DEPARTMENT OF MINERALS AND ENERGY

Minerals and Energy for Development and prosperity

MINE HEALTH AND SAFETY INSPECTORATE

GUIDELINE FOR THE COMPILATION OF A MANDATORY CODE OF PRACTICE TO COMBAT ROCK FALL AND ROCK BURST ACCIDENTS IN TABULAR METALLIFEROUS MINES

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Chief Inspector of Mines

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Date

CONTENTS OF GUIDELINE

PART A: THE GUIDELINE

1. FOREWORD

1.1 The majority of accidents occurring at mines are as a result of rock falls and slope instability. Over the last few years the fatality rate pertaining to rock fall and slope instability-related accidents has reached a plateau and no real or meaningful improvement has been attained.

1.2 In an initiative to solve this problem, a tripartite task group was established under the auspices of the MRAC. The initial terms of reference of the task group were to investigate and identify root causes of rock related accidents.

Current work practices and any compliance and/or non-compliance with regulations, standards, directives, guidelines and COP, and their impact on root causes were scrutinised. Research conducted into solutions under the direction of the Safety in Mines Research Advisory Committee (SIMRAC) was also examined.

1.3 Subsequent to the investigation it was concluded that, as a matter of urgency, a guideline for the compilation of a mandatory COP to combat rock fall and slope instability accidents be produced. Due to the complexity and variability of conditions at mines pertaining to the design, geometry and support requirements, rigid and prescriptive guidelines would not be in the interests of rock related safety. An approach was adopted which allowed for local expertise, experience and knowledge on the mines to be effectively utilised. In addition, the contribution of tripartism to initiate a process to combat rock related accidents would be enhanced.

1.4 This guideline is a generic document and is not intended to address the rock related accident problems encountered on a particular mine.

2. THE LEGAL STATUS OF GUIDELINES AND COPs

2.1 In accordance with section 9 (2) of the **MHSA**, an employer must implement a **COP** on any matter affecting the health and safety of employees and any other person who may be directly affected by the activities at the mine if the Chief Inspector of Mines requires it. In terms of section 9 (3) of the **MHSA**, a **COP** must comply with the relevant guideline issued by the Chief Inspector of Mines. **COP**

2.2 Failure by an employer to prepare or implement a **COP** in compliance with this guideline is a breach of the MHSA. Any contravention of, or failure to comply with a **COP** is not in itself a breach of the MHSA except for contravention or failure by an employer that also constitutes a failure to prepare or implement the **COP**. Since the **DME** does not approve **COPs**, its focus is not to enforce them either. The focus of the **DME** is to ensure that employers provide healthy and safe working environments at mines, i.e. focusing on system failures and compliance with the **MHSA**, rather than enforcing compliance with the **COP**.

2.3 The fact that a contravention of, or failure to comply with the **COP** is not a breach of the **MHSA**, does not mean that such breaches will have no legal implications. As far as the employer is concerned, there are numerous specific and general obligations on the employer in the **MHSA** aimed at ensuring the health and safety of all employees and all persons who are not employees but who may be directly affected by the activities at the mine. Where any failure to comply with a **COP** also constitutes a breach of any of the employer's obligations under the MHSA, the employer could be liable to an administrative fine for such breach. An inspector could also issue various instructions to the employer and employees in terms of section 54 to protect the health or safety of persons at the mine. Failure by an employer to comply with such an instruction could render the employer liable to an administrative fine.

2.4 As far as employees are concerned, section 22 places a number of obligations on employees, including that they must take reasonable care to protect their own health and safety and the health and safety of other persons who may be affected by their conduct. Where a failure by an employee to comply with a **COP** would also constitute a breach of the employee's duties in terms of section 22 [or a breach of section 84, 86 (1) or 88], the employee could be criminally charged for such breach. As is the case with employers, the inspectorate could issue instructions to employees in terms of section 54 and failure to comply with such an instruction constitutes a criminal offence.

2.5 Employers should deal with breaches by employees of the **COP** in terms of the mine's standard instructions and the employer's disciplinary procedures. This is not the responsibility of the State.

3. THE OBJECTIVE OF THIS GUIDELINE

The objective of this guideline is to enable the employer at every mine to compile a **COP**, which, if properly implemented and complied with, would reduce the number of **rock fall** and **slope instability** related accidents at surface mines.

4. DEFINITIONS AND ACRONYMS

In this guideline for a **COP** or any amendment thereof, unless the context otherwise indicates—

COP means Code of Practice;

DME means the Department of Minerals and Energy;

Geology means the scientific study of the earth, the rock of which it is composed and the changes which it has undergone or is undergoing;

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

Ground control districts means a portion of a mine where similar geological conditions exist which give rise to a unique set of identifiable rock-related **hazards** for which a common set of strategies can be employed to minimise the **risk** resulting from mining;

Ground control districts plan means a plan on good quality transparent draughting material of a thickness not less than 0,08mm indicating to a scale of 1 in 2500 all applicable **ground control districts** of the mine;

Hazard means a source of, or exposure to, danger;

MHSA means Mine Health and Safety Act, 1996 (Act No. 29 of 1996);

MRAC means Mining Regulation Advisory Committee;

Permanent support means **support** that, once installed, is not removed;

Pillar means rock left in situ during the mining process to **support** the local hanging wall, roof or to provide stability to the mine or portion thereof;

Primitive (virgin) stress means the state of stress in a geological formation before the stress field is altered by mining operations;

Risk means the likelihood that occupational injury or harm to persons will occur;

Rock engineering means the engineering application of **rock mechanics**;

Rock fall (fall of ground) means a fall of a rock fragment or a portion of fractured **rock mass** not caused by a **seismic event**;

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

Rock mechanics means the scientific study of the mechanical behaviour of rock and **rock masses** under the influence of stress;

Seismic event means the transient earth motion caused by a sudden release of the strain energy stored in the rock;

Seismicity means the geographic and historical distribution of earthquakes;

Significant rock-related risk means the likelihood that the harm from a particular rock-related **hazard** will result in the death or permanent disability of a person;

Slope instability means slope related instability in respect of benches scale or overall failures; and

Support means a **support** system or reinforcing elements installed to maintain the integrity and stability of the rockwalls under static and possibly dynamic states of stress.

5. SCOPE OF GUIDELINE

5.1 This Guideline covers the significant health and safety aspects associated with **rock fall** and **slope instability hazards** at surface mines.

5.2 The Guidelines covering the four principal mining methods are:—

5.2.1 GME 7/4/118-AB1 "----- Tabular Metalliferous Mines";

5.2.2 GME 7/4/118-AB2 "----- Underground Coal Mines";

5.2.3 GME 7/4/118-AB3 "----- Massive Mining Operations"; and

5.2.4 GME 7/4/118-AB4 "----- Surface Mines"

6. TASKGROUP MEMBERSHIP

This guideline was prepared by the **MRAC** Task Group on **Rock Fall** and **Slope-instability** Related Accident in Surface Mines.

Mr. J E Kotze (Chairperson)	–	State
Dr. W K Rymon-Lipinski	–	State
Mr. J W Klokow	–	Employers
Mr. R C More O'Ferrall	–	Employees

The following organisation was also consulted—

Mr. P J Terbrugge	–	SRK Consulting
Mr. A Swart	–	SRK Consulting

Mr. G J Keyter – SRK Consulting

PART B: AUTHOR'S GUIDE

1.1 The **COP** must, where possible, follow the sequence laid out in **Part C "Format and Content of the COP**.**"** The pages as well as the chapters and sections must be numbered to facilitate cross-referencing. Wording must be unambiguous and concise.

1.2 It should be indicated in the **COP** and on each annex to the **COP** whether—

1.2.1 the annex forms part of the **COP** and must be complied with or incorporated in the **COP** or whether aspects thereof must be complied with or incorporated in the **COP**; or

1.2.2 the annexes are merely attached as information for consideration in the preparation of the **COP** (i.e. compliance is discretionary).

1.3 When annexes are used the numbering should be preceded by the letter allocated to that particular annex and the numbering should start at one (1) (e.g. 1, 2, 3, A1, A2, A3, ...).

1.4 Whenever possible illustrations, tables, graphs and the like should be used to avoid long descriptions and/or explanations.

1.5 When reference has been made in the text to publications or reports, references to these sources must be included in the text as footnotes or side notes as well as in a separate bibliography.

PART C: FORMAT AND CONTENT OF THE MANDATORY COP

1. TITLE PAGE

The **COP** should have a title page reflecting at least the following—

1.1 the name of the mine;

1.2 the heading of the **COP** (for example, Mandatory COP to Combat Rock fall and Slope Instability Related Accidents in Surface Mines);

1.3 a statement to the effect that the **COP** was drawn up in accordance with **DME** guideline, reference no. **DME** 7/4/118-AB4, issued by the Chief Inspector of Mines;

1.4 the mine's reference number for the **COP**; and

1.5 revision dates.

2. TABLE OF CONTENTS

The **COP** must have a comprehensive table of contents.

3. STATUS OF MANDATORY COP

Under this heading the **COP** must contain statements to the effect that—

3.1 the mandatory **COP** was drawn up in accordance with **DME** guideline Reference Number **DME** 7/4/118-AB4 issued by the Chief Inspector of Mines;

3.2 this is a mandatory **COP** in terms of sections 9 (2) and (3) of the **MHSA**;

3.3 the **COP** may be used in an accident investigation/inquiry to ascertain compliance and also to establish whether the **COP** is effective and fit for purpose;

3.4 the **COP** supersedes all previous relevant **COPs**; and

3.5 all managerial instructions or recommended procedures (voluntary **COPs**) and standards on the relevant topics must comply with the **COP** and must be reviewed to ensure compliance.

4. MEMBERS OF DRAFTING COMMITTEE

4.1 In terms of section 9 (4) of the **MHSA**, the employer must consult with the Health and Safety Committee on the preparation, implementation or revision of the **COP**.

4.2 It is recommended that the employer should, after consultation with the employees in terms of the **MHSA**, appoint a committee responsible for drafting the **COP**.

4.3 The **COP** must not be an overly technical **rock engineering** document and when compiling the document the participation of supervisory and employee level personnel is essential.

4.4 The members of the Drafting Committee assisting the employer in drawing up the **COP** must be listed giving their full names, designations, affiliations, professional qualifications and experience. This committee should include persons competent in **rock engineering** sufficient in number effectively to draft the **COP**.

5. GENERAL INFORMATION

Relevant information relating to the mine must be stated in this paragraph. The following information must be provided—

5.1 Locality

A brief description and locality map to indicate the location of the mine in relation to towns, existing infrastructure and any other relevant features such as mines sharing a common boundary, dams, rivers and any other topographical features which could influence the strategies adopted.

5.2 Geological Setting

Geological structures, such as faults and dykes and stratigraphy in the **rock masses** must be described and any hazardous conditions highlighted. A typical geological section of the mine must also be included. A detailed geological assessment may not be necessary but a map showing major geological features in relation to mining outlines and shafts must be included.

5.3 Mining Environment

Under this section information regarding major subdivisions dictating specific fundamental extraction strategies must be provided.

The regional hydrology, such as the occurrence of any significant groundwater and/or any other relevant information, must be described.

5.4 Ground control Districts

5.4.1 The location and extent of **ground control districts** must clearly be described in the **COP**. The nature of the stress field in which mining is to take place, as well as the occurrence of significant ground water and any other local geological features, must be included here.

5.4.2 All **ground control districts** within the mining area must be indicated on a **ground control districts plan**, which should be kept in an office designated for that purpose by the employer.

5.5 Mine Rock Fall and Slope Instability Incident Analysis

5.5.1 The **COP** must contain a tabulation of the mine’s five year history of rock-related casualties (fatals, reportables and disabling incidents) and non-casualty incidents (where available), categorised according to **rock falls** per 1000 employees at work for both surface and underground operations.

5.5.2 This information must be graphically represented depicting annual statistics to facilitate easy interpretation of the data and to highlight trends.

5.5.3 The **COP** must reflect the incident trend associated with the identified **hazards**. From this information the **risk** associated with each **hazard** can be established. These statistics should be normalised with respect to production tonnage in the different **ground control districts**.

6. TERMS AND DEFINITIONS

Any word, phrase or term of which the meaning is not absolutely clear or which will have a specific meaning assigned to it in the COP, must be clearly defined. Existing and/or known definitions should be used as far as possible. The drafting committee should avoid jargon and abbreviations that are not in common use or that have not been defined. The definitions section should also include acronyms and technical terms used.

7. RISK MANAGEMENT

7.1 Section 11 of the **MHSA** requires the employer to identify **hazards**, assess the health and safety **risks** to which employees may be exposed while they are at work and record the significant **hazards** identified and **risk** assessed. The **COP** must address how the significant **risks** identified in the **risk** assessment process must be dealt with, having regard to the requirement of section 11 (2) and (3) that, as far as reasonably practicable, attempts should first be made to eliminate the **risk**, thereafter to control the **risk** at source, thereafter to minimize the **risk** and thereafter, insofar as the **risk** remains, provide personal protective equipment and to institute a programme to monitor the **risk**.

7.2 To assist the employer with the **hazard** identification and **risk** assessment, all possible relevant information such as accident statistics, research reports, various geological, hydrological, seismological information and geotechnical parameters or rock excavation processes must be considered.

7.3 In addition to the periodic review required by section 11 (4) of the **MHSA**, the **COP** should be reviewed and updated, if necessary, after every serious incident relating to the topic covered in the **COP**, or if significant changes are introduced to procedures, mining layouts, mining methods, plant or equipment and material.

8. ASPECTS TO BE ADDRESSED IN THE MANDATORY COP

The COP must set out how the significant risks, identified and assessed in terms of the risk assessment process referred to in paragraph 7.1*,* will be addressed unless there is no significant rock related risk associated with that aspect at the mine, the COP must cover at least the aspects set out below—

8.1 Overall Mine Stability

8.1.1 In order to prevent ground instability causing catastrophic accidents or situations that give rise to a multitude of minor incidents or accidents to persons at the mine, the **COP** must set out a description of the strategy to ensure overall stability of the mine;

8.1.2 In order to avoid unplanned or uncontrolled collapses of the mine or portion/s thereof or of surface structures and topography, the COP must set out a description of the design methodology applied to prevent such occurrences;

8.1.3 Where more than one orebody occurs in close proximity to another, and where the mining of one or more orebodies can be expected to have an adverse effect and induce hazardous conditions on another, the **COP** must set out a description of the strategy to be followed to prevent the instability of the orebodies to be mined;

8.1.4 In order to prevent unexpected rock mass failures during mining operations, the **COP** must set out a description of the methodology and frequency for the design and/or review of pit slope angles, details of the **geology**, groundwater and geotechnical properties of the **rock mass** and discontinuities;

8.1.5 In order to prevent failure of bench faces, bench stacks and overall slopes, the **COP** must set out a description of the slope management programme, detailing the strategies for an ongoing stability monitoring and geotechnical mapping programme, together with the development of a mine hazard plan (see **Annex 1,** which is appended for information/reference purposes only);

8.1.6 In order to prevent persons from being injured by loose material on bench faces, and in particular the crest areas, the **COP** must set out a description of the methods to make these areas safe; and

8.1.7 In order to prevent persons from being injured by ground instability while installing **support,** the **COP** must set out a description of the measures to be taken to ensure the correct selection, use and maintenance of the equipment employed in **support** operations.

8.2 Protection of Mine Accesses/Exits

In order to protect the integrity of access/exit ways of the existing mine (e.g. shafts, ramps and/or other main entrances/exits), the COP must set out a description of the strategies for the protection of such access/exit ways covering at least the following—

- a summary of the rock-engineering appraisal of the current stability of mine access/exit ways;
- measures employed to monitor ground movement;
- measures to protect the integrity of access/exit ways; and
- referencing of relevant reports.

8.3 Mining operations

In order to prevent persons from being injured by any rock-related hazard arising from daily mining operations, the COP must set out the strategies to be adopted to address the relevant risks, covering at least the following—

- the general surface conditions of pit slopes such as loose rock arising from stress changes or blasting, face **support**, undercutting and general **slope instability**; and
- the rock wall **support** strategy and pit wall design (see **Annex 1,** which is appended for information/reference purposes only), which must accommodate the conditions expected from the geotechnical settings and the type of accidents encountered. The strategy may vary for different parts of the same mine where the geotechnical environments differ. Reference must be made to the accident/**slope instability** analysis for the identification of problem areas and it must also include specific matters related to the mining equipment used on the mine for different types and shape of the excavations.

8.4 Rock-Breaking

In order to ensure slope stability behind the slope face after blasting operations, the **COP** must set out a description of the rock-breaking strategies to be adopted to minimise blast-induced damage to these slope faces by at least covering the following—

- type of explosives and initiating system/s to be used;
- drilling patterns and accuracy of drill holes;
- selecting and application of explosives and accessories to the conditions prevailing in different **ground control districts**;
- method and sequence of initiation of explosive charges; and
- charging and stemming of blast holes.

8.5 The impact of mining operations on neighbouring mines

Where the mining operations at a mine might cause **slope instability** on an adjacent mine, the **COP** must set out a strategy to be adopted that will ensure that neighbouring mines exchange relevant information, covering at least the following—

- rock excavation processes, methodology, techniques, sequence, excavation speed, etc.;
- prevailing common geological features/regime; and
- positioning of explosive charges in the blast holes.

8.6 Slope instability

In order to prevent persons from being exposed to the **risk** associated by **slope instability**, the **COP** must set out a description covering at least the following—

- monitoring of both the **rock masses** and major geological structures in the mine;
- identification of significant geological discontinuities such as fault shears, slips and intrusions and the existence of wedge structures; and
- monitoring of potential planar failure, toppling and ravelling.

8.7 Other aspects to be addressed

8.7.1 The **significant rock-related risks** and **slope instability hazards** must be recorded, listed and fully described in the **COP** in such a manner that the **risk** management strategies can be cross-referenced to them;

8.7.2 The **COP** must detail all the strategies employed to combat rock and **slope instability**-**related hazards**/**risks**. These strategies embody various principles, techniques and methodologies employed to reduce the **risk** peculiar to a particular **ground control district** and include such aspects as mining layouts, mining sequence, **support** and monitoring procedure;

8.7.3 Where **hazards**/**risks** are related to specific **ground control districts**, the relationship must be clearly indicated;

8.7.4 The strategies adopted to deal with each of the **significant rock and slope instability-related risks** should be described under the appropriate subsections. These strategies must be cross-referenced to the listed significant **risks/hazard(s)** that they address. The strategies must cover even the most obvious significant **risk** created by **hazards** in the working place, such as rock loosened by the blast; time dependent rock dilatation and stress fracturing; bench crest damage and geological discontinuities;

8.7.5 The **COP** must require that where any experimentation with rock excavations or **support** system that differs substantially from that contained in the **COP** is conducted, full documentation regarding such experimentation must be kept at the mine, including records of related **risk** assessments and motivations for the experimentation;

8.7.6 In order to ensure that provisions are made for integrating the management of **rock-related risks** into the overall mine planning process, the **COP** must set out a description of such a management process, and must include the role of all individuals, the recording and archiving of all significant decisions and the execution procedures; and

8.7.7 All strategies in the **COP** to be adopted to address the **significant rock-related risks** must be appraised by a competent person in **rock engineering. Annex 2** sets out those aspects on which a person competent in **rock engineering**, should provide input. (**Annex 2** is appended for information/reference purposes only).

PART D: IMPLEMENTATION OF THE COP

1. IMPLEMENTATION PLAN

1.1 The employer must prepare an implementation plan for its **COP** that makes provision for issues such as organisational structures, responsibilities of functionaries and programmes and schedules for the **COP** that will enable proper implementation of the **COP**. (A summary of, and a reference to, a comprehensive implementation plan may be included.)

1.2 Information may be graphically represented to facilitate easy interpretation of the data and to highlight trends for the purpose of **risk** assessment.

2. COMPLIANCE WITH THE COP

The employer must institute measures for monitoring and ensuring compliance with the **COP**.

3. ACCESS TO THE COP AND RELATED DOCUMENTS

3.1 The employer must ensure that a complete **COP** and related documents are kept readily available at the mine for examination by any affected person.

3.2 A registered trade union with members at the mine or where there is no such union, a health and safety representative at the mine, or if there is no health and safety representative, an employee representing the employees at the mine, must be provided with a copy of the **COP** on written request to the manager. A register must be kept of such persons or institutions to facilitate updating of such copies.

3.3 **The** employer must ensure that all employees are fully conversant with those sections of the **COP** relevant to their respective areas of responsibility.

ANNEX 1
SURFACE MINING

(This annex to be used for information/reference purposes only)

1. GEOLOGICAL AND GROUND CONTROL DISTRICT CONCEPTS

Geological structure

In geotechnical engineering the term “geological structure” refers to all the natural planes of weakness in the rock mass that pre-date any mining activity and includes: joints, faults, shears, bedding planes, foliation and schistosity. Across these natural planes of weakness (or discontinuities), the rock mass has very little or no tensile strength – in comparison to the strength of intact rock. The number, shape and dimension of these blocks of intact rock (which strongly influence the stability of walls in open pit mines) depend on the number, persistence, shape and orientation of discontinuities present. This assemblage of discontinuities is therefore an important characteristic of any given rock mass.

Geological structure can have a range of characteristics including:

- orientation – usually specified by dip angle and dip direction;
- spacing;
- persistence or continuity;
- roughness;
- waviness;
- wall strength;
- aperture;
- filling; and
- seepage/moisture.

The important role that a geological structure has in surface and an open pit mine **ground control** cannot be over-emphasised.

Ground control district

A **ground control district** is a volume of rock with generally similar geotechnical **rock mass** properties. The geotechnical properties that need to be considered when defining the geotechnical districts, 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 mass strength;
- deformation/elastic modulus of the **rock mass**;
- induced stress field; and
- permeability of the **rock mass**.

Rock mass classification methods may be useful in determining the number and extent of **ground control districts** in a mine. The three main rock mass classification systems that have been used in geotechnical engineering are:

- Rock Mass Rating system or RMR system
- Rock quality system or Q-system; and
- Mining rock Mass Rating system or MRMR system.

Although these methods have been developed predominantly for underground tunneling and mining, this does not preclude their use for open pits. It is more common for **ground control districts** in open pits to be divided into more simplistic categories, e.g. pit walls consisting of various categories of weathered rock, foliation or other major structure dipping into, out of, or across the pit.

Ground

Ground refers to rock in all the possible forms that it may take from a fresh, high strength material to an extremely weathered, very low strength, essentially soil-like material. This term can also refer to most fill/buttressing materials.

The open pit mining environment in RSA is characterised by a wide variety of orebody geometries, ground types, mining systems and sizes of mining operations. This diversity, combined with the high level of uncertainty that exists in our knowledge of the rock mass geotechnical conditions, must be recognised as a major challenge facing mine management. There needs to be clear recognition that there are a number of fundamental uncertainties in our knowledge of the rock mass geotechnical conditions and characteristics. Examples of these uncertainties include:

- The **rock mass** is not a continuum but is comprised of a large number of discontinuity bound blocks. The size, shape, orientation, location and number of these blocks throughout the **rock mass** are usually not well known.
- Forces or stresses acting within large volumes of **rock mass** are also not well known and are subject to variation (e.g. variable block interaction) as the mine develops. Measurements of the rock stress field are possible, however, the results from these measurements need to be carefully scrutinised.
- The strength of the **rock mass** is not well known and is difficult to measure in large volumes of rock. Whilst strength testing of core-sized samples of rock is relatively straightforward, large scale rock testing is difficult and expensive to conduct.
- The time dependent behaviour of the **rock mass** is not well known.
- Blast damage to the **rock mass**, particularly from large scale blasting operations, is an additional factor that has generally not been well quantified.

In view of the above uncertainties it is not surprising that even the most carefully planned and designed mines have unexpected ground instability. Consequently, it is unlikely that a particular rule of thumb or specific guideline is universally applicable in every situation, at any mine, in perpetuity.

Ground conditions

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

- geological structure;
- **rock mass** characteristics (e.g. rock type, **rock mass** strength, unit weight and weathering);
- virgin stress state;
- groundwater;
- size, shape and orientation of open pit excavations with respect to geological structure and mining induced stress field; and
- blast damage.

It is imperative that the diverse range of ground conditions that may be encountered in South African surface mines are recognised and understood as a challenge to achieving cost effective and safe **ground control**.

Rock type

It should be recognised that different rock types (e.g. ultramafic, sedimentary etc.) react differently to mining excavations. This is due to the individual characteristics of each rock type (e.g. fabric grain size, texture and alignment), which form the basis of engineering properties of rock (e.g. tensile strength or elastic modulus). In many cases, even rock classified as being of similar type will react differently to mining – e.g. the presence of certain minerals can weaken the rock. In some cases, the cause of diverging behaviour within "like-rocks" is only evident after thin section assessment under a microscope.

Rock mass strength

The strength of the **rock mass** is controlled by the complex interaction of a number of factors including;

- intact rock strength;
- geological structure (planes of weakness) – particularly orientation, persistence, in-fill materials, spacing and shear strength parameters;
- groundwater;
- alteration of minerals on exposure to stress, air and/or water with time; and
- mining effects (e.g. blast damage).

It should be recognised that the estimated strength of **the rock mass**, in general, is dependent on the volume of the rock being loaded/tested. Small core-sized tests on intact rock are therefore not necessarily representative of the overall **rock mass**.

This volume or scale dependence of rock strength is not found in other engineering materials, e.g. concrete or steel. Furthermore, the extent of knowledge of the inherent variability of rock properties throughout a large-scale mine is usually limited compared to engineered materials. Consequently, the design of structures using engineered materials can be undertaken with more confidence, than the design of structures in rock – due to a larger margin for unknown error in **rock mass** properties.

Rock mass strength is one of the least well-defined parameters in the field of geotechnical engineering. There is a need to have a much better understanding of rock mass strength, ranging from small pieces of intact rock with a volume measured in cubic centimeters to very large volumes of rock measured in thousands of cubic meters. There are some obvious practical difficulties in conducting tests on large volumes of rock. The limitations that exist in this area of geotechnical engineering need to be recognised, particularly with regard to the use of numerical modeling techniques.

One of the better-recognised methods of determining rock mass strength is to back-calculate strength parameters from existing wall failures. This presupposes that a reasonably significant failure has occurred before an employer can better design a mine. Whilst mining pit walls to failure is not advocated, should a large failure occur inadvertently, the use of back-analysis of rock mass properties and modes of failure to derive more accurate pit wall design criteria and thereby reduce the risk of similar failures recurring is recommended.

The range of ground behaviour expected around an open pit excavation is, in simplistic terms, dependent on whether the rock mass is classified as "soft rock" or "hard rock".

Soft rock conditions

The recognition of soft rock ground conditions is a very important geotechnical issue. Soft rock ground conditions may be identified as those where the intact rock has a uniaxial compressive strength that can range from approximately 0.5 to 25MPa. It is recognised that the mechanics of soft rocks falls partly within soil mechanics and partly within rock **mechanics**. There is therefore need for the combined application of both soil mechanics and **rock mechanics** principles to soft rock materials.

One of the peculiar characteristics with soft rock is the destabilising effect that high pore water pressures can have on slopes excavated in this material. Conversely, the dissipation of high pore water pressures in the soft **rock mass**, with time, may lead to consolidation of the **rock mass** and lead to ground subsidence and a reduction in **rock mass** strength. Ground subsidence due to fluid withdrawal is well documented. The dissipation or build-up of pore water pressures is controlled by the permeability of the **rock mass**. Some soft rocks can actually gain strength when the interstitial groundwater is evaporated and the rock "dries out".

This apparent time dependent behaviour of soft rock can have a significant effect on the strength of materials and also the stability of pit walls. It is obvious, therefore, that soft rock issues are complex and this needs to be recognised and addressed in the mine planning and design process.

Failure of soft rock within open pit walls can occur along rock mass discontinuities or through intact rock. In some conditions, foundation failure (failure through rupture of the pit floor) is possible. The failure path through intact soft rock usually takes a hemispherical/circular form. The rate of failure is generally slower and signs of impending failure are usually more obvious and more easily monitored when compared to hard rock failures.

Hard rock conditions

In hard rock mining conditions the strength of the intact rock is usually considerably greater than 25MPa. Wall failures in hard rock are primarily controlled by the presence of geological structure, and the geometry of the pit walls. The size, shape and orientation of the potentially unstable blocks of rock depends primarily on the orientation, spacing and length of the planes of weakness in the rock mass plus the geometry and orientation of the mining excavations. Modes of failure for structurally controlled failures in hard rock are commonly divided into one or a combination of three principal types:

- Planar;
- Wedge; and
- Toppling.

Each of these modes of failure has been well documented. There are numerous variations of these failure modes (e.g. raveling, complex wedge formation, flexural toppling etc.; however, each variation has been included as one of the main three groups given above.

Although these modes of failure are generally more relevant to hard rock mines, pit wall instability in soft rock can also result from one or a combination of the three structurally initiated modes of failure. The design of all open pit walls will therefore need to take these modes of failure into account.

It is usually the case that failure through intact hard rock only occurs in well foliated **rock masses** where rock stresses are acting on long thin sub-vertical columns of rock. This general rule may change in very deep mines, where rock stresses at depth are much higher. In deep open pits, particularly those mining through old underground workings, potential exists for seismic conditions to be generated. Under these conditions, violent fracturing of the rock mass rock could result.

Rock weathering

Weathering is the process by which rocks are broken down and decomposed by the action of external agencies such as air, water and/or changes in temperature. The weathering process is limited to the decomposition of rock *in situ* – there is no transportation of material (e.g. by erosion). The two main types of weathering are mechanical (e.g. shrinkage and expansion due to temperature changes) and chemical (e.g. certain minerals being leached from the rock or other compound elements being formed by interaction with water).

It follows that the engineering properties of rock will be significantly affected by the degree and nature of weathering. Weathering is the main agency by which soft rock conditions are developed in metalliferous mines in the RSA.

Stress changes

The rock stress field around the mine has both magnitude and orientation and can be considered to consist of two components:

- Pre-mining (*in situ*) stress field; and
- Mining induced (disturbance) effects.

The pre-mining stress field is dependent on essentially two components:

- Forces exerted by the weight of overlying rock mass; and
- Lateral tectonic forces in the earth's crust.

Some variation in pre-mining stress may develop as a result of changes in groundwater pressure (particularly in saturated sediments) or as a result of tectonic movements.

The removal of rock by mining causes the *in situ* pre-mining stress originally carried by that rock to be redistributed to the remaining surrounding rock. The resultant stress field around an open pit provides the environment that can result in one of the following things happening;

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

The level of stress required to initiate either of these events is largely dependent on the mechanical strength of the rock mass.

Once failure of the rock mass occurs, the elevated stresses are redistributed throughout the remaining rock mass and a modified/induced stress equilibrium established. The duration of the modified equilibrium conditions will depend on the extent of initial ground movement or rock damage and the susceptibility of the remaining rock to further changes in the stress state. In some cases, subsequent smaller changes in stress can induce greater damage than that caused by the initial change in stress.

The subject of stress changes and its potential influence on mining activity needs to be recognised. There are two types of stress measurements that can be undertaken:

- Absolute rock stress measurements; and
- Stress change measurements.

Several methods can be used to estimate the magnitude and orientation of the stress field, in terms of absolute stress levels or stress changes. Should stress monitoring be required, the employer will need to establish the most relevant method.

It is not suggested that every mine undertake a comprehensive program of stress measurement. However, the employer should recognise that stress change is an issue that requires attention when planning a mine. When deciding whether or not to undertake a stress measurement program it is necessary to consider a number of things. This includes the size and operating life of the mine, mining depth, the overall **rock mass** strength, presence of major geological structures, production rates, and the presence of existing underground mining within the immediate proximity of the open pit. Issues of concern for interaction with underground workings include:

- dimensions of underground openings
- **pillars** in relation to the pit walls
- the presence or absence of fill or water
- the potential for natural seismic activity.

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

Groundwater

"**Groundwater**" is the term used to describe the naturally occurring water within the **rock mass**. Depending on the water bearing characteristics of the **rock mass**, the groundwater interacting with a mine can be sourced from within close proximity to the excavation or up to several hundreds of meters away.

Similarly, the quantity of water or the level of water pressure that is necessary to have a deleterious impact on the ground conditions within a mine can vary by orders of magnitude.

The characteristics of the groundwater regime in and around the mine and its potential influence on the **rock mass** should be well defined before producing the final mine design. It is also important to systematically fine-tune the level of knowledge of the hydrogeology of a site in an on-going manner throughout the life of the mine at a level appropriate for the hazard potential to the mine. For instance, the potential for corrosion of ground support and reinforcement, erosion or softening of the **rock mass**, water-related blasting problems and the likely impact of elevated pore water pressure needs to be recognised, investigated and if necessary, re-medied.

Blast damage

Blast damage may be described as the weakening of the **rock mass** by blasting practices in the open pit. Damage may be in the form of fracturing of intact rock, or simply the loosening of geological structure. The aim of any well designed rock drilling and blasting process should be to achieve the required degree of rock fragmentation with the minimum of damage to the remaining rock. Blast damage to the **rock mass** is an unavoidable consequence of conventional drill and blast mining methods. However, much can be done to minimise excessive damage to the rock by the use of controlled drilling and pit limit blasting practices (e.g. pre-splitting and modified production blasting).

The technique of drilling and blasting is a complex field that is constantly evolving and hence cannot be summarised in a few lines. Those interested in pursuing this matter further are encouraged to research the published literature and contact their suppliers of drilling equipment and explosives.

Rock mass failure

A failure of the **rock mass** in open pit walls and/or floor involves the relocation of a body of material from its original position within the wall. This will occur when the driving forces acting on a defined body of material are greater than the forces resisting movement of the body of material. Examples of driving forces include water pressure and gravity; examples of resisting forces are joint friction and compressive forces applied by ground support such as cable bolts.

Ground control

Ground control deals with both ground stability and instability issues that result from mine development and the economic extraction of ore. **Ground control** is an integral part of any well managed mining operation. The aim of an open pit **ground control** program is to design and manage the excavation of pit walls so that the required levels of workforce safety, serviceability, grade control, productivity and design life of a mine are achieved. A successful **ground control** program is not necessarily one that has had no rock mass failures.

Success is measured by the level of awareness developed before any wall/bench failure and the **level** of the consequence of a wall/bench failure on the operations.

The ability to influence and manage ground responses to mining may vary greatly depending on the accessibility to the site and the volume of potentially unstable rock. Nonetheless, the hazard potential must still be recognised and mining strategies modified as required in order to minimise the **risk** to the safety of mine personnel.

In dealing with the complex range of issues in geotechnical engineering it is useful to consider two types of **ground control**:

- Bench-scale **ground control**: involving failed **rock mass** material, which is normally contained within catch/safety berms; and
- Large-scale **ground control**: involving those factors that affect the stability of large sections of the pit wall, typically more than one complete batter slope. These large-scale issues are usually beyond the control of the general workforce to deal with (although poor blasting or excavation practice can initiate large-scale failures), and are the responsibility of the principal employer and mine management.

A variety of terms can be used equally well to describe the scale or size of the issues to be addressed, however, for simplicity, these two (bench and large-scale) have been used in this guideline. The distinction between batter scale and large-scale **ground control** issues is less clear where the vertical distances between catch berms is greater than 20m. Consequently, some of the comments given for one particular area of **ground control** may also apply to the other, depending on the mining method, depth of mining and/or scale of mining operations.

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

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

Put simply:

Ground control

↓

Ground Conditions + Mine Design + Ground **Support** & Reinforcement

It cannot be over-emphasized that a well-managed and systematic approach to **ground control**, necessarily requires a good understanding of the ground conditions.

Ground control in open pit mines is largely brought about by excavating the geometry of the pit walls in accordance with the prevailing ground conditions such that there is no hazardous or unacceptable **rock mass** failure during the operating life of the excavation. Control of the geometry of the pit walls is essentially accomplished by varying the individual bench slope heights and angles, and the widths of intermediate catch berms. Where these geometrical controls do not produce a commercially viable mine, rock **support** and reinforcement can be used to artificially strengthen the **rock mass**.

Ground control strategies must take into account the potential for both bench scale and large scale **rock mass** failure.

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

Design criteria for each of these methods can be determined from either probabilistic or deterministic methods.

It is recommended that a sensitivity analysis be carried out for the critical geotechnical parameters involved in ground control to arrive at the optimal pit wall design. Any deficiencies that are highlighted in the analysis should encourage further work to remedy these matters, extend the use of the methods of analysis or develop a new method.

It is sometimes the case that a system of rock **support** and reinforcement (e.g. cable bolts) may be incorporated within the **ground control** design. The use of rock reinforcement is usually limited (in more recent times) to stabilising localised areas of the pit walls deemed to be susceptible to **rock mass** failure, and which may otherwise be mined out inefficiently. The decision to use rock reinforcement will be based on the cost differential between mining to a shallower overall wall angle, and the cost of the rock reinforcement.

Ground control design methods will continue to evolve and develop in the future. These methods, in keeping with the engineering method, do not present an exact closed form solution with one unique answer. Rather, they are based on underlying scientific principles, strength of materials concepts, engineering computational modeling, static and dynamic loading plus considerable observations of field performance to present a range of solutions. However, any **ground control** design method must be based on sound geotechnical engineering practice. The inherent challenges in geotechnical engineering are absolutely no excuse for not applying sound geotechnical design strategies in all mining projects.

Ground support and reinforcement

The terms "**ground support**" and "ground reinforcement" are often used interchangeably, however, they refer to two different approaches to stabilising rock. Ground **support** is applied to the exterior of the excavation to limit movement of the **rock mass**, e.g. buttressing, meshing, strapping, concrete lining and shotcrete. These methods typically require the **rock mass** to move on to the **support** to generate loads in the support. Ground reinforcement is applied to the interior of the **rock mass** to limit movement of the rock mass, e.g. rock bolts, grouted dowels, cable bolts and friction rock stabilisers. These methods can typically provide active restraining forces to the **rock mass** soon after installation with little or no movement of the rock.

Ground **support** and reinforcement includes all the various methods and techniques that may be used to improve the stability of the ground. Obviously, depth, shape and orientation of the excavations and the ground conditions would need to be considered when selecting the most appropriate ground support and reinforcement system.

If ground **support** and reinforcement are required to stabilise a pit wall, each component must be matched to the ground conditions.

Operating life

The term operating life pertains to the length of time an open pit wall is required to remain stable to protect the safety of mining personnel and equipment infrastructure. For example, once the mining schedule allows for mining personnel to completely avoid any section of a pit wall for the remainder of the mining project, the wall has completed its operating life. For the purposes of this discussion, open pit excavations have been divided into two terms of operation:

- Short term; and
- Long term.

The definition of long term is arbitrary. In this case it has been taken to mean an excavation with an operating life of at least one year and short term walls have an operating life of less than one year. Long term walls, being exposed for greater lengths of time, represent a greater **risk** to the operations due to factors such as the time dependent characteristics of **rock masses**. Pit slope design criteria should therefore take into account the effective operating life of walls.

An example of the relevance of design operating life in **ground control** is the regular use of long-term haulage ramps by the workforce. The potential **risk** of injury is higher because more personnel use haulage ramps and because main haulage ramps are exposed and utilised for longer periods. Hence, a more conservative wall design would be required in these long term areas to manage/control the increased risk.

Longer-term excavations/walls should also demand a greater level of geotechnical investigation, both before developing the mine plan and during mining operations to reduce the level of inherent uncertainty about the **rock mass**.

2. GEOTECHNICAL CONSIDERATIONS

2.1 Planning for total mine life

Design approach

Geotechnical issues must be systematically considered during the whole life of a mining operation, from its beginnings in the pre-feasibility study stage, through the operation of the mine, to the final closure and abandonment of the mine. The design of open pit excavations will endeavour to prevent hazardous and unexpected failures of the rock mass during the operating life of the open pit.

The importance of a systematic approach to mine planning and design using soundly based geotechnical engineering methods cannot be over-emphasised. Open pit mines can represent a complex engineering system with many subsystems that need to function in an integrated manner for the mine to operate safely and economically. Mine planning and design has as its goal an integrated mine systems design, whereby a mineral is extracted and prepared at a desired market specification at a minimum unit cost within the accepted/applicable social and legal constraints.

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

It is strongly recommended that a formal mine planning and design system be established early in the life of a mine. Such a system might involve the regular informed discussion, as often as required, of a range of planning and design issues in the current operational areas and the new areas of the mine. The “mine planning and design meeting” should be an interdisciplinary meeting requiring the involvement, as necessary, of a range of expertise including: survey, **geology**, mining engineering, drilling and blasting, geotechnical engineering, mechanical engineering, electrical engineering, rehabilitation, workforce supervision and management (principal and contractor).

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

Approval of the plan(s) should require the signature of a number of people including those responsible for: survey, **geology**, drilling and blasting, geotechnical, planning and design aspects.

Geotechnical design considerations

It is recognised that during the geotechnical design stage there is usually limited detail of the overall **rock mass** available, and that it is necessary to make a number of assumptions/simplifications to arrive at a balanced mine design.

Geotechnical data for design can be obtained from a number of sources including: published literature, natural outcrops, existing surface and underground excavations, chip and diamond drilling (for determining **rock mass** strength, structure, and hydrogeological data), geophysical interpretations, pump tests, field tests, trial pits, and experience. It would be a statement of the obvious to say that the quality and usefulness of these sources of data is widely variant. However, qualitative information is better than none and, if nothing else, such data can be used to identify the areas requiring more detailed investigation and analysis.

Once the potential for economic mining has been identified it is considered sound practice to geotechnically log diamond cored boreholes as soon as the core becomes available. Re-logging core for geotechnical purposes, after it has been stored or split for assay determination, is necessarily inefficient (double handling) and may give unreliable data on discontinuity characteristics. Also the usefulness of data from re-logging of core initially drilled for exploration purposes, particularly core that has not been adequately stored or oriented, is limited.

Obviously, the number of geotechnical holes required for a particular project will depend on the level of available geological/geotechnical information at the site and the size and mine life of the project. For instance, it is possible that very few, and potentially no geotechnically logged drill holes could be required for mine excavations in close proximity to existing pits (that have similar geological conditions and can be accessed to define the relevant geotechnical design parameters).

The information gained from geotechnical investigations notably provides valuable information for mine design, but also assists with the development of a mineral resource estimate, and ultimately an ore reserve estimate.

Particularly in marginal deposits, the geotechnical mine design limitations may define whether the resource can be classified as a reserve and therefore whether or not it should be mined.

Once there is considered to be adequate geotechnical design information, a ground **control** management plan should be formulated. The plan should incorporate the most appropriate excavation geometry (and ground **support** – where required), excavation methods, and monitoring strategies. The size of the mining operation will obviously be a major factor in determining the amount of effort and resources that are required to develop and implement the **ground control** management plan. It will be necessary to apply considerable mining experience and judgment when establishing the **ground control** management plan at a mine for the first time. With experience, it will be possible to successively refine the plan over time to address the **ground control** issues identified as being important to the continued safe operation of a mine. The issues that would need to be considered include:

- Depth and life of mining projects;
- Expected ground conditions in the wall **rock mass**;
- Production rate;
- Size, shape and orientation of the excavations;
- The location of major working benches and transportation routes;
- Potential for surface water and groundwater problems;
- The equipment to be used, excavation methods, and handling of ore and waste;
- The presence of nearby surface structures (for example public roads, railways, pipelines, natural drainage channels or public buildings);
- The potential for the general public to inadvertently gain access to the mine during and after mining; and
- Time dependent characteristics of the **rock mass** (particularly after abandonment).

It follows that early identification of relevant geotechnical issues at a site will greatly assist with the development of a well balanced **ground control** management plan.

Operational geotechnical considerations

During operation of the pit, the (newly developed) **ground control** management plan is used to improve the geotechnical database, and to assess the suitability of the existing mine design and the general stability of the mine. This on-going assessment is required because of the relative paucity of data that is usually available when the mine design (and **ground control** management plan) is first formulated. Where necessary, alterations to the general mine plan will be required to maintain safe operating conditions; therefore, when designing mines, a certain amount of flexibility is required.

A well managed **ground control** plan should include regular discussions of all **ground control** issues with relevant mine personnel both during mine inspections and in more formal planning meetings. In particular, changes in the geological structure and general **rock mass** appearance and the detection of incipient **rock mass** failures should be noted during the development of a mine. This will allow for early recognition of instability issues so that a review and modification (if necessary) of extraction techniques, mine design, ground **support** and reinforcement, and monitoring practices can be completed before any problems become difficult or expensive to control.

Abandonment

By the time of mine closure, there should be adequate data to address all the long-term geotechnical concerns in regard to the abandonment of a mine.

Before surface can be legally abandoned, the **DME** requires that all long term drainage, environmental and public access issues are adequately considered and controlled. Environmental requirements for abandoned mines are specified by the license conditions imposed by the **DME** and the lease conditions imposed by the **DME** during the mining project approval process.

The application of soundly based geotechnical engineering methods to the mine planning and design process can result in significant improvements to mine safety, productivity and economic efficiency and should be included as an integral part of each mining project.

2.2 Geological structure and rock mass strength

Rock mass failure occurs when the driving forces acting on a given body of material exceed the resisting forces within that body of material. In a freshly excavated slope, the force resisting failure can be attributed to the shear strength of the **rock mass** and/or geological structure. The driving force (that precipitates failure) is primarily dependent on the unit weight of the **rock mass**, the geometry of the wall/slope and the potential modes of failure (which define the geometry and size of the block of potentially unstable material). In soft rock, failure can propagate through the intact rock, and/or along geological structure. In hard rock the path of minimum shear strength/resistance is predominantly along **rock mass** defects/geological structure. It follows, therefore, that mine operators must identify the relevant modes of failure (the sources and magnitudes of the potential driving forces), and also determine and quantify the shear strength and other forms of resisting forces pertinent to that **rock mass** and mode of failure. It is obvious that the shear strength of geological structure dipping into pit walls are less important than that of structures dipping into the mine void, and that as a consequence the relevant orientation of **rock mass** defects must be taken into account.

Determination of representative shear strength values is a critical part of slope design, as relatively small changes in shear strength can result in significant changes in design pit wall geometry. The main detractors to determining reliable shear strength parameters are the availability of sufficient/suitable shear strength test data, the level of understanding about the **rock mass** (particularly prior to mining), and the influence of other factors, such as variable weathering on the shear strength of the **rock mass** and **rock mass** defects.

Where persistent foliation or closely spaced orthogonal jointing exists, problems can develop with maintenance of safety/catch berms. Where safety berms cannot be maintained, a method will need to be developed to limit the **risk** associated with falling rocks or sub-bench scale failures (e.g. catch fences or wider berms).

Therefore, the design size, shape and orientation of open pit excavations relative to the geological structure needs to be recognised as a major factor controlling the number, size and shape of potentially unstable blocks that may form within the pit walls. It follows that the design and selection of any ground **support** and reinforcement also takes due consideration of the size, shape and orientation of the pit walls in relation to the geological structure in the **rock mass**.

It is recommended that a systematic and on-going approach be adopted to develop a site specific geotechnical model of the orientation and other characteristics of the geological structure within pit walls. An example of a systematic approach used to develop a site specific geotechnical model is given below:

- Use scanline or other methods of geotechnical wall mapping and/or oriented core logging to establish baseline geotechnical data on planes or weakness within the rock mass with a minimum of bias. This approach is particularly useful when mines are developed as a series of cutbacks. Wall mapping should attempt to quantify orientation, persistence, spacing, roughness and wavelength, wall rock strength, aperture, infill, degree of weathering and moisture content of planes of weakness.

- Take representative samples of the **rock mass** and determine relevant compressive and shear strengths and groundwater characteristics.
- Use of plotting, analysis and presentation methods of geological structures data in order to define orientation, persistence, spacing and other characteristics of joint sets.
- Identify the general geotechnical districts in the **rock mass** throughout the mine.
- Transfer of this data to geological plans and sections/or computer models for use in the design of pit walls and wall **support** and/or reinforcement (where required).

It must be recognised that steeper and higher benches will generate greater driving forces thereby increase in the potential for **rock mass** failure. It should also be acknowledged that benches excavated within **rock masses** that contain persistent geological structure have greater potential to develop large wall-scale failures than those excavated within **rock masses** that contain defects with shorter trace lengths. The ramifications of small-scale failures are not as important as those of large-scale failures – particularly if the small-scale failures are being contained by catch berms. One common method for control of small bench-scale failures is to install local ground **support** and/or reinforcement. Control of large-scale failures, on the other hand, should be carefully considered and also more difficult. Potential large scale failures are usually controlled by excavating slopes/walls to a shallower angle, depressurisation of groundwater in the wall **rock mass**, or installing more costly ground **support** and/or reinforcement than that used for stabilising small-scale **rock mass** instability.

Geotechnical design methods can be used to assess the likely interaction between the size and shape of the excavation, geological structure and the required levels of ground **support** and reinforcement. The influence of the rock stress field on the excavation geometry can be investigated using stress analysis methods.

2.3 Hydrogeological considerations

The influence of groundwater or incident rainfall is often not given the level of importance it warrants when designing a mine. The importance of hydrogeological considerations for pit wall design and management is well documented. Some of the more significant effects water can have on the general integrity of pit walls include:

- Increase in pore pressure within the **rock mass** (which reduces shear strength);
- Softening of infill or rock material (particularly clays);
- Slaking of soft rock due to wetting and drying cycles;
- Erosion of weaker bands of rock by water seepage or run-off;
- Reduced blasting efficiency; and
- Corrosion of ground **support** and reinforcement.

The hydrogeological environment of an open pit needs to be understood to an appropriate level to ensure adequate provision is made for the removal of rainfall and groundwater inflow as the mine continues to expand. Groundwater is likely to be more of an issue in a new mine, or new area(s) of a mine, where very little of the groundwater has been actively extracted before mining commences.

In order to understand the hydrogeological conditions at a mine site, it is necessary to undertake adequate investigation of the range of geological conditions, and characteristics of water flow throughout the site. It is recommended that this investigation be carried out in conjunction with exploration drilling. The characteristics of aquifers within the **rock mass** should be determined during exploration drilling. Relevant information can be sourced from packer testing, and from simply noting the depth of any water make or loss during drilling. If it is recognised early in the resource investigation phase that groundwater control will be an issue, exploration drill holes can be planned for use as piezometers/monitoring boreholes or production boreholes, and advance dewatering programs can be better designed so that the required levels of depressurisation can be achieved.

Exploration drill holes intersected by open pit excavations can be a potential source of high pressure and/or high flow rates of water – particularly in artesian conditions. The sudden unexpected in-rush of water from a drill hole can jeopardise the safety of the workforce and increase the cost of production if the flow rate is sufficiently large. In such cases, exploration holes should be used to investigate the hydrogeological nature of the host rocks, and establish the most appropriate methods for sealing open drill holes. Effective grouting of all exploration holes requires a good understanding of the sources of the water in the **rock mass** likely to be transmitted by the hole. Effective grouting also requires that the down-hole path of all exploration holes should be surveyed and plotted on plans and cross-sections, not just the collar and the toe positions.

Water drainage paths through and around the mine must be designed such that rainwater runoff or groundwater seepage does not pond at the crest or toe of slopes within pit walls. Surface drainage should also be designed to at least take account of rainfall expected from a 1 in 100 year, 72 hour flood event. The adequacy of the design and construction of any diversion works of natural channels will need to be proven by geotechnical principles.

Any significant natural drainage paths truncated by mining will need to be reestablished prior to abandonment.

The potential for corrosion or weakening of any artificial ground **support** or reinforcement should be established. In order to qualify the potential for this, water samples should be taken and chemically analysed. It is preferable that these samples be taken during exploration drilling.

2.4 Rock support and reinforcement

As reinforcement of rock within open pit walls usually involves large volumes of **support** material, it is essential that each rock reinforcement element is correctly designed and installed.

It is recommended that the design of ground **support** and reinforcement be based on a thorough understanding of the following points:

- Geological structure of the **rock mass** in and around the pit walls;
- Stress levels and the changes in stress around excavations during the life of the excavation;
- **Rock mass** strength;
- Behaviour of the rock **support** or reinforcement system under load;
- Groundwater regime (particularly in terms of corrosion potential); and
- The potential for **seismic events**,

It is essential that the design of rock **support** and reinforcement be matched to the ground conditions. Anything less could not be said to be sound geotechnical engineering practice.

The timing of the installation of ground **support** and reinforcement should be considered as an integral part of the design to limit the potential for raveling of the **rock mass**. In those areas requiring reinforcement, the delay in the installation of the ground **support** should be minimised as far as is reasonably practicable. It is recognised that several days or longer may elapse from the firing of a blast, before the shot area is clear of debris and is made ready for the installation of ground **support** and reinforcement. However, extended delays in the installation of ground **support**, in the order of weeks to months, may jeopardise effectiveness of the **ground control** because of the **rock mass** loosening and consequent reduction in the shear strength of the **rock mass** that may occur.

Corrosion is an important factor that needs to be considered in the design and selection of the rock **support** and reinforcement. The influence of corrosion will mean that virtually none of the conventional forms of rock **support** and reinforcement can be considered to last indefinitely as they all have a finite design life. The two main causes of corrosion are: oxidation of the steel elements, and galvanic consumption of iron by more noble (inert) metals, for example copper.

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

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

Installation

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

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

Quality control

The importance of quality control to the successful design and installation of adequate ground support and reinforcement needs to be clearly recognised and proper quality control procedures should be put in place. The supplier of the ground support and reinforcement elements should provide information on the factors that determine the quality of the installation. It is recommended that the following issues be taken into consideration when designing ground support and reinforcement programs:

- Storage and handling of the rock **support** and reinforcement should be such as to minimise damage and deterioration to the elements;
- **Rock mass** strength should be adequate to allow the full capacity of expansion shell rock bolts;

- That recommended hole diameter ranges for the particular type of **support** or reinforcement can be achieved consistently in all the rock conditions likely to be encountered;
- That correct hole length can be drilled and holes flushed clean of all drilling sludge prior to **support**/**reinforcement** installation;
- Orientation of holes is appropriate for the excavation geometry and expected mode of failure;
- Corrosion issues should be recognised and remedied;
- Blast vibrations may loosen threaded rock bolt systems;
- Cement grout is mixed at the recommended water: cement ratio, at the recommended angular speed in the specified equipment for the time specified;
- Water used for cement grout mixing is of the required quality or the cement used should be able to develop the required uniaxial compressive strength with the run of mine water supply;
- Any additives (e.g. retarders, accelerators, fluidisers, etc.) to the cement grout mix should be added in the recommended amounts and at the specified time in the mixing and pumping process;
- All steel components designed to be encapsulated in resin or cement grout are to be clean of all oil, grease, fill, loose or flaking rust and any other materials deleterious to the grout;
- Where full grout encapsulation of the steel element(s) are required, the method of grouting should show a grout return at the collar of the hole; other methods that can demonstrate complete hole filling may also be appropriate;
- Correct tensioning procedures (when required) should be used for the various types of rock **support** and reinforcement. The purpose of tensioning of cables in the grout **support** system must be determined to establish whether post tensioning or pre-tensioning is required;
- Plates and/or straps against the rock surface should have the required thickness to prevent nuts or barrel and wedge anchors being pulled through the plate and/or strap at the ultimate tensile strength of the tendon when loaded against the rock surrounding the bore hole;
- All grout mixing and pumping equipment should be cleaned and maintained on a regular basis;
- Shotcrete mix specification should state the slump of the mix, the uniaxial compressive strength and a measure of the toughness of the product at specified time intervals prior to or following field application as appropriate;
- Samples of the shotcrete mix should be collected at specified intervals, under normal operating conditions, and tested in a registered concrete testing laboratory for compliance with the shotcrete design specifications; and
- Shotcrete thickness should be tested regularly during placement to ensure that the specified thickness has been applied – a means of permanently marking the shotcrete surface with a depth gauge probe may be appropriate.

The marginal cost associated with the different types of cable bolt strand is insignificant in comparison to the fixed costs associated with the hole drilling and grouting (e.g. equipment depreciation, drilling consumables, transportation, grouting and labour). Hence, it is vital to ensure the correct cable bolt strand type is selected for the ground conditions and expected ground behaviour, particularly where soft rock conditions exist.

2.5 Pit wall design

Before mining commences, it is necessary to establish an appropriate excavation design geometry on which to base the overall mine plan. It is acknowledged that the "final" pre-mining design may be modified with time, as additional data becomes available during operation; however, it is essential that the "final" pre-mining geotechnical design be adequately attuned to the local ground conditions before mining commences. In this way, the potential for **rock mass** failures to occur unexpectedly during mining is reduced significantly.

The process of geotechnical analysis of pit wall stability and design is well documented. An example of one specific factor to be accounted for in pit wall design is the potentially adverse effects of "bullnose" promontories within long straight open pits.

It follows that to achieve higher levels of accuracy of pit wall design, a greater level of investigation, careful engineering, and sound judgment are required. It should also follow that when particularly poor ground conditions are identified in the early stages of investigation, or there are significant surface infrastructure or natural features near the pit, then the level of geotechnical data required is also greater.

It is also recognised that the final design of open pit walls represents a balance between safety and the economic viability of the operations, as it is generally not feasible to design the pit walls for "permanent" stability. It is often said that the best geotechnical design is one that fails the day after mining ceases.

In practice, however, a fall-as-you-leave pit wall design cannot be realistically achieved.

It is recommended that the following steps should be followed with any mine design together with an evaluation of the rehabilitation of the slope design:

- Define the **ground control districts** and mining sectors.
- Conduct a bench design analysis to determine the maximum inter-ramp slope.
- Conduct inter-ramp design analysis using economic criteria for the selection of inter-ramp angles.
- Evaluate the resulting overall slope for potential instability, and modify the design if required.

The design methods that can be used include:

- Empirical or experience based methods developed from extensive local information;
- Deterministic/limit equilibrium methods - using geotechnical parameters derived from either laboratory testing or back analysis of existing failures;
- Kinematic (stereographic and block analysis methods) – e.g. SAFEX, DIPS;
- Numerical modeling; and

Design criteria for each of these methods are usually expressed in terms of either probability of failure or factor of safety and are based on the level of acceptable **risk** of any particular failure and the degree of inherent uncertainty regarding the characteristics of the **rock mass**.

It is recommended that a sensitivity assessment be carried out to determine the effect of critical geotechnical parameters involved with wall stability. This will assist with an assessment of the quality of geotechnical data obtained and required and the appropriate mine design options. Common methods used to increase the effective stability of pit walls include reducing slope angles, installing reinforcement, and depressurisation of groundwater. Any deficiencies that are highlighted in the analytical methods should encourage further work to remedy these matters, extend the use of the method or develop a new method.

The most common forms of design analysis are the kinematic or deterministic methods for which there are several packages available commercially. These methods are relatively simple to follow. Numerical modeling allows the design of pit walls and interaction with underground workings to be considered in much more detail than is the case with empirical or deterministic design methods. One of the drawbacks for the use of numerical methods however, is that they generally require considerably more data input, which cannot always be adequately provided.

Computer-based numerical modeling packages have developed rapidly during the past 10 to 20 years and this trend is likely to continue. A wide range of design packages are currently available that can be run on most standard mine site computers. However, it must be recognised that differences exist between the solution methods used by the major numerical modeling techniques – e.g. finite element, finite difference, boundary element, and distinct element codes. These different solution procedures can give rise to some variation in computation of stresses and strains. The design engineer must acknowledge the differences between each of the limitations of numerical model codes with respect to the problem at hand.

It is a prerequisite that significant mining experience and judgment is required to interpret and use the results correctly. It is also recommended that each numerical modeling technique be calibrated against observed ground response to mining at each mine, which would require the monitoring system to be appropriately designed.

Considerable engineering judgment and mining experience is required to determine the appropriate levels and methods of geotechnical investigation required for the development of a geotechnical model for a particular mine, and to determine the method/s of analysis best suited for pit wall design.

2.6 Blasting considerations

Inappropriate drilling and blasting practices can result in substantial damage to the **rock mass** within the final pit walls. There is a need to have standardised drilling and blasting patterns that have been determined using well founded and recognised blast design procedures, and that are appropriate to the ground conditions at the mine site.

The factors that control the level of wall damage caused by drilling and blasting include:

- **Rock mass** properties, orientation, persistence and spacing of geological structures, presence of groundwater;
- The degree of "confinement" and amount of burden shifted by the proposed blast;
- Inadequate removal of rock debris from earlier blasts from the toe of batter slopes;
- The degree of rock fragmentation required;
- Selection of the appropriate hole diameter;

- Control of individual hole collar position, hole bearing, inclination and length;
- The type and amount of stemming used;
- Placement of holes in a suitable pattern to achieve the required excavation geometry;
- The use of specific perimeter holes such as stab holes, or smooth blasting techniques (e.g. pre-splitting, post-splitting, or cushion blasting);
- Selection of appropriate initiation system(s) and initiation sequence of the blast or blasts;
- Specific types or combinations of explosives. Explosives must be selected according to the given ground mass conditions, e.g. groundwater or reactive shales can affect the result of a blast. Explosives must also be selected to achieve required energy levels, maintain compatibility with the initiation systems, and the explosives' expected product life in blast holes;
- Control of explosive energy levels in the perimeter holes and preferably using decoupled explosive charges, with a cartridge diameter less than the blast hole to minimise blast damage at the excavation perimeter;
- The required mining bench height and the depth of subgrade drilling (subdrill); and
- Availability of well maintained drilling, explosives handling and charging equipment of appropriate capacity.

The perimeter/final wall blast hole and explosives system will need to take into account all these relevant issues to arrive at the optimal final product (safe pit walls). There are a number of commercially available, computer-based, drilling and blasting design packages that may be used on a mine-ownership or consulting basis. The application of recognised drilling and blasting design practices and procedures developed to suit local conditions should be an integral part of a balanced **ground control** management plan. Where necessary, the advice of the explosive manufacturer(s) and supplier(s) should be sought on the appropriate use of various combinations of explosive(s) and initiation system(s).

It is considered good practice to qualitatively monitor the extent of blast damage and evaluate the success of blasting methods as the open pit expands and deepens. Blast monitoring tools include; visual observations and documentation of charging, drill pattern and final results, vibration records, noise records, video footage, displacement markers, and complaint records. Blast monitoring results should then be used, as part of an ongoing critical review of drilling and blasting to ensure that the blast design is performing to the standards required.

While consultation of the workforce on such matters is recommended, it is not appropriate that fundamental decisions on important aspects of blast design and practice be left in the hands of individual miners on the job, without any blast engineering **support**. Nonetheless, mine management needs to ensure that the workforce is provided with on-going training in the safe and efficient handling and use of explosives and initiation devices.

When open pits are located in close proximity to significant surface or subsurface infrastructure of natural features, blast vibration monitoring may be required to help determine the likely impact of blasting on the specific infrastructure and the pit walls (and any associated ground support and reinforcement) that may be supporting the infrastructure.

The detonation of explosives, particularly large production blasts in open pits that mine through large scale underground workings, can trigger seismic activity or audible rock noise. The occurrence of this should be recorded, noting for example the location, time, subjective description, number of events, any rock falls, etc. If the rock noise continues for some time, or occurs at unexpected times, then further investigation of the situation may be advisable, as this could be a pre-cursor of more serious seismic activity in the future.

2.7 Monitoring

During the mine design process, it is necessary to make simplified assumptions of the complex *in situ* **rock mass** characteristics. In each case, these simplifications introduce sources of uncertainty and potential failure into the design. The inherent uncertainty associated with geotechnical engineering means that it is necessary to regularly monitor the performance of the pit walls to verify the stability or otherwise of relevant areas in the mine.

Sources of uncertainty include inadequate details of the **rock mass** (e.g. variable time dependent behaviour of **rock masses**, ground water, variation in geology within walls), human error (e.g. observation, computation and testing errors), and operational mining variation from the design (e.g. undercutting of bench faces). Monitoring of the pit walls therefore becomes an important tool for locating any potential failures of ground before the unstable rock mass becomes hazardous. Well-designed monitoring programs can help differentiate between normal elastic movements, inconsequential dilation and incipient pit wall failure. Early detection of wall failure allows mine operators to plan and implement appropriate actions with sufficient notice such that the effect of the failure on mine safety and productivity is minimal.

The specific nature of monitoring programs required for a given open pit would be dependent on the site-specific conditions of the mine. For example, stiffer rocks will tend to deflect less than softer rocks before failure and certain rock types or geological structures can be weakened by water, thus necessitating more frequent monitoring after periods of rain. Regardless of the variation in the performance of various mine slopes, if there is adequate monitoring and a good level of understanding of the ground conditions at each site, there should be no “unexpected” failures. Slope failures do not occur spontaneously. There is scientific reasoning for each failure, and failures do not occur without warning if the failed area is being well monitored.

Conversely, once unusual pit wall movements such as cracking have been observed, it does not necessarily follow that the wall will fail.

It is clear, therefore, that each site must have its own monitoring strategy, matched to local ground conditions.

Pit slope monitoring programs should start off in a logical manner, and become more refined or complex as conditions demand. To begin with, monitoring can be kept to visual inspection only, provided safe foot access can be maintained to relative and critical areas. Where safe foot access cannot be maintained or guaranteed, monitoring equipment that can be operated remotely should be installed on the respective slope faces or crests. Visual monitoring alone is acceptable until the pit wall expresses one or more signs of potential instability. Early monitoring does however serve to calibrate actual **rock mass** deformation with those predicted using analytical techniques.

Visual signs that allude to incipient failure of pit walls include:

- Formation and widening of cracks;
- Rock noise and ejection;
- Bulging of the slope face or toe;
- Raveling of rock within the slope:

- Increased water seepage; and
- Bending of reinforcement or rock **support** elements.

Records of visual observations made during regular inspections of pit walls play a very important part in building up a history of ground behaviour for assessment of pit wall conditions.

If any signs alluding to incipient pit wall failure exist, visual monitoring will need to be supplemented with more frequent, accurate, and/or wide spread monitoring, using a variety of one or more instrumentation methods. Considerable judgement, experience and technical support are required for the selection, location, operation and maintenance of some of the more advanced monitoring equipment.

Monitoring techniques

In open pit mining, the most common monitoring technique used is one of several forms of displacement monitoring. A wide range of displacement monitoring equipment and techniques has been used by the mining industry to assess the condition of pit slopes. Some of the more commonly used include:

- Survey techniques (e.g. EDM and GPS leveling or photogrammetric surveys);
- Displacement monitoring pins and tape extensometers fixed across cracks or major rock defects; or
- Borehole inclinometers; and
- Extensometers anchored within the **rock mass** via boreholes drilled into pit slopes.

In some conditions, e.g. in deep open pits that mine through underground workings, seismic monitoring can be used to detect changes in the performance/condition of the pit walls.

It should be noted, when monitoring dilation of tension cracks, that tension cracks may propagate in series from the slope crest outwards and that the selection of both the pit wall area to be monitored and the appropriate displacement monitoring method should take this into account. It should also be noted that survey monitoring has some inherent error, which can vary due to a number of parameters such as diurnal effects, dust, vibration and installation problems. Pit walls will also invariably move elastically, once the overlying material is removed. The amount of elastic movement that will occur will largely depend on the elastic modulus of the material, and the magnitude of confining pressure removed by mining (a function of density and depth). Every effort must be made to minimise or quantify the effects of these variables so that wall monitoring will provide meaningful results. Pit slope survey monitoring procedures have been described in several publications. It is expected that a mine will employ a recognised method of monitoring that provides a suitable degree of accuracy.

In critical areas, it is recommended that monitoring systems be installed with warning devices attached (e.g. a horn, or flashing light). The preferred method for setting off alarms is to use a monitoring system that is compatible with a data logger with computational capability so that solenoid switches can be activated electronically once a specified rate or amount of movement has been recorded.

It is strongly recommended that mines adopt a systematic approach to the collection, analysis and interpretation of geotechnical monitoring data as it applies to mine design. It is also recommended that the mine operator implement more than one of these techniques in every monitoring program. This will help identify sources of error, and provide more information on the mode of failure from which the best course of remedial action can be established.

An important aspect of any monitoring program is the development of a monitoring strategy, which is implemented rigorously within the mine's **ground control** management plan. The strategy should define the monitoring schedule, the time allowed and methods used for data recording, interpretation and reporting, and provide basic courses of action to be taken in the advent of signs of impending pit wall failure. It is essential that the monitoring data collected is correctly assessed and the results and recommendations passed on to the relevant operations personnel at regular intervals for assessment of the performance of pit walls.

The common approach is to graph the rate of movement of a pit wall. Imminent failure is expected when this plot becomes "asymptotic". Again, the judgement of the onset of asymptotic movement will be based on a well founded geotechnical engineering assessment.

The course of action to be taken by the mine operator once asymptotic rates of movement are noted will depend on the circumstances prevailing at a given mine site.

Selection of an appropriate monitoring method

In implementing an appropriate monitoring system as outline above, the following criteria should be considered in respect of the surface mining operation:

- The cost per unit of monitoring equipment, e.g. the cost of using a surveyor, already employed at the site for general volumetric definition can be argued to be nil, and the only real cost is survey prisms.
- Time taken to get the raw data, e.g. if simple crack monitoring methods take too much time to access and measure, it could be necessary to employ additional personnel, or other work may have to be delayed.
- Required accuracy levels, e.g. if it is required that the exact source/extent/depth of the movement in the slope be known for stabilisation, it could be necessary to install expensive borehole extensometers/inclinometers. If, due to inexplicable or inherent errors, there is excessive deviation of results, other methods must be used.
- Robustness – mine dust, or vibration, excessive heat, or fly rock may create problems for the instrumentation.
- Time taken to process the raw data. If the format of the required information, e.g. movement rates, cannot be provided to the appropriate personnel with enough warning, other methods should be used.
- Site access. If berms have been "lost" or the site is remote from the mine site office, automatic monitoring systems become more viable.
- Vision. If there is a requirement that monitoring continues through the night, EDM survey or visual monitoring is not practicable.
- Training or specialist personnel requirements and associated costs, e.g. contract labour used to either install equipment or treat data.
- Susceptibility to vandalism or theft. The monitoring system needs to be easily securable.

2.8 Mining through underground workings

Mining through underground workings presents a number of potential **hazards** that must be accounted for in the mine design. A range of mine planning related geotechnical issues must be investigated, including:

- Definition of the extent and status of the underground excavations (e.g. use of probe drilling to locate the mine voids, determine whether underground mine voids are filled or partially collapsed, and/or whether the underground voids encountered in the base of the open pit equate to those shown in the mine plans of the underground workings).
- Definition of the minimum pit floor **pillar** thickness such that mining equipment and personnel can safely traverse during normal mining operations.
- Determination of the likely stability of ground at the edges of underground voids to minimise the **risk** to personnel or equipment working near underground voids – particularly near unfilled stopes.
- Determination and potential for not holing of surface during caving operations beneath an open pit.
- Determination of the safe thickness of "rib" **pillars** left between open pit walls and underground workings to ensure continued stability of the pit walls.
- Definition of infilling and barricading procedures (where required).

It is the responsibility of the employer to ensure that safe working procedures, that address each of these issues, are formulated and rigorously followed. The implementation of these procedures should be incorporated as part of the overall mine **ground control** management plan.

3. GROUND SLOPE MANAGEMENT PLAN

It is suggested that a ground slope management plan be produced for a mine using a combination of professional expertise; for example geotechnical engineers, surveyors, geologists, miners, and mining engineers. The ground slope management plan should be critically reviewed at least six monthly, or more frequently if necessary, to highlight and correct any areas of deficiency noted by geotechnical monitoring and variations noted in general mine performance.

An effective ground slope management plan should be applied to the life of the mine. Development of the ground slope management plan may be facilitated by the use of qualitative risk assessment techniques. These techniques can assist in identifying the high **risk** aspects of a mining operation and develop a range of appropriate controls to effectively manage the **risks**. A range of geotechnical and **risk** assessment expertise is available in a variety of organisations such as mining companies, geotechnical consulting companies, **risk** assessment companies, research organisations and universities. The successful implementation, review and, where necessary, modification of the ground slope management plan is the responsibility of the employer.

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

The ground slope management plan should recognise the importance of developing a mining culture in the workforce that understands the vital importance of the rock mass, as well as the people and equipment to a viable mine. This is best achieved by establishing a team approach to ground control management, possibly involving the whole workforce. Failure to recognise the important role of the rock mass, at all scales of mining, can result in unsafe and unproductive mining.

4. HAZARD RECOGNITION

It is obvious that the level of exposure of the workforce to potentially hazardous conditions will govern the occurrence of injuries and fatalities at a mine site. It is also obvious that in order to reduce the level of exposure to hazards, a system must exist whereby **hazards** can be systematically recognised/identified and managed. This system of **hazard** recognition and management (in this case **ground control hazards**) should be incorporated within the overall mine plan. The implementation of an all-encompassing mine plan presents a major challenge for the employer. A sound understanding of the ground conditions is vital for the selection of the most appropriate mine design, mining method(s) and **risk** management for a new or existing mining operation. The level of **risk** in health and safety as well as economic terms, will be substantially increased if the ground conditions are not sufficiently well understood.

4.1 Mine design criteria

It could be said that all excavated pit walls have potential for failure. The acceptability of any given failure will depend on its consequence/s. If the failure of a particular slope is deemed to have no bearing on the surrounds, or the safety and production of a mine, it is likely to be of limited concern. However, as pit wall failures usually do have an impact on their surrounds, mine slopes need to be designed to an acceptable standard, taking into account the consequence/s of failure and the inherent uncertainty in the geotechnical model used as the basis for the pit wall design. Therefore, pit wall design is essentially governed by two factors:

- The consequence/s of failure; and
- The degree of inherent uncertainty.

To accommodate these two design factors, it is normal practice to apply an appropriate factor of safety (FOS) and/or probability of failure (POF) to the design geometry of the pit wall. These design criteria provide a margin of conservatism to the pit wall design that is in proportion to the apparent **risk** of failure. When the consequence of failure and/or the level of uncertainty are high, the design criteria should be raised accordingly (resulting in a more conservative pit wall design).

The design must take into account the consequences of pit wall failure at the specific mine site. Secondly, the geotechnical data and modeling methods used to design pit walls, must be of an adequate standard to suitably represent the **rock mass** (to attain an acceptable level of geotechnical uncertainty) and discontinuity patterns for the perceived consequences of failure.

It is therefore a prerequisite that significant mining experience and judgement is required to design the geometry of open pit walls.

An example of justification of the use of a particular criteria; is the use of good quality site-specific case history data of wall performance in identical geological conditions to verify the proposed design. In conjunction, the employer should implement a well-matched pit wall monitoring program to verify the as-mined performance of the pit walls during the life of the mining operations.

It is important to recognise that ground conditions can change during mining and that the level of geotechnical uncertainty is dependent on a number of factors that are not directly attributable to “standard” rock mass properties, including:

- Loosening of the **rock mass** due to blast or seismic vibrations.
- Alteration of properties of some rocks on exposure to air or water over time, e.g. slaking, pore water pressure variations.
- Variable time-dependent behaviour of **rock mass** under static loading.
- Quality of excavation and sudden changes in wall geometry, e.g. poor blasting or the formation of a “bull-nose” promontory along the wall.
- Localised variation in stress, e.g. stress reduction or increase in pit wall **rock mass** near the side-walls and **pillars** associated with large underground stopes.
- Surcharge loading – e.g. waste dumps close to pit crests, or mining into the side of a steep hill or mountain.

Should any variation from the “assumed” geotechnical design parameters be detected during mining, a reassessment of the pit wall design is required. Therefore, the mine plan must be sufficiently flexible such that changes in wall design, where required, be accommodated as easily as possible.

In summary, the final pit wall design will need to be verified by appropriate geotechnical methods, taking into consideration a **risk** assessment; that includes all the parameters relevant to the stability of that particular pit wall and the safety and profitability of the operations. The scale and scope of geotechnical investigation required for pit wall design would be greater when the mine site **geology** is complex (when the level of geotechnical uncertainty is high) and/or the consequences of failure are significant.

The employer must therefore ensure that the standard of geotechnical data and design criteria used to design open pit walls are suitably matched to the scope of the project.

ANNEX 2

THE ENVISAGED ROLE, FUNCTION AND CONTRIBUTION OF EFFICACIOUS ROCK ENGINEERING SUPPORT SERVICE

(This annex to be used for information/reference purposes only)

1. PURPOSE

The purpose of an efficacious Rock Engineering Support Service (**RESS**) is to assist the employer in ensuring that **rock mechanics** principles for the safe and economic design of mine workings, is applied.

The **RESS** should assist the employer with the proactive identification of significant rock-related **hazards/risks** and to advise on appropriate measures to treat such **hazards/risks** before persons are injured or workings damaged.

2. ENVISAGED BASIC SUPPORTIVE FUNCTIONS AND DUTIES

To achieve the purpose of an efficacious **RESS**, the **RESS** must provide a basic supportive role, function and contribution as follows:

2.1 Participate in planning activities in order to identify and evaluate all layouts and face positions to determine any potentially dangerous or damaging situations created by, or likely to be created by, mining operations.

2.2 Review, identify and make recommendations to management with regard to systems, procedures and techniques employed by the mine to reduce or eliminate **rock fall hazards**.

2.3 Establish an efficacious monitoring, recording and reporting systems, which will ensure that relevant information is timeously provided to the correct people in planning and operating functions.

3. PARTICIPATION IRO PLANNING AND DESIGN ACTIVITIES

The **RESS** should participate/assist/make the following contributions to the rock excavation and design processes/activities:

3.1 Assist with the design of orebody excavation layouts, which will provide conditions conforming the requirements of affected relevant authorities with regard to surface structures.

3.2 Design/propose efficacious mine **support** systems.

3.3 Assist in the selection of the most appropriate orebody excavation processes, techniques and accompanying **support** system for prevailing conditions by applying a best practice rock-engineering assessment to ensure that the desired level of stability of excavation are maintained throughout the required operations time horizon.

3.4 Advise on efficacious **risk** management strategies to treat significant rock-related **hazards**/**risks**.

3.5 Advise on the use of control, **support** of pit slopes at the mine as required for stability purposes.

3.6 Advise on the location, shape, damage prevention measures and **support** of all excavations to ensure stability throughout the excavation's active life as required.

3.7 Evaluate and advise in respect of rock excavation processes, sequences and plans so as to ensure, as far as reasonably practicable, that;

3.7.1 the probability of **seismic events** is minimised or controlled;

3.7.2 the factors affecting the stability of excavations outside the orebody are taken into account; and

3.7.3 **support** systems perform to the specified design criteria under current and anticipated rock-related conditions.

4. SEISMIC MONITORING, ANALYSIS AND DAMAGE CONTROL

The **RESS**, assisted where necessary by competent persons using appropriate seismic monitoring equipment, should monitor, analyse and interpret incidence of seismicity and advise on damage control measures;

4.1 to the employer on a efficacious strategy to treat the incidence, for inclusion in the mine’s Mandatory **COP**; and

4.2 on mines or sections of mines, to perform a periodic detailed hazard identification and **risk** assessment of the whole mine, focussing on sequencing or phasing of the extraction of the orebody in such a manner as to ensure that they can be mined out without significant **risks** to persons involved with such excavations.

5. ROUTINE MONITORING AND SPECIAL INVESTIGATIONS

The following roles, assistance and inputs are envisaged for the **RESS** in respect of routine monitoring and special investigations:

5.1 regular monitoring of the performance of **support** systems to ensure that they conform to specified design requirements;

5.2 regular inspections of production and service workings to detect abnormal conditions and departures from the planned layout;

5.3 regular inspections of critical slopes during the excavation, to ensure adherence to the designed excavation sequence installation of permanent **support** as required;

5.4 where a significant potential for instability of pit slopes exists, regular monitoring of displacements and, in particular, on fault plane and/or shear zone intersections;

5.5 investigation of unusual ground conditions, report findings and recommendations regarding remedial action;

5.6 appropriate participation in/assistance with the investigation of all rock and **slope instability**-related accident/incidence, inclusive of the completion of the **rock engineering** aspects in a report; and

6. QUALITY ASSURANCE IRO SUPPORT SYSTEM/ELEMENTS

The **RESS** to advise the employer in respect of an efficacious quality assurance system for the **support** elements/system as well as the slope management plan used at the mine.