viscous than usual, the water:cement ratio was too high
Consistency of grout column	Check the end of the breather and/or grout tubes to see if they are full of grout. Cut the end of the grout or breather tubes when carrying out this check if possible If the tubes are not full of grout, the crew responsible for the poor installation practices should be checked to determine whether they are carrying out all quality control standards for mixing and pumping grout satisfactorily
Plates and straps	Check the angle of the cable bolt with respect to the rock surface. The cable bolt behind the surface fixture should be approximately perpendicular to the surface. If it is not, check the individual wires in the cable bolt strand for damage Check the plates and straps. They should be correct size and flush with the rock surface. Fixtures should not be able to be moved by hand. If these fixtures are loose, they can be "shaken off" by blast vibrations or will be too loose to perform their design function Look at the orientation of any domed or butterfly plates. The rounded part of the plate should be facing away from the rock surface
Barrels and wedges	Check the barrel for looseness. It should be impossible to move the barrel if it has been installed correctly Look at the barrels and wedges. The wedges should be protruding slightly past the end of the barrel and should not show any sign of damage. There should be no grout, oil or dirt on any of the barrel or wedge surfaces
Condition of the cable end has changed as a result of rock failing around the cable or the cable bolt failing	The visual condition of the cable after failure can provide a rough estimate of the load being placed on the cable (After MacSporran et al 1992) Stripped – Unravelled – Pigtailed – Ruptured  0-5 tonnes – 5-15 tonnes – 15-25 tonnes – >25 tonnes
Large number of bolts have fallen out of the backs or wall encased in rock	Possible inadequate design, structurally controlled failure, seismic activity or incorrect bolt type in seismically active conditions

Table 54: Checklist to assist in performing spot checks to ascertain the quality of cable bolts some time after the installation of the reinforcement

Note that remedial actions are not included in the above table as a detailed evaluation of site specific conditions must be carried out in conjunction with the possible causes listed above to ascertain the cause of any cable bolt quality control issues. Specific remedial action instructions could potentially be misleading.

MESH SPOT CHECK POST INSTALLATION		
Observation / Test	**Cause**	**Possible Remedial Action**
Large gap (distance) between mesh and rock surface, or Mesh is sagging away from the rock surface	• Bolts not installed correctly • Rock bolt plates not firm against rock surface • Irregular rock surface or excavation profile. Not enough bolts have been installed or bolts are not installed in the optimum position • Loose rock accumulates behind mesh causing sagging/loading of mesh	• Spot bolt to pull mesh tight to surface profile as required • Bleed mesh if the mesh supplier's specifications on deformation or capability and/or site standards for acceptable deformation are close to being exceeded (always use the site approved procedure to bleed mesh safely)
Welds broken at point where wires intersect	• Faulty manufacture of mesh sheets • Sheets excessively forced or stretched during installation • Mesh grade may not be strong enough to accommodate loading or stress for the particular application • Corrosion	• Check other sheets in batch for similar defects. Discard, repair or cut away damaged portions if possible • Place additional sheet on top of damaged area if required • Consider using a higher grade mesh • If corrosion present across a whole section of support, rehabilitate the area using additional mesh or other surface support. If condition is occurring in other areas within the mine on a larger scale, consider a revised or alternative surface support system

Table 55: Checklist to assist in performing spot checks to ascertain the quality of mesh some time after the installation of the surface support

6

SHOTCRETE SPOT CHECK POST INSTALLATION		
Observation / Test	**Cause**	**Possible Remedial Action**
Substantial amounts of shotcrete on the ground (excessive rebound)	• Distance of shotcrete nozzle was too close or at too great an angle to the surface being sprayed • Air pressure may have been too high when shooting	• Check thickness of the applied shotcrete by drilling holes in the sprayed surfaces at regular intervals • Respray areas where shotcrete is below design thickness, considering the correct air pressure, nozzle proximity and angle to the rock surface
Shotcrete drops off surface after application	• Rock surface has not been cleaned (washed down) properly • Too much water in shotcrete mix • Not enough accelerator added to batch prior to application • Water quality used when batching shotcrete may have been sub-standard (e.g. high total dissolved solids or salt content)	• Wash down affected area thoroughly. Respray after checking water content/quality and accelerator levels used in the next batch • If high water inflows to the excavation are present, consider options such as pressure grouting the affected area (if the ground is badly cracked to stem the flow), or installing plugs fitted with shut off valves into intersecting drill holes
Shotcrete looks lean or has appearance of dry aggregate	• Mix too dry • Distance between spraying nozzle and surface too great • Cement particles in mix may become completely hydrated if a batch undergoes long travel times before spraying. Results in accelerator dosages having an increasing effect of up to four times the design dosage	• Re-spray area after mix quality has been checked and modified if required, or • Mesh over existing shotcrete • Admixtures such as super plastercisers may have to be changed if time between batching and spraying is too great
Rock or mesh protrudes from beneath shotcreted surface	• Irregular surface profile • Shotcrete has been sprayed below the design thickness • Mesh not installed close enough to the surface. Shotcrete had to be sprayed on the rock and built up considerably in an attempt made to cover the mesh. This results in an effect called "shadowing" • Mesh aperture too small	• Assess shotcrete efficiency. If required, re-spray. In future application, consider the following: • Building up the required thickness in two or more passes, or • Use fibre reinforced shotcrete as a mesh replacement if large gaps behind the mesh cannot be avoided • Ensure that fibre reinforced shotcrete is adequate for the condition and anticipated loading condition *Note: It is not good practice to spray fibre reinforced shotcrete through or over mesh, especially where large gaps exist between mesh and the rock surface, as it has a greater tendency to form voids and shadows than plain shotcrete*

continued on next page

SHOTCRETE SPOT CHECK POST INSTALLATION (continued)		
Observation / Test	**Cause**	**Possible Remedial Action**
Cracks appear in shotcrete	• Any combination of high ambient temperatures, high concrete temperature or low relative humidity may have impaired the quality of the concrete by accelerating the rates of moisture loss and cement hydration • Ground deformation as a result of changing stress conditions	• The addition of stabilisers or coagulants can arrest or slow the hydration process. Discuss any changes to the ingredients in shotcrete mixes with the product suppliers, shotcrete contractors, concrete suppliers or batching technicians to ensure that quality is improved in accordance with the appropriate technical guidelines and standards • Geotechnically re-evaluate the failed area to determine if there are any additional support requirements • If tension cracking of plain shotcrete is only present close to the outer surface, consider using fibre-reinforced shotcrete Fibrecrete will reduce or eliminate curing tension cracks, improve ductility, energy absorption and eliminate the need to install mesh • Assess the conditions over the long term. Consider installing simple devices such as crack monitors (pin on each side of a crack) to measure movement on a regular basis

Table 56: Checklist to assist in performing spot checks to ascertain the quality of shotcrete some time after the installation of the surface support

6.1.4.2 Quality control by measurement

There are a number of electronic instruments, mechanical devices and testing methods available to evaluate the status, performance or condition of installed ground reinforcement and support. When analysed over time, the information provided by this equipment can also allow geotechnical personnel and supervisors to establish whether the impact on support performance is solely quality control-related, the result of changing ground conditions/stress, or a combination of factors.

It is considered standard practice to ensure that bolts installed for pull-out testing are not designed to be part of the ground support pattern so that the test bolts do not affect the integrity of the surrounding reinforcement elements. Clear instructions on the location and frequency of test bolts should be shown on installation plans and reiterated to personnel responsible such as supervisors and engineers who are involved in managing the testing program.

The following tables outline some of the available equipment used in QC measurement. It should be noted that these tables might not contain all the available types of instruments. Reinforcement and support manufacturers or instrumentation suppliers should be consulted to ensure that the correct instruments or equipment are used to carry out monitoring or testing activities for the specific support types that are used at a mine.

MECHANICAL ANCHOR POST INSTALLATION MEASUREMENT	
Test	**Application and Important Points**

Torque or tension test	• A torque wrench is used to give a fairly crude indication of the current tension in a bolt
	• The range for the acceptable torque/tension readings should be established specifically for an individual mine site after consultation with the product supplier
	• If the bolt is threaded at both ends, a torque tensioner can be used as it provides a direct reading of the tension in the bolt
	• There are a number of factors that will affect the torque-tension relationship including:
	  • Angle of installation
	  • Corrosion of the shell (bail and wedge)
	  • Corrosion of the plate
	  • Friction between various components

Table 57: Description of post installation measurement techniques for mechanical anchor bolts

FRICTION ROCK STABILISER POST INSTALLATION MEASUREMENT	
Test	**Application and Important Points**
Pull tests	• Pull tests can be used to determine the approximate load carrying capacity of the friction rock stabiliser • This is achieved by fitting a pull and spacer ring between the ring on the friction rock stabiliser and the bearing plate. A pulling tool (which is connected to a portable hydraulic jack fitted with a gauge) is placed over the pull ring. Pressure in the jack is then increased until the bolt starts to move • A reading is taken on the gauge. The bond capacity (tonne/m) of the bolt can then be established e.g. a 2.4 metre long friction rock stabiliser may move after a 10 tonne load is applied. Considering an effective imbedded length of 2 metres, the bolt may be capable of carrying a load of approximately 5 tonnes/metre

Table 58: Description of post installation measurement techniques for friction rock stabiliser bolts

RESIN GROUTED BOLT POST INSTALLATION MEASUREMENT	
Test	**Application and Important Points**
Pull tests	• Pull tests are of limited value for resin anchor bolts because a short length of resin can sustain a high load. However, such tests may identify severe QC problems • Poor quality resin (supplied or installed) or any gaps in the resin may not always be identified by pull tests
DYWIDAG control nut	• If a DYWIDAG threadbar is used, the available control nut can be used to monitor loading on the bolt. It is made up of two parts separated by slots • The width of the slots decreases as the bolt loading increases

Table 59: Description of post installation measurement techniques for resin grouted bolts

CABLE BOLT POST INSTALLATION MEASUREMENT	
Test	**Application and Important Points**
Pull tests	• Short cable bolt lengths can be pull tested after installation. The bond length for these tests should be approximately between 250 mm to 500 mm of grout bond. In these tests, a load is applied to the cable bolt and the resulting deformation is measured. Where stress change could occur, it is useful to perform pull tests at different stages of the mining sequence • Cable bolts with grouted lengths greater than 2 metres should only be pull tested when serious quality control problems such as incomplete hole filling (grout) or if stress decreases are suspected. This is because grout columns >2 metres will generally exceed the critical embedment length required to break the steel tendon. It should be noted that a serious problem exists if these cables pull out at all

Table 60: Description of post installation measurement techniques for cable bolts

Post Installation Measurement of Mesh

Instrumentation is not commonly used in the field to measure the displacement or condition of mesh. Laboratory tests (point and distributed loads), have been carried out to simulate mesh loading and ascertain displacement and/or load-carrying capacity. However, the visual checks outlined in Table 55 are generally used throughout the industry as a guide to monitor and carry out remedial action, if required, where mesh has been installed.

Post Installation Measurement of Shotcrete

Instrumentation is not commonly used to measure the performance of shotcrete after installation. The visual checks outlined in Table 56 are generally used throughout the industry as a guide to monitor and carry out remedial action, if required, where shotcrete has been installed.

There are however, testing methods of monitoring shotcrete material quality both prior to and after spraying including:

- Slump tests for water:cement ratio
- Testing of ingredients in the mixing tank
- Uniaxial compressive strength testing using a Schmidt hammer for concrete cylinder specimens of product from the mixing tank, or core samples of 'in-place' or 'test panel'. The test panel specimens can be obtained from shotcrete sprayed on rock surfaces underground or under controlled laboratory test conditions

6.1.5 ISSUES NOT CONSIDERED

There are a number of different aspects of quality control for ground reinforcement and support that were not described in detail, or have purposely not been listed due to the different practices undertaken throughout the industry. Some of these issues are outlined below.

6.1.5.1 Personnel and procedures

QC is heavily dependent on the skill and experience of the personnel installing support. Some of the factors may include, but are not limited to:

- Owner/operator versus contractor workforces
- Site-based versus fly-in/fly-out
- Method of remuneration
- Level of training
- Company policy
- Mine site standards
- Available training and management resources
- Chosen method of installation (equipment and procedures)
- Level of compliance requirements with State/Territory legislation, regulations, national training standards, etc.
- Whether International Organisation for Standardisation (ISO) accreditation is sought or adopted

These issues can all have a bearing on how well ground reinforcement and support quality control standards are developed, implemented and maintained. Each company or mine will have its own policy for their chosen strategy or approach.

6.1.5.2 Ground support types

Only generic reinforcement and support types have been listed in this document. Within these support types, there are a variety of products on the market developed by manufacturers with their own specific capabilities and installation requirements. Mine sites can use any number of different products to suit their own conditions. Regular revision of quality control measures may be required if new generic support types become widely used and accepted within the industry, e.g., spray-on surface liners.

6.2 Pro-active Inspection to Detect Potential Rockfall Hazards

This section reviews strategies for monitoring the rock mass behaviour and how it responds to mining activities with the purpose of understanding and anticipating how rockfall hazards may develop in the future at specific locations within a mine. Monitoring systems commonly used in underground mines have been described in Section 5.1.6 and are summarised in Table 61.

DESCRIPTION	QUANTITY MEASURED	NATURE OF MEASUREMENT	COMMENTS
Visual observations	Physical characteristics	Surface of excavations or borehole	Observers look for signs of instability, stress effect, rock mass deterioration, etc.
Wire extensometer	Movement of the anchor position relative to the borehole collar	Inside the rock mass, along a line: 1 dimension	Extensometer installed in a borehole. The measurement is made to the anchor location only. Measurements are best over small displacements
Time domain reflectometry (TDR)	Location of break along TDR cable	Inside the rock mass, along a line: 1 dimension	TDR installed in a borehole. Provides continual monitoring along length of the TDR
Instrumented reinforcement	Elongation of the reinforcement	Attached to rockbolt or cable bolt: 1 dimension	Can provide an indication of the load acting on the rock bolt/cable bolt
Stress cells	The strain of the rock is interpreted to estimate stress changes	Point measurement inside the rock mass	Installed in areas where stress change is anticipated
Cavity monitoring systems (CMS)	Laser measurement of distance to the excavation boundary from a fixed point	Void measurement: 3 dimensions	Access to the cavity will be limited. Risk of losing expensive equipment is high. CMS will give the actual void geometry
Seismic monitoring	Seismic wave generated by rock failure. Location and seismic parameters are estimated from recorded waveforms	Large volume of rock mass: 3 dimensions	Equipment installation can be remote from the production area. The only assessment of rock mass response over a large volume. Mine scale seismic systems are expensive and require extensive interpretation to be useful

Table 61: Summary of monitoring techniques commonly used in underground mining (Modified after Duplancic 2002)

6.2.1 PRO-ACTIVE INSPECTION OF EXCAVATION

The pro-active inspection of excavations, looking for rockfalls and other hazards, is every individual's duty of care and an integral part of everyday procedures for accessing and carrying out their work-related task in the workplace.

These observations must be embedded into a system, which will ensure that the entire workforce is well trained to recognise rockfall and other hazards. Furthermore, well-defined procedures for taking appropriate actions to minimise the risk when such hazards are identified must be in place. These procedures may include, but are not limited to:

- Mitigating the hazard, if personnel are competent and empowered to address the hazard
- Barricading the area, if the hazard cannot be mitigated
- Contacting the appropriate personnel
- Reporting observations

Good practices for supporting pro-active observations from the workforce have been described in Section 4.3.3 Excavation Assessment: Examples of Informal Risk Assessment (RA) Methods. This may involve field books describing "what to look for" and/or typical failure mechanisms at the mine, a "tick a box" checklist of potential hazards, or the integration of such information with other general workplace safety systems.

Pro-active inspection of excavations can also take the form of routine inspections of the mine by front line supervisors, mine management and/or geotechnical personnel. Formal geotechnical audits involving geotechnical personnel accompanied by selected competent personnel, (regulators, consultants, management, front line supervisors and/or operators), should also be performed periodically. It is important that all inspections are followed-up with appropriate action plans to remediate any immediate or longer-term concerns.

6.2.2 CONVENTIONAL ROCK MASS MONITORING INSTRUMENTS

Extensometers and stress cells are sometimes used to monitor areas of the mine where a concern exists regarding stability. The data is most useful in recording the trends in displacement or pressure as a function of time and mining activities. Data showing no significant change with time indicates stable conditions. A steady increase is typical of rock mass deforming as a result of stress change or creeping. In such cases, it is important to investigate the cause and confirm that the deformation is within the anticipated response of the rock mass. At that point, the instrument should be read frequently. Acceleration of the increase in deformation or pressure relates to unstable rock mass response and may be a sign of imminent failure. Appropriate action should be taken to minimise the risks. Figure 54 illustrates typical trends and interpretations for extensometers and stress cells data. It is essential to realise that these interpretations rely on the assumption that the failure will be progressive instead of sudden or violent (rockburst). This emphasises the requirement to understand all potential failure mechanisms before using instruments as a warning system.

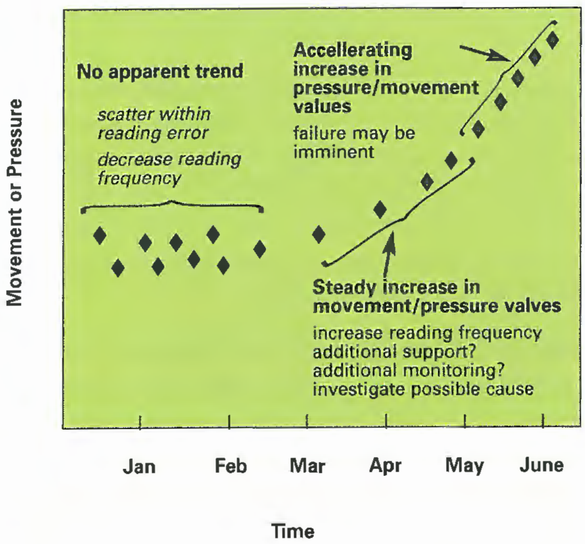


Figure 54: Generic plot of monitoring data versus time indicating trends, general interpretations and possible actions (After Milne 1997)

6.2.3 INSTRUMENTED REINFORCEMENT

There are a few instruments commercially available to monitor the elongation of reinforcement elements (mechanical rockbolts or cable bolts). It is possible from this data to estimate the load acting on the instrumented rock reinforcement element and interpret its proximity to failure. This interpretation is generally not always easy to make.

Again, one must be very aware of the potential failure mechanisms to analyse the significance of this data. It is also important to realise that the load distribution amongst the reinforcement elements inside a bolting pattern can, and is likely to be variable. Consequently, the reading from one instrument alone cannot be extrapolated to be representative of every bolt in the pattern.

The load distribution along a single reinforcement element, grouted or friction bolt, can also vary depending on the failure mode and the location where the crack(s) opens. The parallel use of other monitoring approaches such as borehole cameras and extensometers can assist in obtaining a reliable interpretation of the data to supplement the reinforcement monitoring data. This is of great importance if such instrumentation programs are used as a warning of imminent failure.

6.2.4 THE ROLE OF SEISMIC MONITORING IN SUPPORTING MINE PRODUCTION

Note: This section has been taken from Potvin and Hudyma (2001) and modified for this manual.

From an underground mine worker's perspective, seismic events and rockbursts are in most cases unexpected phenomena over which he or she has no control and little understanding and which can pose a clear risk to his/her safety. No one can be comfortable and fully productive working in such an environment.

One of the main benefits of seismic monitoring is for mine staff to be in a position to reassure the workforce following major seismic events or flurries of smaller events. This reassurance comes from the rapid and accurate identification of the location and magnitude of events. Communicating this information efficiently to the workforce is a major step towards demonstrating that the seismic problem is confined to a certain area of the mine and is being addressed. Prompt communication plays a key role in minimising production disruption from mine seismicity.

Site-specific criteria are usually developed in seismically active mines to define temporary exclusion zones and re-entry procedures based on past instances of event frequency and magnitude. Figure 55 shows an example of a frequency of seismic events against time plot, where most peaks correspond to blasts.

6

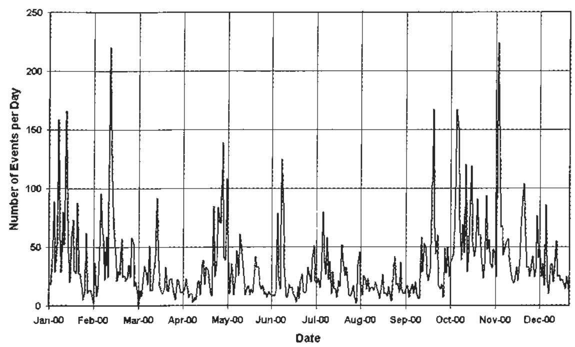


Figure 55: Example of a frequency of seismic events against time plot, showing most peaks corresponding to blasts

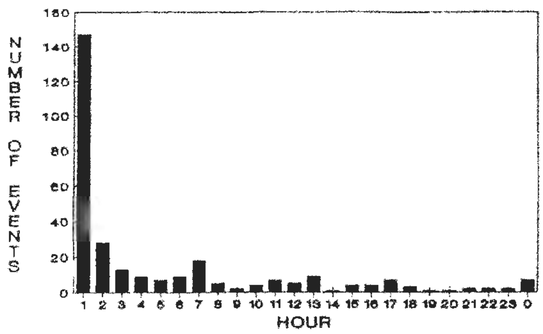


Figure 56: Example showing number of seismic events decaying rapidly after each blast

Figure 56 shows that the number of events decays rapidly after each blast meaning that the seismic risks remain high in these areas for only a short period of time. This is the type of data that can be used as a basis for temporary exclusion zones and re-entry procedures.

Seismic monitoring can potentially play a very pro-active role by identifying high risk areas of a mine. A good example of this is shown in Figure 57, where a crown pillar has experienced a history of problematic seismicity. During nine months of crown pillar mining, more than 20,000 seismic events were generated, ranging in magnitude from –3 to +2.6. The figure shows 300 seismic events detected in the month prior to the commencement of crown pillar mining. All 300 of these events had a magnitude of –2 or smaller. This seismicity was located on what have become seven of the eight most microseismically active geological features in the crown pillar during mining. In effect, seven of the eight most active features during the crown pillar mining could be identified before pillar mining started. The implications of this early information for stope design, stope sequencing, infrastructure positioning, development location and ground support are enormous.

The early (even before production starts) identification of seismically active geological features, such as faults or dykes using sensitive microseismic monitoring, may allow for improved support to be installed in key areas. This can alleviate the need for time consuming and costly rehabilitation during production mining. It may also be possible to alter the mining strategy and extraction sequence to minimise the disturbance of the stress field acting near previously identified seismically prone features, or choose the most appropriate timing for mining in burst prone areas.

The more recent trend in using seismic monitoring to support mine production activities is towards the integration of microseismic data with other relevant sources of information (geology, mining, geomechanics, etc.), to produce seismic risk assessment.

In general, the monitoring of seismic activity contributes to better understanding of how the rock mass responds to mining activities and identifies areas where seismic risk may be higher. As such, it provides improved knowledge for decision making.

6.3 Rockfall and Rockburst Investigation and Documentation

Regulations in most States and Territories require that all serious accidents, including the ones related to rockfall and rockburst, involving personnel injuries be investigated and reported. These are generally rigorous investigations and are often based on recognised techniques such as fault tree or event tree analyses.

The investigation and documentation of all significant rockfalls and rockbursts incidents, whether they had consequences or not, offers an opportunity to better understand the nature and the key contributing factors to these hazards at a specific mine site. The definition of significant rockfalls should be derived locally. It may consider factors such as whether:

- Personnel could have been exposed to it, (entry area, not during the blast)
- It was unforeseen
- It was large enough to have serious consequences
- It caused damage to equipment

It is good practice for a mine to have a clear and documented procedure to initiate an investigation and to implement a risk mitigation strategy when a rockfall occurs. This procedure can be a stand

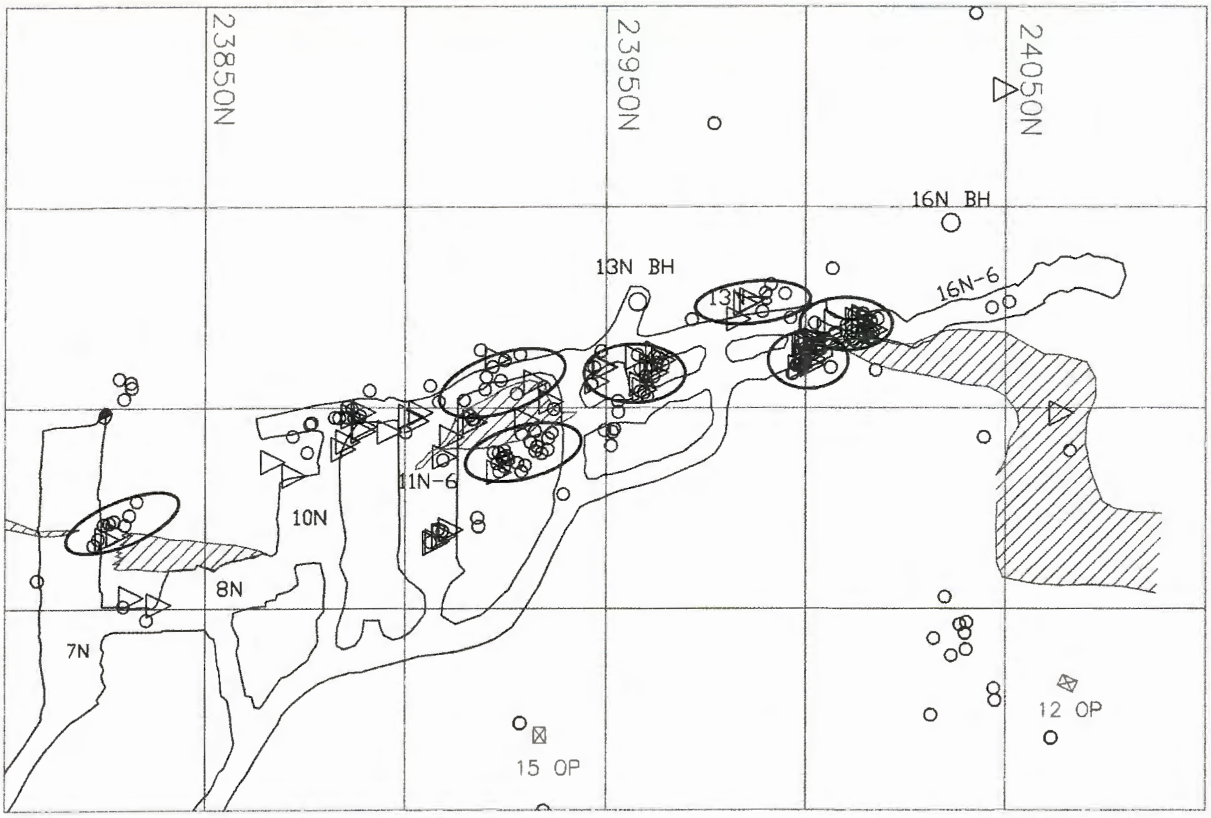


Figure 57: Example of the pro-active role of seismic monitoring in identifying high rockfall risk areas

alone document or could be part of the ground support standard or other operation standard procedures. All personnel assigned to underground duties should know how to initiate a rockfall investigation. They also should be trained and made aware of the importance of reporting all significant rockfalls and rockburst incidents.

The investigation should involve geomechanics personnel and possibly other relevant personnel, operators, supervisors, managers. This will assist in considering both geomechanics and operational factors. These investigations do not necessarily rely on extensive and recognised accident investigation techniques but rather attempt to fast track the identification and documentation of the major causes. An important outcome of all rockfall and rockburst investigation is to address the question, What can be done to prevent this type of incident from happening again?

The documentation of rockfalls and rockbursts will allow for the analysis of historical data, the identification of trends and possibly, provide insight on the principal causes leading to the development of remedial actions.

The more complete the data collection, the more information is available for future analyses leading to an improved understanding of rockfall hazards. However, there is a requirement to keep the documentation process simple and effective. Table 62 provides a relatively comprehensive rockfall data collection form that could be adopted or modified to suit local requirements.

It is good practice to communicate rockfall and rockburst data to the workforce in a simple and easy to understand format. Figure 58 is an example of a typical graph showing the number of uncontrolled rockfalls per month. Such graphs could be displayed on mine notice boards and in other highly visible areas.

Posting rockfall data and other safety statistics help to demonstrate everyone's commitment to improve safety. It informs the workforce on current progress and trends and also keeps the level of awareness high. Good communication practices provide the feedback required to motivate the feedback required to motivate the reporting of significant rockfalls and rockbursts.

ROCKFALL DATA COLLECTION SHEET

SECTION 1: GENERAL

Date on which fall occurred:______/_____/______

Personal injury ☐ Equipment damage ☐ Neither injury or equipment damage ☐

Cross reference to any other rockfall reports (internal investigations etc.)? ______________________________

____

SECTION 2: LOCATION

Depth below surface________________(m)

Drive / Intersection / Entry Stope / Stope Brow / Other (specify) ______________________________

Distance from active face/stope____________(m) Not relevant ______________________________

(specify reason) ______________________________

SECTION 3: EXCAVATION DETAILS

Age of excavation______________ years Expected life of excavation ________________________years

Dimensions:__________m (W) x __________m (H) Proximity to other voids ____________________________

*(Describe void type and condition)*____________________________

Shape: Square ☐ Arch ☐ Shanty ☐

SECTION 4: GROUND SUPPORT DETAILS

Was the area supported? Yes ☐ No ☐

Ground support standard drawing attached? Yes ☐ No ☐

Bolt type(s):____

Bolt length:____

Pattern: _____________(m) x ____________(m)

Surface support: ____

*(type and areas covered)*____

____

SECTION 5: FAILURE DETAILS

Dimensions_________m (H) x _________m (W) x _________m (L) Aprroximate weight_____________(t)

Attach a diagram describing position and shape of failure

(a) Describe failure mechanism (also provide any details not shown in the diagram) __________________________

____

(b) What events led up to the fall?____

____

(c) Types of support failure (e.g. bolts ruptured, pulled out, shear, mesh parted, etc.) __________________________

____

SECTION 6: POTENTIAL CONTRIBUTING FACTORS

Ground Support	Blasting	Stress	Ground Conditions
Too short ☐ Corrosion ☐ Lack of surface support ☐ Incorrect installation ☐ Bolt spacing too wide ☐ Broken bolts ☐ Other ________	Excavation profile in 10 metres preceding fall: As design ☐ Overbroken ☐ Time, size and distance to the nearest blast prior to the rockfall: ________ ________ Other ________	High (increase) ☐ Relaxation ☐ Rockburst ☐	Good ☐ Poor ☐ Highly deformable ☐ Shears/faults ☐ Blocky ☐ Ground water ☐

Have human factors contributed to the rockfall?

*(if yes, please provide details)*____

____

SECTION 7: PERSONAL EXPOSURE

Time of occurrence: Firing ☐ During shift ☐ Unknown ☐

What other human activities were taking place in the area at the time? ________________________

____

____

How often do personnel travel in this excavation? Hourly ☐ Daily ☐ Weekly ☐

Other ☐ (specify)________________________

SECTION 8: WHAT COULD BE DONE TO PREVENT A RE-OCCURRENCE?

Could this fall of ground have been prevented by any of the following:

	Yes	No	*If yes, provide explanation*
Improved ground support?	☐	☐	________
Improved training?	☐	☐	________
Improved planning/design	☐	☐	________
Improved supervision?	☐	☐	________
Improved work practices/procedures?	☐	☐	________
Improved scaling?	☐	☐	________
Improved communication?	☐	☐	________
Other?	☐	☐	________

*Form completed by:*________________________ *Position:*________________________

(print name)

Table 62: Example of a rockfall data collection sheet

continued on following page

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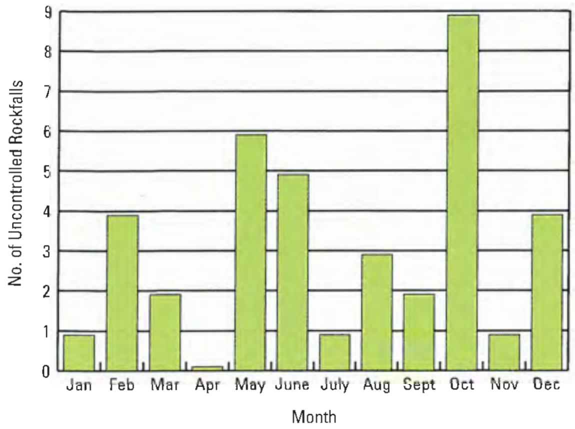

Figure 58: Example of a monthly rockfall statistics graph

6.4 Recording Mine Seismicity

Rockbursts are a subgroup of rockfalls that are induced by seismic events. Most rockbursting conditions are difficult to manage because rockbursts are often sudden and violent events offering limited forewarning. Not all seismic events are or will ever be associated with rockfalls. In fact, only a small proportion of all seismic events produce damage and are classified as rockbursts. As discussed in Section 5.1.6 and 6.2.4, the recording and analysis of seismicity can provide some insight into the rock mass response to mining and to some extent, into the likelihood of rockfalls, particularly in seismically active mines.

Microseismic monitoring systems automatically collect seismic data and also have capabilities for processing, managing and displaying the data. Therefore, mines operating a microseismic system are in a position to keep good records of the seismic activity, with relatively low input from mine staff. However, further analysis of seismic data for the purpose of calibrating numerical models or understanding the rock mass failure processes will require extensive commitment, expertise and effort.

When seismicity at a mine is relatively low and the purchase and installation of a seismic system can not be easily justified, a rock noise report card may be used. An example of a Rock Noise Report is given in Table 63. The rock noise card is to be distributed and completed by all underground personnel every time they witness a seismic event. Since such systems rely heavily on the workforce to collect the data, training on completing the card and raising the awareness of collecting this data is essential. The frequent compilation and analysis of the data can assist in assessing potential seismic related problems and how they are evolving with time.

All monitoring information gathered, whether it is from observations or instrumentation programs, contributes to a continuous appraisal of a mine's geomechanical performance. This information becomes particularly useful when re-assessing the design and operating procedures. This may be done periodically or as a result of a significant event or change in practices and is represented by the major loop in the rockfall management process illustrated in Figure 1.

ROCK NOISE REPORT

TIME AND DATE:	**YOUR LOCATION:**
YOUR NAME AND YOUR ACTIVITY AT THE TIME OF NOISE:	

Did you hear the noise? ☐ Yes ☐ No

What did it sound like?

☐	Popping and cracking	☐	Sharp cracking noise	☐	Loud bang or explosion
☐	Distant rumble	☐	Air concussion or air blast	☐	Was there more than one noise?
Other details:					

Did you feel the noise? ☐ Yes ☐ No

What did it feel like?

☐	Slight vibration	☐	Extended vibration (a second or longer)
☐	Thump or thud	☐	Felt vibration in your legs
☐	Felt like ground dropped	☐	Felt vibration on surface

Did you notice other conditions? ☐ Yes ☐ No

☐	New loose / ground falls / spalling of rock	☐	New cracks in the rock or movement on old cracks
☐	Damage ground support, ie rock bolt heads / plates popped off	☐	Abnormal amount of dust after the rock noise
☐	New damage / cracking of brick or concrete walls, floors, etc.	☐	Did you hear rock moving, rolling, or falling?

Other details. Describe:	

Do you want feedback on your report? ☐ Yes ☐ No

Table 63: Rock noise report to be filled out by workforce when a seismic event is felt or heard underground

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Appendix 1 Geotechnical Risk Assessment Guideline for Underground Mining Operations

Appendix 2 SAF-1371 Ground Support Standards

Appendix 1

GEOTECHNICAL RISK ASSESSMENT GUIDELINES

for

UNDERGROUND MINING OPERATIONS

Developed by the

GROUND CONTROL GROUP (WESTERN AUSTRALIA)

Revision 0 (DRAFT)
February 2000

GEOTECHNICAL RISK ASSESSMENT GUIDELINES

Developed by the Ground Control Group (W.A.)

September 1999

1. OBJECTIVE

The objective of the guidelines is to provide tools for assessing (analysing and evaluating) the geotechnical risks associated with rockfalls. The guidelines must be practical, repeatable and non-prescriptive.

The Australian Standards for Risk Assessment AS/NZS 4360:1999, are used as a basis for developing the GCG (W.A.) Geotechnical Risk Assessment Guidelines.

2. DEFINITIONS AND INTERPRETATION

- **Rockfall**: Volume of rockfalling from the back, side-walls or face of an underground excavation where workers have access. Rockfalls are classified as small rocks (typically in between rockbolts), wedges (larger than rockbolt patterns) or dynamic failures; rockbursts (unrelated to size, but ejected with high kinetic energy)
- **Hazard**: "A source of potential harm or a situation with a potential to cause loss" *Australian Standards AS/NZS 4360:1999.* (Context in the geotechnical risk assessment: the hazard is defined as a rockfall)
- **Event**: "An incident or situation which occurs in a particular place during a particular interval of time". *Australian Standards AS/NZS 4360:1999* (Context in the geotechnical risk assessment: an event is defined as a rockfall that causes an injury to personnel)
- **Exposure**: a measure reflecting the amount of mine workers' activities in each underground excavation
- **Likelihood of an event**: "Used as a qualitative description of probability or frequency". *Australian Standards AS/NZS 4360:1999* (Context in the geotechnical risk assessment: the likelihood is a combination of the probability of hazard with the exposure)
- **Consequence of an event**: "The outcome of an event expressed qualitatively or quantitatively, being a loss, injury, disadvantage or gain". *Australian Standards AS/NZS 4360:1999*
- **Risk**: "The chance of something happening that will have an impact upon objectives. It is measured in terms of consequences and likelihood". *Australian Standards AS/NZS 4360:1999*
- **Geotechnical domain**: "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
  - Rock stress field (pre-mining and induced stress fields)
  - Permeability of the rock mass

  (After W.A. DME Guidelines: Geotechnical Considerations in Underground Mines)

3. SCOPE OF THE GUIDELINE

A distinction must be made between "Ground Control Management Plan", "Risk Management Plan" and "Risk Assessment". The Ground Control Management Plan refers to the application of sound geotechnical engineering practice to the management of ground control challenges during the whole mine life *(After W.A. DME Guidelines: Geotechnical Considerations in Underground Mines).*

As part of an effective Ground Control Management Plan, the potential hazards must be identified, the risks analysed, evaluated and treated (controlled). This is the risk management process, which is illustrated in Figure 3.1 from AS/NZS 4360:1999.

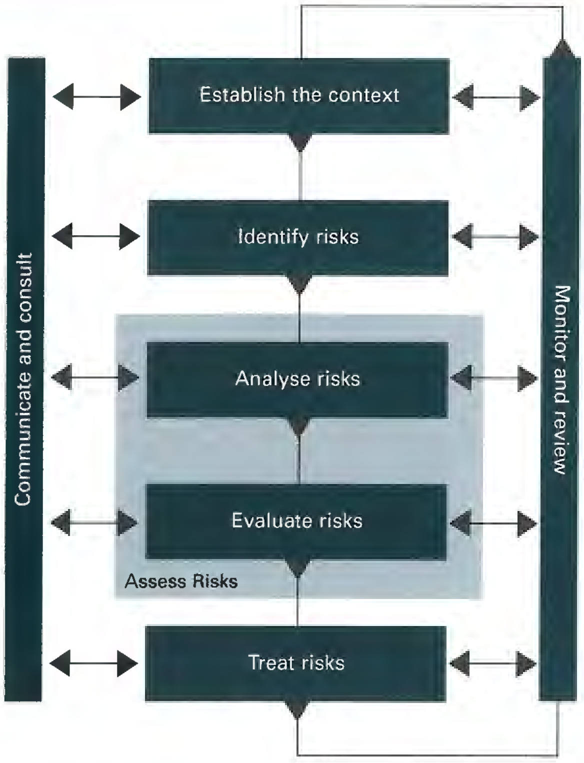
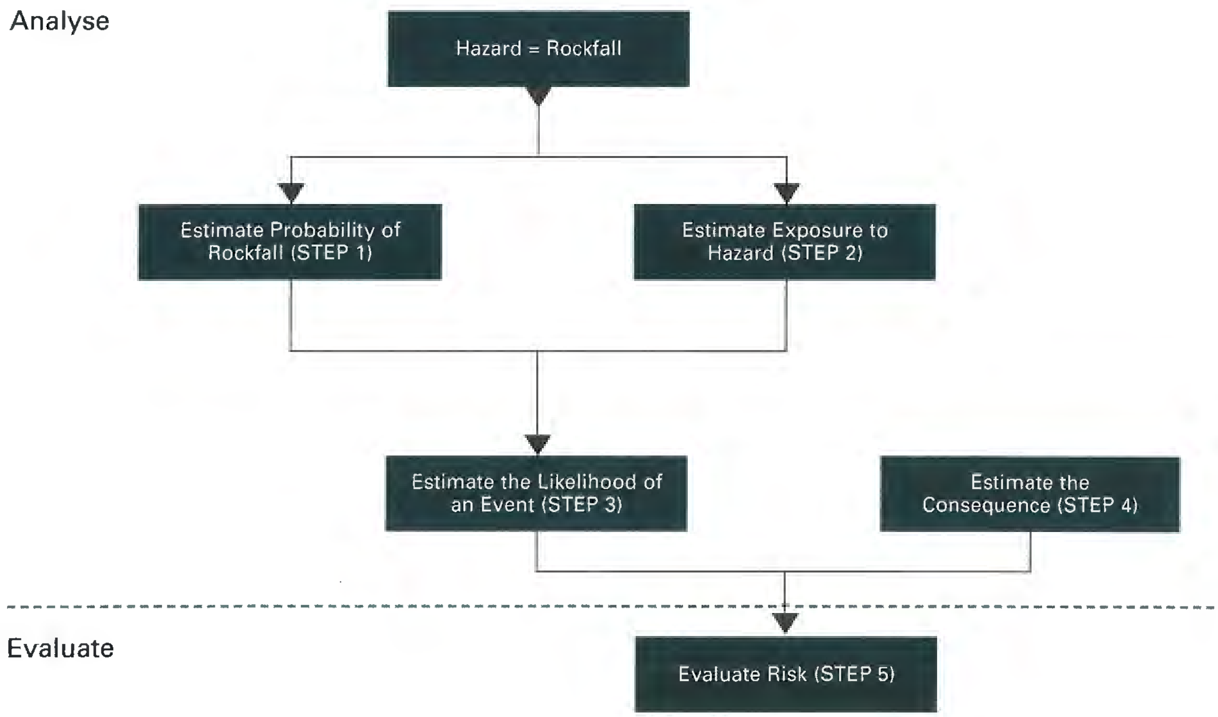


Figure 3.1 Risk management overview

The scope of the guidelines for Geotechnical Risk Assessment described in this document, concerns itself only with assessing the risk, the shaded area of Figure 3.1. The risk assessment process illustrated below has two major components; analysis and evaluation of risks.



4. PROCESS

STEP 1. Estimation of the Probability of Rockfall

The estimation of the probability of a rockfall can be qualitative or semi quantitative. A purely quantitative approach relying on probability and statistics is beyond current technology and is currently not practical at the scale of a mine.

Each operation will need to develop their own system or customise existing systems. The factors to be included in estimating the probability of a rockfall, as well as the weighting of each factor, will be site specific.

The following is a list of factors that could be considered when developing/ customising a system for estimating the probability of rockfalls:

- Rock mass quality
- Structural geology (joints, faults)
- Mine-induced stress
- Blast damage and blast vibration
- Size of excavation
- Shape of excavation
- Life of excavation
- Presence and corrosiveness of water
- Seismic activity in the area
- Ground control measures in place (support, scaling, etc.)

It is recommended to sub-divide the mine into geotechnical domains. A probability of rockfall can then be estimated for each domain. For example, the probability can be expressed on a scale from high to low or on a scale ranging from almost certain to rare or, alternatively, using an arbitrary rating (numeric) system.

An example of a qualitative interpretation of the probability of rockfall is given below.

HIGH ↓ LOW	• Has happened several times at this mine • Has happened at least once before at this mine • Has happened elsewhere in similar conditions, but not at this mine • Could potentially happen, but there is no known case in similar conditions • Could not envisage how it could happen

Further examples of systems used for estimating probability of rockfall hazards are given in the reference manual (See Section 5).

Note: Geotechnical domains may change with time, e.g., stress induced by mining. Mechanisms to identify these changes should be an integral part of the risk management program.

STEP 2. Estimation of Exposure to Hazard

The level of human activity within each excavation is critical in establishing the safety related risks associated with rockfalls. A qualitative, semi quantitative or quantitative approach can be used to estimate the level of activity for each excavation. Although it is understood that workers located inside vehicles are often partially protected against rockfalls, this is not necessarily factored in the estimation of exposure in order to keep the analysis simple and conservative.

All excavations accessed by mine workers require an exposure rating or ranking. For example, the ranking could be expressed in terms of "daily, weekly, monthly", etc., or on a scale from frequent to rare or as a percentage of time or other ratings suitable to the operation.

Note: The usage of excavations and, therefore the level of human activities for an excavation, may change with time. Mechanisms to identify these changes should be an integral part of the risk management program.

STEP 3. Estimating Likelihood of an Event

The likelihood of a rockfall injuring a mine worker can be estimated by combining the probability of a rockfall with the exposure. The likelihood is then expressed according to the Australian Standard AS/NZ 4360:1999 as:

- Almost certain
- Likely
- Moderate
- Unlikely
- Rare

An example of how the probability of ground fall is combined with the exposure to determine the likelihood is shown on next page:

LIKELIHOOD ASSESSMENT MATRIX FOR GEOTECHNICAL RISK

EXPOSURE	PROBABILITY OF ROCKFALL HIGH → LOW				
Continuous	Almost certain	Likely	Moderate	Unlikely	Rare
↓	Likely	Moderate	Unlikely	Rare	Rare
	Moderate	Unlikely	Rare	Rare	Rare
	Unlikely	Rare	Rare	Rare	Rare
No exposure	Rare	Rare	Rare	Rare	Rare

Where:

Almost certain: Is expected to occur in most circumstances

Likely: Will probably occur in most circumstances

Moderate: Might occur at some time

Unlikely: Could occur at some time

Rare: May occur only in exceptional circumstances

STEP 4. Estimating the Consequence of an Event

The consequence of a rockfall hazard can vary from being insignificant, if no one is injured, to multiple fatalities. The following interpretation of the five categories of consequences is proposed below: *(After Australian Standards AS/NZS 4360:1999)*

- Insignificant: No injuries, low financial loss

  (Note that the insignificant consequence is not applicable to the proposed definition of an event; "...a rockfall that causes an injury to personnel"; See Section 2)
- Minor: First aid treatment
- Moderate: Modified or lost time injury (MTI or LTI)
- Major: Severe or long term injury (LTI)
- Catastrophic: Fatality or multiple fatalities

Conventional risk analysis must account for the worst credible consequence of an event, which in the case of a rockfall, is a fatality (catastrophic).

STEP 5. Evaluating the Risk

Once the likelihood, (STEP 3) and the consequence of an event, (STEP 4) have been estimated, the risk can be evaluated using a risk analysis matrix. In accordance with *Australian Standards AS/NZS 4360:1999,* which stipulate that the proposed matrix needs to be tailored to meet the needs of organisations and the particular subject of the risk assessment, Table E3 of the *Australian Standards AS/NZS 4360:1999,* has been modified as follows:

QUALITATIVE GEOTECHNICAL RISK ASSESSMENT MATRIX

LIKELIHOOD	CONSEQUENCES CATASTROPHIC (FATALITY)	MAJOR (SEVERE INJURY)	MODERATE (MTI)	MINOR (FIRST AID)	INSIGNIFICANT
Almost certain	E	E	H	M	L
Likely	E	H	M	M	L
Moderate	H	M	M	L	L
Unlikely	M	L	L	L	L
Rare	L	L	L	L	L

Where:

(E) Extreme Risk: Do not proceed until risk is modified, reduce exposure or reduce probability of rockfall

(H) High Risk: Do not proceed until risk is modified, reduce exposure or reduce probability of rockfall

(M) Moderate Risk: Develop an action plan to reduce risk

(L) Low Risk: Monitor

5. DEVELOPMENT OF A REFERENCE MANUAL

It is proposed that a reference manual be developed to assist potential users of these guidelines. The manual is to be divided into two sections, in which the first section contains a copy of risk assessment systems currently used in Western Australian underground operations. The second section of the reference manual is to list relevant literature on the subject of risk assessment and include a copy of the Western Australian Code of Practice for Surface Support.

The Ground Control Group (W.A.)

The Ground Control Group (W.A.) is a forum for the discussion and dissemination of ground control information for Western Australian mines. Group members represent companies that either operate or manage a mining operation. Members are free from commercial interests in terms of the supply of services and products to the mining industry. The Group was formed in February 1999 and a year later it became a sub-committee of the Eastern Regional Council (ERC) of the Chamber of Minerals and Energy of Western Australia. The GCG (W.A.) objectives are:

- *To investigate all aspects of ground control using available expertise*
- *To promote wide spread industry based discussion in all aspects of ground control practice*
- *To comment and provide guidance on ground control practice to members and other interested parties where considered appropriate*
- *To promote the use of ground control practices to optimise safe and productive work*

The Ground Control Group (W.A.) may be contacted through the ERC secretary:

Ph: +61 8 9021 2155, email: come@cmewa.com

Appendix 2

SAF-1371
GROUND SUPPORT STANDARDS

Intent

To prevent injury to personnel and protect equipment from damage by the correct design and installation of ground support and reinforcement.

Responsibility

Mine manager

- Ensure compliance with the requirements of this procedure

Superintendent/supervisor

- Implement and administer approved ground support standards

Rock mechanics engineer

- Provide geotechnical support to operational personnel as required

All employees

- Assess ground conditions, and take action as appropriate to ensure a safe work place

Requirements

■ Legislative Regulations

- Mining and Quarrying Safety and Health Act 1999, Mining and Quarrying Safety and Health Regulation 2001 – commencement of Regulation 6 April 2001
- Reference Part 6 – Facilities and Processes, Ground Control 44.(1), 44.(2) and 44.(3)
- Regulations apply to all persons employed in the mine who share an obligation to manage the risk of ground control through established measures in place. Key elements to this legislative compliance include the assessment of the workplace by appropriate qualified staff personnel, as well as operators, inspecting the working environment and managing hazards identified through established processes. ***To assist in complying with the new regulations, it is now a requirement that, for each development cut taken, individual operators will have to complete a 'Mine Ground Condition Risk Assessment' sheet (SAF-1371/2)***

Legislative Summary

- **44.(1).** "A person who has an obligation under the Act to manage risk in relation to ground control at a mine during the mine's design, operation or abandonment must ensure appropriate measures are taken to prevent local and area failures in ground integrity"
- **44.(2).** "The person must have regard to the following in deciding the appropriate measures:
  (a) local geological structure and rock properties and their influence on rock stability
  (b) the size and geometry of the mine's openings
  (c) the presence of previously excavated or abandoned underground workings
  (d) water inflow, drainage patterns, groundwater regimes and mine dewatering procedures and their influence on rock stability over time
  (e) the analysis and interpretation of relevant geotechnical data, including the monitoring of openings and excavations
- **44.(3).** The measures must include the following:
  (a) the minimisation of rock damage, from blasting, at the excavation perimeter
  (b) the use of appropriate equipment and procedures for scaling
  (c) the proper design, installation and quality control of rock support
  (d) the timing of ground support to take account of rock conditions and behaviour"

■ Mine Ground Control Risk Management Plan

- The Mine Ground Control Risk Management Plan is a process by which the mine will effectively manage the hazard of rockfalls
- The methodology involves a systematic assessment of the geotechnical risks to all underground mine personnel and equipment associated with potential rockfalls in access ways and infrastructure
- The system is fully auditable through the *Mine Geotechnical Database*
- The database allows for easy and efficient tracking of any rehabilitation and outstanding actions

- The risk management plan concentrates on the process of analysis and evaluation of risk through a process of steps
- These steps consider assessing the probability of a rockfall and the exposure of people to these falls of ground, with an evaluation of the consequences of such events
- Based on the risk assessment evaluation, the urgency of action plans for any particular area can be developed
- Recommended rehabilitation works are passed to the mine superintendent and scheduling engineer to organise according to priorities – ***reducing risks to acceptable levels***
- The database tracks those areas requiring rehabilitation, which remain as outstanding actions until completed
- The data management system, incorporated within the risk management plan, comprises of three distinct areas – planning, operations and workplace inspections
- The most appropriate ground support for a specific area of primary development is identified at the planning stage (with relevant plans issued by the planning engineer), and verified at the operations stage through the use of the mine ground condition risk assessment sheets (SAF-1371/2). Existing development areas are assessed in terms of the quality of the ground support and the potential need for rehabilitation at the workplace inspections stage
- All data generated as part of the data management system is entered into the *Mine Geotechnical Database*

Mining, Design and Ground Rehabilitation

- All geotechnical aspects shall be adequately considered in relation to the design of all development and stopes
- No mining of any development heading may take place unless development has been approved and a survey memorandum has been issued
- Mining shall take place according to the survey memo, minimising any over-mining
- All drilling and blasting patterns shall be designed so as to minimise blast damage and overbreak to the surrounding ground. A low strength or de-coupled explosive charge shall be used
- The need to rehabilitate ground as a result of deterioration will be made by the development superintendent, in consultation with the rock mechanics engineer. The development superintendent and supervisor (and rock mechanics engineer when deemed necessary by the development superintendent) will inspect each area requiring rehabilitation in order to determine the necessary rehabilitation steps

Scaling

- All personnel working underground are responsible for keeping ground conditions safe. This is primarily done by constant check scaling, or sounding the ground and barring down unsafe ground
- The backs and sidewalls shall be mechanically scaled after every cut and prior to boring holes for ground support installation
- The backs and sidewalls shall be checked through manual scaling using the appropriate length of scaling bar and PPE
- The five points of safe check scaling and barring down are:
  1. Have the correct length bar
  2. Have a firm footing and a safe retreat
  3. Bar from good to bad ground
  4. Watch for unexpected falls
  5. Drop the bar if a rock slides towards you
- Good ground is identified by a sharp ringing sound when tapped. Bad ground is identified by a drummy or hollow sound

Timing of Support and Unsupported Spans

- Unless otherwise specified, some form of primary ground support shall be installed as close as practical to the face after every cut of development advance. ***No employee shall work under an area of unsupported ground***
- Older areas of the mine may not have any ground support installed. These require the appropriate precautions to be taken when travelling and working in such areas. This requires inspection and assessment by all employees, and if deemed necessary, taking action to mitigate associated risks and hazards, including rehabilitation and installation of appropriate ground support. This is also formally undertaken as part of the workplace inspections, which form part of the data management system

incorporated in the Mine Ground Control Risk Management System

- Where the width of the advancing face exceeds 6 metres due to design requirements or poor ground conditions, the development supervisor and superintendent shall consider additional ground support or reinforcement

Installation of Support

- The ground support design to be applied in any circumstance (See attachment SAF-1371/1 Description of Ground Support Systems) shall be decided by the relevant planning engineer in consultation with the development superintendent and rock mechanics engineer, with reference to these procedures as well as actual ground conditions
- ***Additional ground support may be requested by any employee.*** Where appropriate, the development superintendent and/or rock mechanics engineer are to be consulted prior to any agreement
- The relevant planning engineer, development superintendent and/or rock mechanics engineer shall ensure that the standard ground support designs are appropriate for the actual ground conditions encountered. This may involve modification to the standard design or installation of additional support
- Ground support involving drilling of holes and installation of grouted cable bolts shall be completed in entirety before any further firing takes place within a 15 metre radius of the newly installed reinforcement. Unless otherwise stated, all grout shall be allowed to cure for 12 hours before plating and jacking (using the standard water and cement mix design). Where deemed necessary by the development superintendent, the cement curing time can be reduced to four hours with the addition of Sikament HE 200NN (the appropriate mix design will be issued for each specific job, see SAF 1371/1)
- Personnel involved in the installation of ground support shall in detail, assess the condition of the area and install appropriate ground support or take other action as appropriate. The Mine Ground Condition Risk Assessment sheet must be used (Refer to attachment SAF-1371/2) – ***completed in compliance with the Mining and Quarrying Safety and Health Regulation 2000***

Reduction of Ground Support Standards

- A reduction in ground support standards shall require written approval from the mine manager, development superintendent and rock mechanics engineer. A standard Variation to Ground Support Standards form shall be used (See attachment SAF-1371/3)

Cable Bolting of Turnouts and Intersections

- New turnouts and intersections should be cable bolted with blanket reinforcement using single strand Garford bulb cable bolts
- A decision not to cable bolt a new turnout or intersection can be made providing competent and stable ground conditions exist, there are no structures or other planes of weakness present, and future adverse mining factors are understood. Such occasions shall require the area to be mapped and inspected by appropriate personnel, with the reason recorded on the standard Variation to Ground Support Standards (See attachment SAF-1371/3)
- The use of single strand Garford cables should only be considered provided the area has been inspected to determine whether those joint sets present have the potential to form a wedge or not, and the state of stress and stress changes are understood
- If a potential wedge does exist and is of a sufficient size, then twin strand cables must be installed with a specific design issued
- Unless a Variation to Ground Support Standards form (SAF-1371/3) has been completed, cable bolting should be installed before completion of the full width excavation geometry (ie., the turnout and intersection)

Widening of Development Headings

- When an existing heading is to be widened, an assessment of ground support requirements shall be undertaken by the development superintendent and rock mechanics engineer, with appropriate risks assessed

Shotcrete Applications

- Shotcrete shall be considered for use when ground conditions are extremely poor and/or significant deterioration is anticipated due to stress change, blast damage or other factors

- The mine manager, in consultation with the relevant superintendent and rock mechanics engineer shall take the decision to shotcrete
- Shotcrete shall only be applied by a competent person and in an appropriate manner
- The thickness and other design parameters for shotcrete will be determined on a case-by-case basis by the rock mechanics engineer
- The performance and quality of shotcrete used as a ground support system shall be measured through laboratory unconfined compressive strength testing
- The minimum unconfined compressive strength of plain shotcrete and steel-fibre reinforced shotcrete shall be 14 MPa at seven days and 35 MPa at 28 days as measured on cores recovered from test panels according to AS 1012.14-1991 and tested to AS 1012.9-1986
- The thickness of the sprayed shotcrete shall be measured by drilling a small hole using a masonry drill bit to determine depth. Holes are to be drilled every 2 to 5 metres in the sidewalls and back (3 holes per ring where applicable), with the shotcrete thickness marked next to the individual hole with spray paint

■ **Ground Fall Reports**

- All ground falls greater than one tonne, or which cause damage or injuries (regardless of size) are to be reported immediately to the employees supervisor, who will then notify the relevant superintendent and rock mechanics engineer
- The mine manager must be informed immediately of any fall of ground that causes damage or injury
- The appropriate supervisor is to then fill out the fall of ground notification sheet to alert the rock mechanics engineer, which provides basic information of the incident
- The fall of ground report (See attachment SAF-1371/4) shall be completed by the rock mechanics engineer
- Any recommendations or follow-up actions are to be implemented by the relevant superintendent

■ **Support Inspections**

- The development supervisor and employee shall inspect installed ground support on a monthly basis (See attachment SAF-1371/5), including rockbolt patterns, turnouts, meshing standards and cable bolt installation
- The development superintendent shall review the audits and take appropriate actions

■ **General**

- It is every employee's responsibility to check-scale/bar down – **never assume the ground is safe**
- Ground support and reinforcement that is to be fully encapsulated with cement grout must be kept free of grease or oil – ***grease or oil on ground support or reinforcing elements will cause de-bonding with the cement grout, significantly reducing their load transfer capabilities.*** Visually inspect the ground support and reinforcing elements. If the grease or oil is present and cannot be removed, the ground support and/or reinforcing elements should ***NOT*** be used. These elements should be 'tagged-out' and returned to surface
- Any excessive rock noise is to be taken as indicating potentially hazardous ground conditions. Employees shall withdraw immediately to safe ground. Wait, listen, watch and reassess ground conditions. If unusual and unexpected noises are heard, or if uncertain, barricade the area and contact your supervisor

■ **Training**

- Employees shall be trained in ground support, as relevant to their role
- Training shall be recorded in the company recording system

Bolting Design Standards

■ **Bolting Design Standard No. 1**

- Shall be applicable in **PERMANENT/LONG TERM ACCESS IN GOOD GROUND CONDITIONS**

Primary support type shall be:

- – 47 mm diameter, 2.4 metres long black steel friction rock stabilisers

- Surface fixture shall be:
  - 150 mm x 150 mm x 4 mm thick black steel friction rock stabiliser dome plate
  - 100 mm x 100 mm 5.0 mm gauge black steel sheet mesh
- Bolt spacing and inclination shall be:
  - 1.2 metres
  - 3 central vertical bolts in the back, 1 bolt inclined at around 80° on each side of the vertical bolts and 1 bolt inclined at around 30° at the base of each shoulder ***– a total of 7 bolts/ring***
  - where ground conditions necessitate additional friction rock stabilisers and mesh should be installed down the sidewalls
- Ring spacing shall be 1.4 to 1.5 metres unless otherwise instructed

Secondary support type shall be:

- 3 metre long single strand Garford cables

- Surface fixture shall be 150 mm x 150 mm x 6 mm thick dome plates, installed with a hemispherical ball washer, barrel and wedge and tensioned at 3 to 5 tonnes. Trim the exposed cable to a 100 mm length after jacking
- Cable bolt spacing and inclination shall be:
  - 2.5 to 3.0 metres
  - 1 central vertical cable in the back, 1 cable inclined at around 800 on each side of the vertical cable and 1 cable inclined at around 300 at the base of each shoulder – ***a total of 5 cable bolts /ring***
- Ring spacing shall be 2.5 metres
- Additional ground support or reinforcement may be considered based on the exposed ground conditions. Separate instructions and design will be issued

Standard drawing see attachment SAF-1371/6.

■ Bolting Design Standard No. 2

- Shall be applicable to **STOPE DEVELOPMENT AND SHORT-TERM ACCESS IN GOOD GROUND CONDITIONS**

Support type shall be:

- 47 mm diameter, 2.4 metres long black steel friction rock stabilisers

- Surface fixture shall be:
  - 150 mm x 150 mm x 4 mm thick black steel friction rock stabiliser dome plate
  - 100 mm x 100 mm 5.0 mm gauge black steel sheet mesh
- Bolt spacing and inclination shall be:
  - 1.2 metres
  - 3 central vertical bolts in the back, 1 bolt inclined at around 80° on each side of the vertical bolts, and 1 bolt inclined at around 30° at the base of each shoulder ***– a total of 7 bolts/ring***
  - Where ground conditions necessitate additional friction rock stabilisers and mesh should be installed down the sidewalls
- Ring spacing shall be 1.4 to 1.5 metres unless otherwise instructed
- Additional ground support or reinforcement may be considered based on the exposed ground conditions. Separate instructions and design will be issued
- Standard drawing see attachment SAF-1371/7

Definitions

■ Poor Ground Conditions

- Poor ground conditions can be identified by the following characteristics:
  - Excessive barring down (>1 hour of mechanical scaling in a standard development heading, generating approximately 15 tonnes of material)
  - Significant over breaking from development firings
  - Significant blast damage from stoping
  - Soft and oxidised
  - Laminated/fissile in nature
  - Graphite present ('greasy back')
  - Significant stress-related fractures (scats in the back, buckling, rock noise, corner crushing or wall slabbing)
  - Joints forming numerous blocks
  - Faults and potential wedges observed in walls and back
  - Anywhere where talc is present
  - Excessive unravelling

■ **Average Ground Conditions**

- Average ground conditions can be identified by the following characteristics:
  - Mechanical scaling taking between 30 minutes and 1 hour in a standard development heading, generating approximately 2 to 5 tonnes of material)
  - Bedded ground but not fissile (minimal chance of the ground unravelling)
  - Minor scats (can be managed with scaling)
  - Minor discontinuities, fairly continuous rock mass

■ **Good Ground Conditions**

- Good ground conditions can be identified by the following characteristics:
  - Minimum barring down (<30 minutes of mechanical scaling in a standard development heading, generating up to approximately 500 kg of material)
  - Minimal over breaking from development firings
  - Minimal disturbance from adjacent stoping
  - No stress fractures (no scats in the back, buckling, rock noise, corner crushing or wall slabbing)
  - Absence of graphitic joints or talc
  - No visible faults, joints or cracks with the potential for forming wedges
  - Unravelling behaviour is not excessive
  - Massive rock mass conditions

■ **Ground Support Design**

- A ground support design includes the locations, number, type and length of the support that is to be installed

■ **Standard Ground Support Design**

- This is the minimum specified ground support for a section of the mine
- For any given development heading, a supervisor and operator can install additional ground support or reinforcement, where required, after the ground condition risk assessment has been completed (SAF-1371/2)

RELATED DOCUMENTS

AS 1012.9-1986	Method for the determination of the compressive strength of concrete specimens
AS 1012.14-1991	Method for securing and testing cores from hardened concrete for compressive strength
SAF-1368	Barricades and barriers
SCP-1101	Document control

ATTACHMENTS

SAF-1371/1	Description of Ground Support Systems
SAF-1371/2	Mine Ground Condition Risk Assessment Sheet
SAF-1371/3	Variation to Ground Support Standards
SAF-1371/4	Fall of Ground Report
SAF-1371/5	Monthly Ground Support Inspection Sheet
SAF-1371/6	Bolting Design No. 1
SAF-1371/7	Bolting Design No. 2

SAF-1371/1
DESCRIPTION OF GROUND SUPPORT STANDARDS

FRICTION ROCK STABILISER – 2.4 M LONG

- The friction rock stabilisers used at the Copper Mine are 2.4 metres long and 47 millimetre in diameter. The friction rock stabiliser is forced into a drill hole of smaller diameter, which provides an outward radial force, inducing friction between the friction rock stabiliser and rock to provide support
- The friction rock stabiliser provides an effective back and sidewall support in most ground conditions at the mine, particularly in fissile shales and sheared rock where it is difficult to generate a point anchor. In moving ground, the friction rock stabiliser has the ability to provide support along its entire length and essentially creates a thicker bed of laminated ground
- The limitation of the friction rock stabiliser is the low initial bond strength. As a result, it is insufficient to guarantee support of large wedges. ***It is critical to the support system that the correct sized drill bit is used – use the bit gauge before drilling (use only bits with diameters between 43 mm and 45 mm – DSI Arnall will carry out regular pull testing as an independent check)***

CABLE BOLTS

- Single or twin strand Garford bulbed cable bolts are used to supplement the support provided by friction rock stabilisers
- Cables are used as an effective means of reinforcement where the standard primary ground support systems are insufficient due to larger excavation sizes or the rock mass/geological structures
- After inserting one or two cables into the appropriate sized hole (51 mm and 64 mm diameters respectively), a standard thick cement grout is made by mixing eight litres of water with 20 kg of cement. This is pumped into the hole and allowed to cure for 12 hours before tensioning of the cable. The cable is plated with a 150 mm x 150 mm x 6 mm thick dome plate and hemispherical ball washer, and fixed with a barrel and wedge. The cable is then tensioned at approximately 3 to 5 tonnes
- If there is a need to reduce the curing time for the cement grout, the admixture Sikament HE 200NN can be added using one the following mix designs:
  - Tamrock Cabolter:

Cement	160.00 kg
Water	37.50 litres
Sikament HE 200NN	5.33 litres

  - Hand installed:

Cement	60.00 kg
Water	14.50 litres
Sikament HE 200NN	2.00 litres

  - **Do not over-dose – *consequence is that the grout will have a considerably reduced pot life***
  - **Do not continuously mix the cement grout and admixture for more than one and a half hours – *consequences are permanent damage to the grout pump and mixing bowl with the grout observed to set at one hour and forty-five minutes***
  - Mixing procedure is water first in the mixing bowl, then Sikament HE 200NN, then the cement

SHEET MESH

- Meshing forms an integral part in providing a safe working environment in all ground conditions at the Copper Mine
- Mesh is a form of passive support required to provide surface restraint at the exposed excavation boundary
- The use of sheet mesh allows for mechanised placement
- The aim of meshing is to prevent small pieces of rock from falling, particularly in rock masses having small block sizes or undergoing stress changes
- Mesh is not designed to carry excessive loads of broken rock without failure and can be easily damaged by flyrock from blasting when installed very close to an active face. This is particularly the case when the sheet mesh has not been tightly installed against the rock face
- Mesh is secured firmly against the rock face with friction rock stabilisers

SAF-1371/2
MINE GROUND CONDITION RISK ASSESSMENT SHEET

LEVEL ____________________

LOCATION ____________________

DATE ____________________

OPERATOR ____________________

UNIT ____________________

	Bolt Type	Number per Ring	Ring Spacing	Sheet Mesh
WHAT DID YOU INSTALL ?				Yes/No

1. General ground conditions:

   ☐ Recent deterioration ☐ Cracks present ☐ Fresh ground ☐ Excessive loose in mesh ☐ Rock noise

2. Mechanical scaling produces:

   Time spent mechanically scaling ________

   ☐ Excessive fall off from
   - ☐ Back ▶ install additional ground support
   - ☐ Hangingwall ▶ install additional ground support
   - ☐ Footwall ▶ install additional ground support
   - ☐ Sidewall ▶ install additional ground support

   ☐ Produces large blocks ▶ STOP. Barricade heading and inform supervisor

   ▶ ☐ Consider the installation of additional ground support or reinforcements

   ☐ Minimal fall off ▶ install standard ground support pattern

3. Is there a potential for a wedge to exist ?

   ☐ Yes ▶ ☐ Back ☐ Sidewall ☐ Hangingwall ☐ Footwall

4. Do the ground conditions require inspection by technical personnel ?

   ☐ Yes ▶ STOP. Barricade heading and inform supervisor

   ☐ No

5. Any additional information useful to the risk assessment ?

   ____

ONCE COMPLETED, PLEASE RETURN TO THE SUPERVISOR AT END OF SHIFT

SAF-1371/3
VARIATION TO GROUND SUPPORT STANDARDS

DATE ____:

LOCATION ____:
(attach plan of area)

STATE STANDARD ____:

____

PROPOSED VARIATION ____:

____

REASON FOR VARIATION ____:

____

_____________________________   _____________________________

Development Superintendent   Rock Mechanics Engineer

____

Mine Manager

cc: Mine Manager
Mine Development Superintendent (and Supervisors)
Rock Mechanics Engineer
File

SAF-1371/4
FALL OF GROUND REPORT

LEVEL/LOCATION OF ROCKFALL: ______________________________

DATE/TIME: ______________________________

SUPERVISOR/SECTION: ______________________________

NAME(S) OF PERSON(S) INVOLVED, INJURIES, EQUIPMENT DAMAGE: ______________

____

When did the rockfall occur?

____

From where did the rockfall occur?

____

Size of fall of ground and ground conditions description.

____

What sort of ground support (if any) was installed?

____

What activity was being done at the time of the rockfall?

____

Other details?

____

What must be done to prevent this type of rockfall from happening again?

____

Rock Mechanics Engineer: ______________________ Date: ____________

Comments/Follow up

____

____

Mine Manager: ______________________ Date: ____________

cc :

SAF-1371/5
MONTHLY GROUND SUPPORT INSPECTION SHEET

Location:	Supervisor:	Date:
Level:	Employee:	Pay No.:

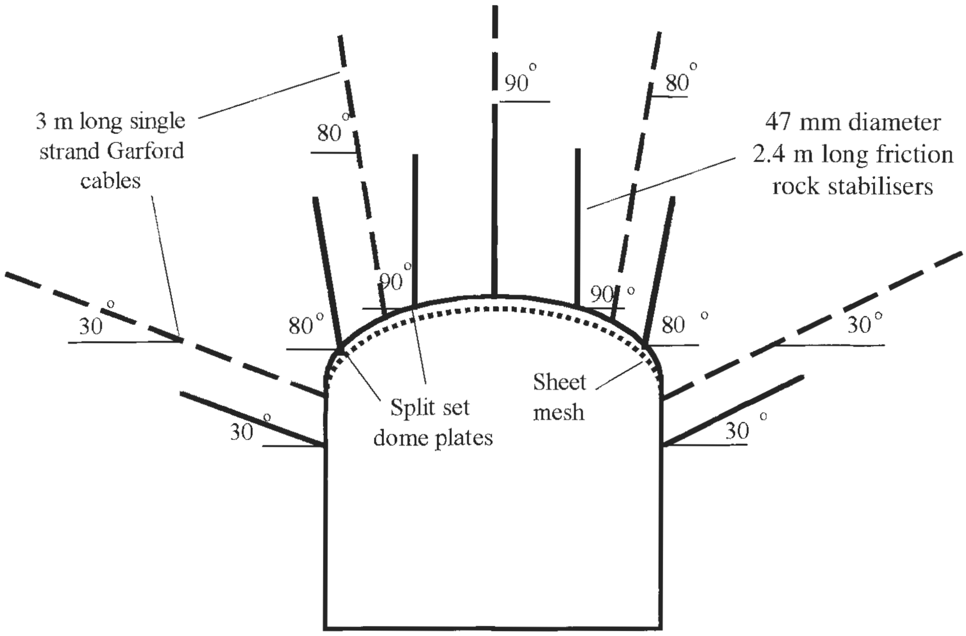
STANDARDS TO BE CHECKED

Audit	To Standard	Comments
Drive dimensions		
Rock bolts		
Spacing of bolts in the: Walls Backs		
Rock bolt angles		
Mesh coverage		
Cables required		
Is it a turnout/intersection?		
Is there a wedge potential?		
Are cable bolts installed?		

ACTIONS:

SAF-1371/6
BOLTING DESIGN NO.1

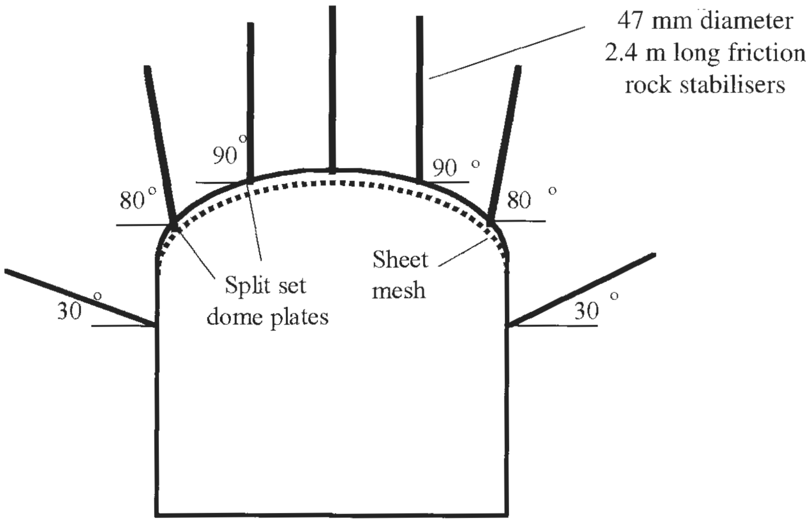
Permanent Long Term Access
(Good Ground Conditions)



- Excavation dimensions are 4.7 m wide by 4.7 m high
- 47 mm diameter, 2.4 m long black steel friction rock stabilisers
- Friction rock stabiliser dome plates
- 100 mm x 100 mm x 5 mm sheet mesh on backs and around sholders
- Maximum of 1.2 m bolt spacing
- 1.4 m to 1.5 m ring spacing
- 3 m long single strand Garford bulbed cable bolts
- Cable bolt spacing of between 2.5 m and 3 m
- Cable bolt ring spacing 2.5 m
- 6 mm thick dome plates
- Barrel and wedge
- Tension to 3 to 5 tonnes
- Trim exposed cable to 100 mm length after jacking

SAF-1371/7
BOLTING DESIGN No. 2

Stope Development Short Term Access
(Good Ground Conditions)



- Excavation dimensions are 4.7 m wide by 4.7 m high
- 47 mm diameter, 2.4 m long black steel friction rock stabilisers
- Friction rock stabiliser dome plates
- 100 mm x 100 mm x 5 mm sheet mesh on backs and around shoulders
- Maximum of 1.2 m bolt spacing
- 1.4 m to 1.5 m ring spacing

Safety and Health
vision

"An Australian minerals industry free of fatalities, injuries and diseases."

Safety and Health
beliefs

- All fatalities, injuries and diseases are preventable.
- No task is so important that it cannot be done safely.
- All hazards can be identified and their risks managed.
- Everyone has a personal responsibility for the safety and health of themselves and others.
- Safety and health performance can always improve.

Safety
awareness

"The state of mind where we are constantly aware of the possibility of injury and act accordingly at all times."