AUSTRALIAN CENTRE FOR GEOMECHANICS
CSIRO | Curtin University | University of WA Joint Venture

Volume No. 29 December 2007

AUSTRALIAN CENTRE FOR GEOMECHANICS
NEWSLETTER

What's in this volume?

Mine planning – its relationship to risk management ... 1
Rock Mechanics Symposium ... 8
Time dependent deformational behaviour of unsupported rock slopes ... 9
Canadian and Australian ground support practices ... 12
Mine Closure 2007 and 2008 ... 16
Tailings – from concept to closure ... 19
Paste 2008 ... 23
ACG 2008 event schedule ... 24

Mine planning – its relationship to risk management

By Oskar Steffen, corporate consultant, SRK Consulting, South Africa

Mine planning is a typical engineering design function which integrates the geology, metallurgy, geotechnics, mining and economics disciplines

Introduction

Mine planning is a typical engineering design function which integrates the disciplines of geology, metallurgy, geotechnics, mining and economics. The numerous uncertainties associated with geological understanding, the exposure of people to potential hazards in the workplace and the need to provide a specific dollar outcome, requires a proper assessment of the risk. This article addresses the use of a risk criterion into the design of a mine to ensure a pre-defined level of risk to the mine. This process is therefore not a 'risk analysis' or a 'risk assessment', it rather should be referred to as risk based design.

There seems to be a trend developing in the last five years of mining projects not meeting their targets in terms of cost escalations as well as time overruns. This can probably be attributed to the economic upturn in the minerals industry worldwide and the pressure of delivery schedules with a shortage of skills to satisfy the demand. The greater incidence of major slope failures in open pit mines in recent years also testifies to an increased appetite for risk to maximise economic value in the operation.

The common thesis within the financial community is that greater rewards are possible when a higher risk is tolerated, which therefore establishes the risk/reward relationship. In the case of mining enterprises, the consequences could be safety of personnel, financial or company image. For quantitative evaluation, risk is being defined as the product of the probability and the consequences of an event, i.e. Risk = P(Event) · (consequence).

Reliability of a risk assessment process is a function of harnessing all available information in a structured manner. Experience and knowledge is an important

Continued page 2

Continued from page 1

information source and is compiled from group workshops and is probably the most reliable data to be fed into the risk analysis process. The "Delphi Method"(1) is one such process and relies on a "panel of experts". Results of qualitative processes are normally presented in a risk matrix format, either as block diagrams of likelihood versus severity, or in the form of bubble charts as shown in Figure 1.

Sources of risk

Figure 2 shows a fault tree for a typical large copper mine. Each of the blocks contains uncertainties that contribute toward the probability of not achieving the output target, defined as the top fault: not enough copper. Using the range analysis technique, the likelihood is determined of not achieving or over achieving the target production. Risk is the measure of under achieving while opportunity is the measure of over achieving.

This article is specifically focussed on risk associated with the mine planning aspects only, but Figure 2 illustrates the context within the overall mining business.

Technical and management risks

The fault tree in Figure 3 illustrates the sources of risk associated with the mine plan. Technical risks are largely associated with the uncertainty in data and assumptions in design parameters and arise when the geological model does not predict the mineral resource within acceptable accuracy, the geotechnical model does not perform as required, or the mine plan turns out to be over optimistic. All of these technical risks can be evaluated quantitatively, mitigated pro-actively and the mine plan adjusted to satisfy management's risk criteria.

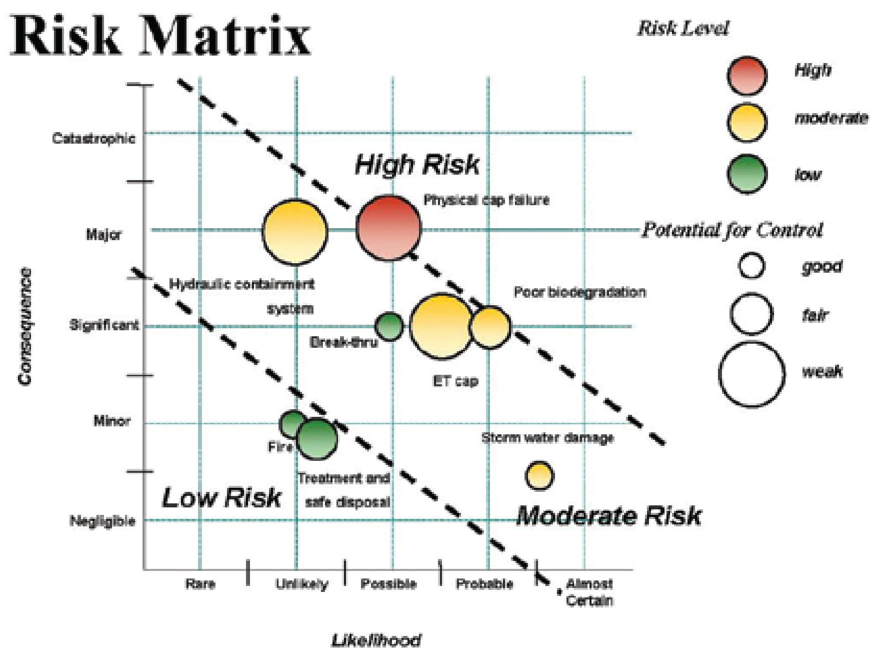


Figure 1 Bubble chart of risk representation of a waste containment facility

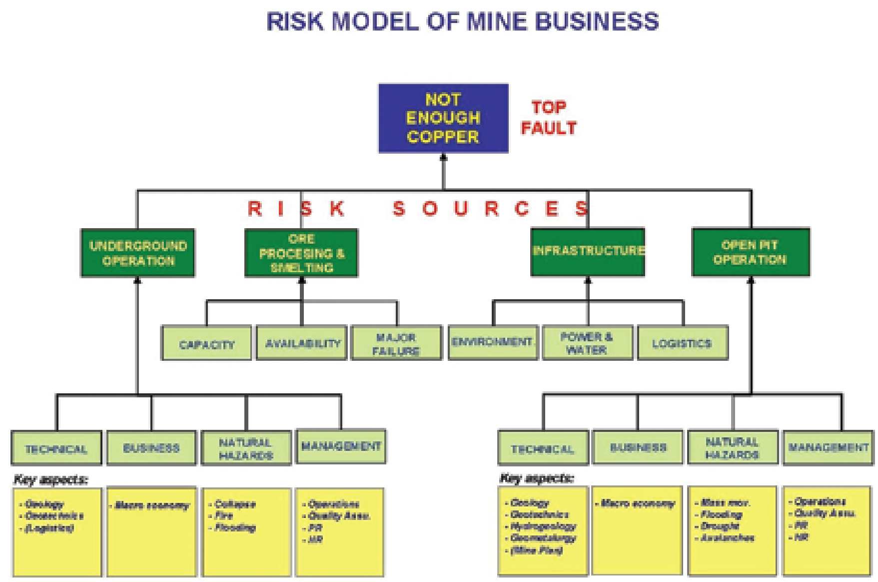


Figure 2 Fault tree for a typical large copper mine, identifying the sources of risk

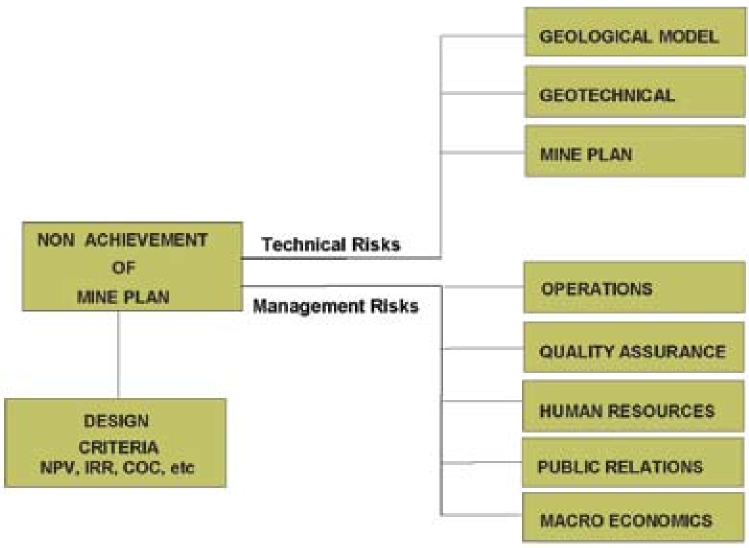


Figure 3 Risk sources within the mine planning function

Management risks are mostly associated with the personnel skills, training programmes, investor interests and macro economic scenarios. These risks arise when operational standards are not up to required expectation, QA/QC of operations and reconciliations to actual performance are not carried out diligently, sensitivity to HR issues are not handled correctly and communication is poor, investor needs are put on the backburner and reporting standards are lacking.

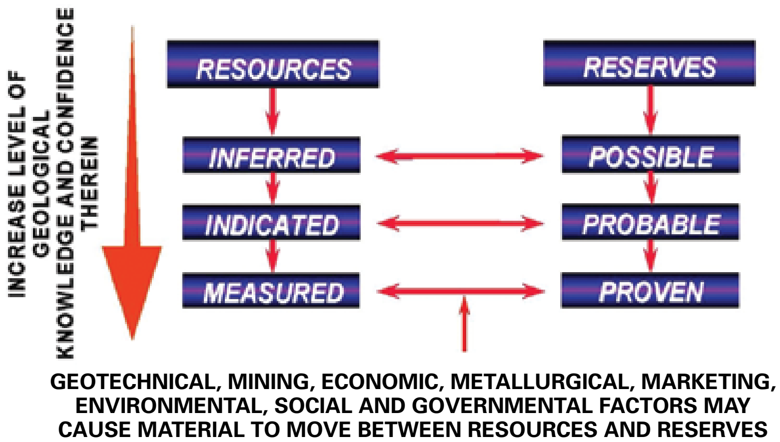


Figure 4 Mineral resource and ore reserve classification according to JORC

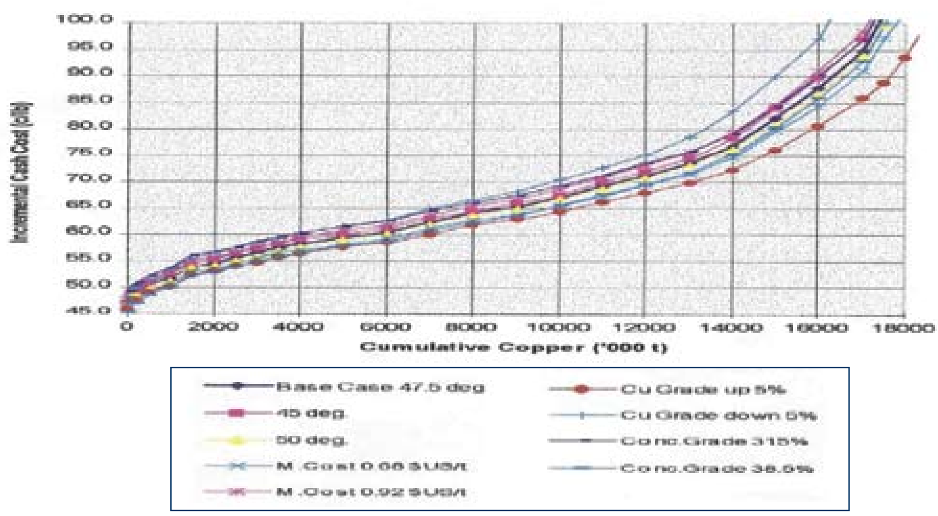


Figure 5 Marketability curve for a typical copper porphyry

Mine planning

One of the most difficult decisions for a mine manager to make is to define how much information is enough to proceed with the mine plan. Mineral resource geologists have overcome that problem by adopting a code (JORC or SAMREC) for defining the different levels of confidence into Measured, Indicated and Inferred. These classifications are presented in Figure 4.

To convert mineral resources to ore reserves all the modifying factors as listed at the bottom of the figure, need to be known at the same level of confidence as the resources to obtain a balanced design. This provides the standard by which all information should be judged and therefore also defines the data requirement for each of the modifying factors.

The definition of ore inventory, erroneously referred to as pit optimisation, is the first step in the design process. Having determined the level of confidence required for the particular stage of design as discussed above, the inventory of economic ore is determined by using the Lerch-Grossman algorithm or the floating cone method. An important output from this design process is the marketability curve shown in Figure 5.

Since the optimisation process is based on incremental prices, only profitable ore within the particular price limit is defined as ore. This process is therefore effectively a marginal cost analysis of the orebody, from which Figure 5 can be derived.

Macro economic parameters such as price forecasting, exchange rates, royalty and taxes etc. are not usually the responsibility of the planning engineer, but belong to the boardroom. Information on which these decisions are based should be provided to the board by the planning engineer, e.g. a minerals balance sheet(3) (MBS) which would include the marketability curve for the mineral resource. A typical example is shown in Figure 5.

This curve represents the competitiveness of the resource within the supply market, when compared to the world producer cost curve. Figure 5 also presents the sensitivity of the resource to key uncertainties such as grades, slope angles and costs.

Concept of the business risk period (BRP) has been discussed by Steffen(3). In mining, as in any other business, time is an important ingredient in the risk exposure. The period of time over which a mining company is prepared to risk operating capital in developing the mineral resource has to be a conscious decision for that capital can only be retrieved from the ore to be mined from that development. In the case of open pit mines, pushbacks in deep open pits can take up to 10 years to complete. There has to be a level of confidence and risk that the development is adding value. The BRP effectively becomes the period of the business plan, because investments have to be made for that period. Business plans are therefore not arbitrary time intervals that appear convenient to accountants, but based on real business principles of risk and return.

The volume variance characteristic of the orebody is the most important parameter from which the mine plan can be optimised. This characteristic determines the volume of ore to be exposed and the number of ore operating faces required to maintain a constant feed to the plant. Plant sensitivity to short-term changes in feed needs to be addressed with a suitable stockpiling strategy. Effectively, this defines the logistics of the mining operation.

Expansion optimisation is key to the efficient operation of the mine. A tradeoff between narrow pushback to minimise waste stripping and increased productivity in wider pushbacks has to be evaluated. There is little reliable data on productivity of equipment in relation to bench height, pushback width and length and access geometry. These decisions are mostly taken on personal experience and preferences. Some useful tools have been developed to assist the planning engineer in this regard, e.g. COMET software. This part of the design process is best assessed by carrying out a quantitative risk assessment on alternative layouts, since the input parameters are not certain.

Slope angles are a key economic and risk parameter in open pits with high stripping ratios. Small changes in angles can provide large economic benefits, but can also determine the limit between stable and unstable slopes. Since the objective of mining is to maximise the value, steepening the slope angles to their limits are always under scrutiny. This is a clear case of evaluating risk against reward, where risk is not the failure of the slope, but the consequences of a failure. The author is of the opinion that slope failures are acceptable in open pit mines, provided that the consequences have been properly managed.

Ramp layout is another important consideration in the mine plan. Common perception is that single ramps save overburden stripping. This is probably true in small open pits, mined in very competent rock. It is also a truism that single ramps constitute the highest risk to the operation due to the potential of failure. Mitigation would be to design the slopes flatter, increase the width of the road or providing a second access road. When evaluated on a risk basis, a dual ramp system could be preferred as the slope angles could be increased to that of the single ramp design without changing the risk, or could even improve the risk exposure and improve truck productivity. Dual access is also preferred when haul routes traverse the slope below an operating pushback due to the rill (overspill) problem.

Ramp location within the pit walls can also be optimised when considering the relationship between the P(F) versus slope angle for the different geotechnical domains and slope orientation.

Production rate from a mining area is determined by the operating footprint and the bench height. These parameters constrain the rate of vertical advance that can be achieved for the particular orebody. In wet climate zones, it is further restrained by the capacity of the sump for the duration of the wet season. Again ,there is little reliable data that can be used to guide planners to schedule production rates for these situations. Mostly they are estimated from experience and mining simulation models.

Risk evaluation

Review of mining plans are complex for it inter-relates many activities into a single outcome. The reviewer is expected to pronounce if the plan is achievable in practice and what the risks are associated

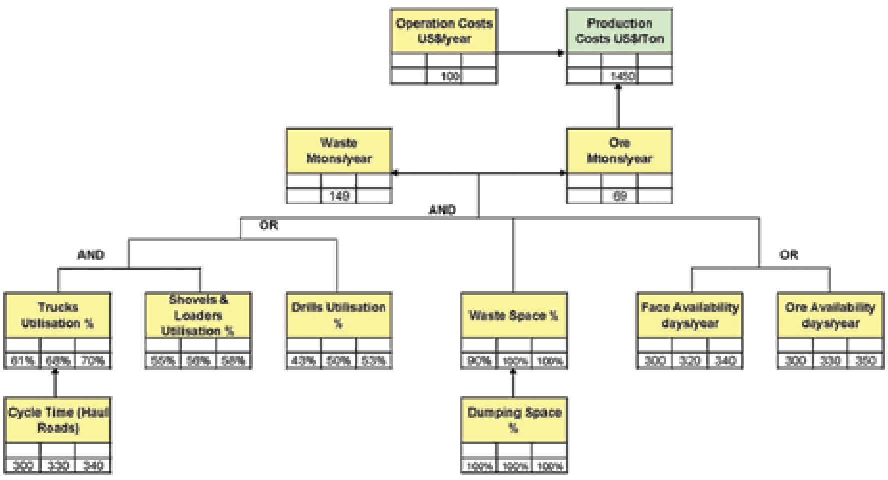


Figure 6 Typical logic tree

with the plan. More often than not, different reviewers will express opinions in terms of high, medium or low risk. While subjective opinion can never be totally eliminated from the process, a methodology is required that would address all the same variables and provide a suitable ranking to each.

The methodology used is based on the decision tree process. The structure of the decision tree simulates the mining process and dependent and independent variables are identified. A typical result is shown in Figure 6.

In this modelling process, subjective assessments are made of the range of values for each input variable, with credible lower and upper values. The modelling process also identifies the most sensitive parameters affecting the distribution of outcomes, allowing these to be investigated further.

Invariably the NPV is the most common criterion for adjudication, but since the mine planning function is largely aiming to minimise the cost, the net present cost is often used as a closer estimate of the efficiency of the mine plan, or the profile of operating cost per ton RoM. The question that still remains is: what is an acceptable confidence level of achieving the criterion, say NPV. In normal operating practice, it would generally be accepted that a plan should deliver within the 5 to 10% accuracy of cost, corresponding to a confidence level of 90 to 95%. The author is of the opinion that no single criteria can define the true value of any mining plan. For that purpose a comprehensive criteria has been suggested[3] as follows:

Comprehensive economic criterion for mining operations in order of importance:

1. A reasonable return to shareholders, i.e. a dividend in line with shareholder expectation for the sector of the market in which the mine competes.
2. Risk: A competitive cost profile with respect to the world producer cost curve.
3. Optionality: provide sufficient flexibility within the mine plan to utilise opportunity and mitigate against low prices in the future.

Maximise economic value in terms of NPV, IRR etc. only after the previous three components have been satisfied. These values should be accompanied by a statement of confidence, expressed as a percentage.

Prediction of slope performance has replaced the mineral resource models as the greatest risk factor due mainly to the lack of sufficient geotechnical data

Risk mitigation

The major risk mitigation factors available to the mine planning engineer are flexibility, option creation, the adoption of a business risk period and the use of tools like the mineral balance sheet.

Flexibility translates to availability of ore. Most mining plans incorporate a policy of minimum ore exposed at all times to cover the short-term requirement of ore delivery to the processing facility. There is clearly a cost associated with the provision of buffer stocks within the pit and the optimum tonnage provided can be evaluated in economic terms. Normally these are based on the ore circuit only, and ignore the risk associated with a shortfall in waste stripping.

Option creation is a larger version of the above flexibility. It is again developed by providing greater ore availability but not necessarily in the immediate short term. It encompasses advanced stripping to the extent that within a one year period, equipment can be redeployed and additional ore made available for increased metal production by changing the cog policy. The reverse scenario is when costs need to be lowered, stripping can be reduced without affecting the ore output to the plant. This degree of flexibility comes at a cost greater than that for normal operational flexibility, but adds additional value that can be quantified in terms of option valuation theory and therefore adds to shareholder value.

Adoption of a business risk period limits the investment exposure of the mine to a defined period, which can be repeated regularly through out the period of the mine life.

The minerals balance sheet has been discussed in detail in 1997 by Steffen(3) in detail. It is a communication form that allows decision makers from different backgrounds to synthesise the value and risks associated with different ore deposits. It is a form of data presentation that facilitates strategic process.

Risk: reward

Within the mining operation there are a number of different areas in which the acceptance of additional risk results in increased rewards to the mine and visa versa. These are areas that should be actively evaluated and presented to decision makers, for it represents the corporate view on tolerability of risk. These areas are the ore exposure, stockpiling strategy and slope design.

Ore exposure focusses on short-term ore supply to cover normal operational interruptions.

Stockpiling strategy is tied closely with the cut-off grade strategy and addresses the utilisation of the mineral resource. It therefore also impacts on the total value harnessed from the resource and is linked to the future commodity price scenarios. Stockpiling is the main risk mitigation strategy available to planning engineers to manage uncertainties to the ore flow. Cost of the stockpiling strategy can be determined from the volume variance characteristics of the orebody as previously described, and the benefit is determined from the improved recoveries obtained in the process plant due to a constant quality ore supply. Many examples exist of mines gaining big benefits from improved stockpiling strategies.

Categorisation of slope design confidences as per the classification of ore reserves will provide a basis of information requirements to meet the required confidence in the ore reserve definition. The risks to reserves are therefore compatible with that of the mineral resource. This assumes that the metallurgical information on processing costs and recoveries are at the same level of confidence, using the same classification basis. Benefits of the process result from planning the exploration campaign to obtain the correct amount of information to satisfy the classification of the resource model.

Consequences of slope failures can be expressed in terms of fatalities, economic impact of minor to medium scale and major catastrophic impact requiring a force majeur declaration. Consequences may also result in worker reactions to unsafe working conditions and investor reaction to unexpected design failures.

The most difficult criterion to accept for miners is that of fatality. All mining companies have a mission statement of zero tolerance for fatalities. "There is no such thing as nil risk". This is not reasonable, but also not necessary as there are many codes in engineering that stipulate the design criteria for fatalities that are acceptable. These criteria are related to the incidence of deaths due to natural causes, expressed as annual lifetime probability of death.

Value optimisation

Utilising the methodology of option valuation as applied to alternative mine planning options is a convenient application for optimising the value of a mine plan. As mentioned previously, the options revolve around the degree of flexibility that is introduced within the mine plan at a measurable cost, for opportunities to be exercised at a later date, valued using option theory. The most commonly used methodology is the Black and Scholes model used in financial option markets. This process effectively allows the planning engineer to maximise the value by introducing a range of the degree of flexibility.

In open pit mines where the depth is governed by limiting costs compared to an underground mine alternative, the most tangible option to increasing value is by steepening the slope angles. This increase in value is accompanied by an increase in risk of slope failures. A clear optimisation process presents itself to the mine management that has to make the ultimate decision on the risk that they are prepared to tolerate. This requirement is specifically in contrast to the commonly accepted approach of management abdicating their responsibility of deciding tolerable risk levels under the banner of "we employ geotechnical engineers to advise us of these matters". The geotechnical engineer's competence extends to advising the manager of the quantitative correlation between slope angles and risks, but not to the business decision of "what risk is appropriate for the economic benefit gained for the shareholders".

Conclusions

Prediction of slope performance has replaced the mineral resource models as the greatest risk factor due mainly to the lack of sufficient geotechnical data. Groundwater understanding and predictive modelling has also become an increasingly important risk factor in mine design.

Future prices will always remain the major uncertainty and also a risk factor as there is little that can be done to control these in the present volatile financial environment. Capital and operating cost estimates have become increasingly more difficult to manage in the present boom environment.

Optimisation of cutback designs presents a major opportunity for improved returns. Similarly, introducing the volume variance statistic into the planning cycle presents a opportunity for value adding. In valuation terms, the use of option analyses to determine the value of introducing planned flexibility options into the mine plan will not only add value to a mining project but also reduce the likelihood of destroying value.

Unless the tolerable risk levels are clearly defined to the mine planners, the resulting risk exposure will be totally different to what the mine owners had in mind. From the mine planning and operations perspective, safety and economic risks can now be defined in specific terms to allow the planners to achieve the maximum returns for the stated risk levels.

Acknowledgements

The author is indebted to his many colleagues in client organisations and within SRK worldwide, who have contributed to developing the approaches mentioned in this article. There are too many to mention individually who have provided insights and thought provoking questions requiring solutions, but since they know who they are, my sincere appreciation to all of you.

Article references are available on request from the ACG. This article is based on the keynote address presented at the ACG's 2007 International Symposium on Rock Slope Stability in Open Pit Mining and Civil Engineering.

Oskar Steffen,
SRK Consulting

David Ortlepp tribute – farewell to an industry giant

By SRK Consulting

David Ortlepp, affectionately known by his peers as "Uncle Dave", was passionate about his interests of which rock mechanics was one. His enthusiasm for rock mechanics, and specifically rockbursts, stemmed from his desire to prevent the loss of life in deep level mining. It was this passion that drove him to observe, document and research the problem of rockbursts which, through many years of constant struggling with the challenge, led to his very valuable intuitive understanding and insight.

David Ortlepp

His book entitled "Rock fractures and Rockbursts – An illustrative Study" serves as an example of his powers of observation and keen drive to understand the mechanisms of rockbursts and fracture propagation, which he took to a level of detail that few could imagine.

In the last couple of years Dave's passion for saving lives led him to the designing and testing of not only yielding support units but complete support systems. Dave recognised the deficiency in the industries available ground support testing facilities, with regards to testing support systems, and designed and constructed several mesh and bolt drop test facilities and a tabular stope support test facility.

Dave was a mentor to many of his peers and he gained great pleasure from explaining his observations and teaching people what he had learnt over a wide range of subjects and instilling some of his passion in the process. Of all his achievements the one that stands out above all is that, even though he sometimes grew tired of it, he never stopped asking those difficult questions that he knew needed answering.

Dave's contribution to rockburst research and understanding shear fracture propagation will only be realised in the years to come. Dave will be remembered as a very kind and generous man who always had time to pass on his knowledge.

Dave was a mentor to many, particularly in the field of rock mechanics

Ground Control Group of Western Australia update

More than 20 people attended the Ground Control Group of WA meeting that was held at the Western Australian School of Mines in August 2007. Traditionally, GCGWA meetings were restricted to underground and open pit mining engineers. The afternoon session of this meeting provided consultants and suppliers with an opportunity to join with mine site personnel to discuss industry's wants and needs. John Player, Ken Mercer and Richard Varden gave presentations on crown pillars. The next GCGWA meeting is likely to focus on shotcrete. The meeting will be held in Kalgoorlie in February 2008.

Mine training departments are encouraged to view the GCGWA membership as a means of advancing staff development through networking and interaction with peers from other sites. Please contact GCGWA chair Richard Varden via rvarden@barrick.com for more details.

SHIRMS 2008

1st Southern Hemisphere International Rock Mechanics Symposium

ACG AUSTRALIAN CENTRE FOR GEOMECHANICS
CSIRO | Curtin University | University of WA Joint Venture

CSIRO

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

THE UNIVERSITY OF WESTERN AUSTRALIA

16 – 19 September 2008, Sheraton Perth Hotel, Perth, Western Australia

The ACG, in collaboration with The University of Western Australia, the CSIRO and The University of Newcastle is excited to host the First Southern Hemisphere International Symposium on Rock Mechanics (SHIRMS) in Australia next year.

Following the North American Rock Mechanics Symposium "NARMS" model, recently re-badged the Canada-US Rock Mechanics Symposium, we aim to create a similar forum in our part of the world, involving the very active South American, African, Asian, New Zealand and Australian rock mechanics communities.

The Symposium co-chairs are: Dr Yves Potvin (Australian Centre for Geomechanics), Professor John Carter (The University of Newcastle), Professor Arcady Dyksin (The University of Western Australia), and Dr Rob Jeffrey (CSIRO Petroleum).

SHIRMS will feature four main technical themes:

- Mining rock mechanics.
- Civil rock mechanics.
- Fundamental rock mechanics.
- Petroleum rock mechanics.

Some other fascinating areas of rock mechanics currently emerging in our region, such as geosequestration and underground disposal of nuclear waste material, will also be explored.

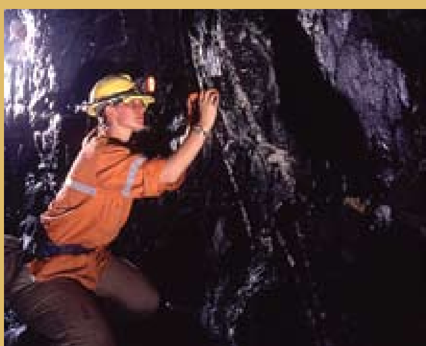
Keep abreast of event developments by visiting www.shirms.com

Key dates

Abstract submission	3 March 2008
Paper submission	26 May 2008
Rock Mass Workshop	15 Sept 2008
SHIRMS 2008	16 – 19 Sept 2008

Breaking news!

Dr Peter A Cundall will present a SHIRMS keynote address



SHIRMS' topics include: rock physics and geophysics, waste disposal, risk assessment, lab and in situ testing and stress measurement and stability and support of underground and open pit operations

First Southern Hemisphere International Rock Mechanics Symposium International Organising Committee

Yves Potvin (Co-Chair) *Australian Centre for Geomechanics, Australia*
John Carter (Co-Chair) *The University of Newcastle, Australia*
Arcady Dyskin (Co-Chair) *The University of Western Australia, Australia*
Rob Jeffrey (Co-Chair) *CSIRO Petroleum, Australia*
Younane Abouseliman *University of Oklahoma, USA*
Will Bawden *University of Toronto, Canada*
David Beck *Beck Arndt Engineering Pty Ltd, Australia*
Robert Bertuzzi *Pells Sullivan Meynink Pty Ltd, Australia*
Barry Brady *Condamine Engineering Consultants, Australia*
Andrew Bunger *CSIRO Petroleum, Australia*
Oliver Buzzi *The University of Newcastle, Australia*
Alan Bye *Sustainable Minerals Institute, Australia*
Emmanuel Detournày *University of Minnesota, USA*
Phillip Dight *Coffey Mining Pty Ltd, Australia*
John Dudley *Shell International Exploration and Production B.V., The Netherlands*
Andrey Eremenko *Institute of Mining, Siberia Branch, Russia*
Stephen Fityus *The University of Newcastle, Australia*
Klaus Gessner *The University of Western Australia, Australia*
Anna Giacomini *The University of Newcastle, Australia*
Chris Haberfield *Golder Associates Pty Ltd, Australia*
John Hadjigeorgiou *Université Laval, Canada*
Bruce Hebblewhite *The University of NSW, Australia*
Buddhima Indraratna *The University of Wollongong, Australia*
Antonio Karzulovic *A. Karzulovic & Asoc. Ltda, Chile*
Stanislaw Lasocki *AGH University of Science and Technology, Poland*
Peter Lilly *CSIRO Exploration & Mining, Australia*
Derek Martin *The University of Alberta, Canada*
Anthony Meyers *Rocktest Consulting, Australia*
Peter Mikula *Mikula Geotechnics Pty Ltd, Australia*
John Napier *CSIR, South Africa*
Alison Ord *CSIRO Exploration & Mining, Australia*
Zhihua Ouyang *Wuhan University of Science & Technology, China*
John Read *CSIRO Exploration & Mining, Australia*
Klaus Regenauer-Lieb *The University of Western Australia and the CSIRO, Australia*
Cameron Schubert *BHP Billiton, Australia*
Daichao Sheng *The University of Newcastle, Australia*
Scott Sloan *The University of Newcastle, Australia*
Dick Stacey *The University of the Witwatersrand, South Africa*
Iain Thin, *BHP Billiton, Australia*
Jody Todd *BHP Billiton, Australia*
Gerhard van Aswegen *ISS International Ltd, South Africa*
Michel Van Sint Jan *Pontificia Universidad Católica de Chile, Chile*
Terry Wiles *Mine Modelling Pty Ltd, Australia*
David Williams *The University of Queensland, Australia*
Robert Zimmerman *Royal Institute of Technology, Sweden*

Time dependent deformational behaviour of unsupported rock slopes

By Ken Mercer, senior geomechanics engineer, BHP Billiton

Introduction

Deformation has long been recognised as one of the most important parameters which define the state of rock masses. Deformational behaviour of excavated slopes and the failures that potentially result can be extremely complicated and up to now there have been no methods or models that have adequately addressed the range of behaviour that is possible during excavation of rock slopes in different geological environments. Recently, a research project was completed at the University of the Witwatersrand in South Africa, the principal objective of which was to develop a fundamental characterisation of the different components of time dependent deformation. In total, 30 literature case studies and 12 detailed international mining case studies were collected and 83 associated failure events were reviewed. The purpose of this article is to give a brief introduction to time dependent deformation behaviour of unsupported rock slopes developed from the findings of this research.

General overview of time dependent deformation

Time dependent deformation of geological features has been widely recorded and documented in the past. Descriptions of deformation behaviour have ranged from large scale valley rebound and up-warping of valley rims due to rapid erosion or glacier melting, deep seated continuous creep deformation of entire mountain sides, observed in the European Alps, rebound of excavations and foundations for large structures such as dams, to numerous small scale landslides and slope instabilities commonly associated with open pit mining. No two failure behaviours are ever the same and the characteristics of instabilities are highly site specific. The reason for this is that deformation and failure in fresh or hard rock slopes are controlled principally by structural discontinuities which are themselves site specific.

Jointed rock masses consist of both time-dependent as well as time-independent resistance to deformation. It is important to consider the relevance of the "time factor" in equating the potential reduction in the rock or joint strength within the time frame of the required active life of the slope. In this regard, the deformation of intact hard rock occurs over such a lengthy time scale in comparison to that of the limited required life of the slope that it can potentially be ignored. In contrast, the time dependent behaviour of discontinuities is considered significant where the creep deformation time potentially leading to failure can be well within the required length of slope life. It has also been shown in studies on the time dependent deformation behaviour of discontinuities that the magnitude of the peak and residual shear strengths of the joints are themselves time related.

The case studies confirmed significant similarities in the characteristics of rock mass deformation in slopes. It was shown that specific events, especially mining (blasting) and high rainfall are responsible for triggering a deformational response of a slope. Deformational response typically involves an initial sudden and rapid increase in the deformation rate which is termed the initial response. This is followed by a period of relatively rapid reduction or decay in the deformation rate of the rock mass, which is in turn followed by a long period of slowly reducing steady state creep.

Importantly, it was identified that the closer to failure the slope becomes, the more the deformational behaviour of the decay functions change. The decay functions start to take an increasingly longer time to recover and eventually a point in time is reached where the deformation rates of the unstable rock mass starts to increase in an exponential manner, until collapse occurs. This is termed progressive behaviour. Although differing in rates and magnitudes, the pattern of behaviour as described above tends to be reflected in slopes displaying completely different failure mechanisms. Post collapse deformation can range from complete disintegration of the rock mass to complex alternating progressive, and/or regressive behaviour, provided that the collapsed rock mass has maintained its integrity.

Generalised time and event dependent deformation behaviour model

A time and event dependent deformation model was developed which describes how deformation behaviour of an excavated rock mass may be presented using deformation pathways. The model accommodates five principal stages of deformation ranging from primary and secondary rock mass creep modes through the onset-of-failure to collapse and post collapse or post mining recovery deformation behaviour. A significant feature of the model is the provision of changing deformation rate decay functions as a slope progresses towards failure.

The model is illustrated as simply as possible by using the horizontal deformation pathway of a single hypothetical point on a continuously excavated slope, which eventually collapses. The conceptual deformation pathway for the point is plotted using a deformation time relationship, where the deformation can be expressed in terms of horizontal or vertical displacements or displacement rates. The deformation pathway in terms of horizontal displacement is illustrated in Figure 1 and in terms of deformation rate in Figure 2. Both figures should be read in conjunction with each other.

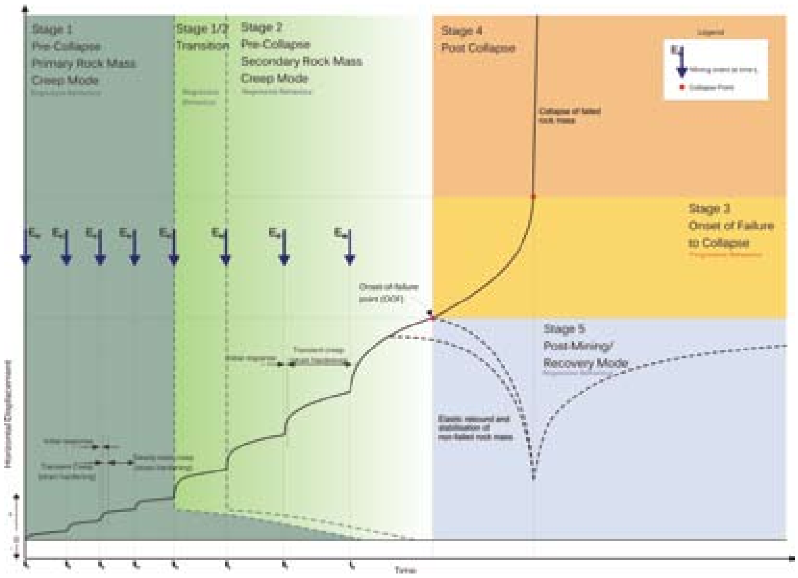


Figure 1 Generalised time and event dependent rock mass deformation model. An illustrative deformation pattern for horizontal displacement behaviour

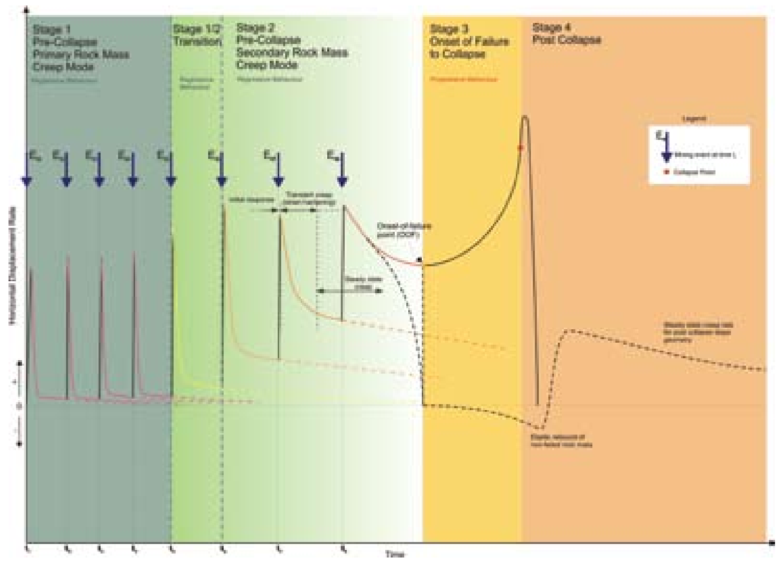


Figure 2 Generalised time and event dependent rock mass deformation model. An illustrative deformation pattern for horizontal displacement rate behaviour

Based on the evolution of slope behaviour leading up to the onset-of-failure, the pre-onset-of-failure deformation characteristics in rock slopes can be differentiated into two broad categories, which are principally concerned with the presence or absence of event driven deformation behaviour. Category 1 deformation behaviour is characterised by deformation that reflects a continuous period of specific, macro event (mining) driven, deformation behaviour prior to the onset-of-failure. In contrast, category 2 pre-onset-of-failure deformation can occur relatively quickly and can often be attributed to micro events, time dependent decay of strength parameters and/or crack propagation. Category 2 deformation behaviour typically occurs in the form of smaller, hard rock failures, which develop relatively rapidly as "hot spots" on the wall of open pits.

Time and event dependent deformation behaviour in the model can be characterised into five distinct stages of deformation behaviour as follows:

- Stage 1 : Pre-collapse, Primary Rock Mass Creep Mode
- Stage 2 : Pre-collapse, Secondary Rock Mass Creep Mode
- Stage 3 : Post-onset-of-failure to Collapse Behaviour Mode
- Stage 4 : Post-collapse Behaviour Mode
- Stage 5 : Post-mining/Recovery Behaviour Mode

The characteristic deformation behaviour of each stage is briefly explained.

Stages 1 and 2

Stages 1 and 2 deformation patterns encompass the time frame from initiation of excavation activities up until the onset-of-failure (OOF) or alternatively, excavation is completed. All the patterns for these two stages are characterised by regressive behaviour, i.e. deformation behaviour where failure (collapse) has not been initiated. In general, the deformation rates after each mining event for stages 1 and 2 are characterised by an initial acceleration spike, followed by a reduction in the deformation rate, which returns ultimately to zero. This overall reduction in the deformation rate is referred to as a deformation rate decay function and usually encompasses an initial (sudden) response, characterised by rapid acceleration, followed by a transient creep phase and finally a steady state creep phase.

The principal difference between stage 1 and 2 is that in stage 2, steady state creep deformation behaviour is no longer achieved within the time frame between events and therefore deformation is characterised by two phases. The average deformation rates associated with deformation decay (transient creep) remain increasingly higher for longer and longer. In effect the decay function changes from an approximated two stage linear function into a negative exponential relationship.

Stage 3

A deformation pathway enters stage 3 when the rock mass passes the OOF. This stage is characterised by a continuous acceleration in the magnitude of the deformation, and the deformation rate, of the unstable rock mass, up until the point of collapse. At the same time, the stable rock mass behind the failure mass starts to undergo a corresponding elastic rebound as shown by the dashed deformation pathway. The overall behaviour of the failure mass is termed progressive.

Stage 4

Post collapse refers to the behaviour of the rock mass after the deformation pathway crosses the point of collapse. The post collapse behaviour of the rock mass can be complicated but for the initial illustration, a classic disintegration of the rock mass is shown. The rebound (dashed line) deformation rate of the non-failed rock mass may follow a complicated seesaw pattern whereby the non-failed rock mass, after fully rebounding away from the failure then rebounds to a lesser extent back again in the direction of the failure, finally establishing a steady state creep rate corresponding to the new slope geometry, and similar to the steady state creep established after a mining event.

Stage 5

The stage 5 deformation behaviour of the non-failed rock mass usually relates to the stabilisation and recovery of the deformation patterns following mining or a failure. It is by definition a time frame where the rock mass is only influenced by time dependent behaviour set up during stages 1 to 4.

Alternative modes deformation behaviour

Deformation behaviour of rock slopes associated with different failure mechanisms can be expected to exhibit a considerable range of complexity and variation. For this reason a range of deformation pathways occurs, which can nevertheless still be accommodated in the model. This range is illustrated in Figure 3 and briefly expanded upon below.

In relation to stages 1 and 2 different failure modes and mechanisms influence the sensitivity of the rock mass and may cause a considerable variation in the deformation pathways.

Progressive deformation pathways starting from the onset-of-failure to collapse (stage 3) may show a considerable variation in time from almost instantaneous brittle failures which occur within minutes to hours, to failures that develop over a considerable time period. In the case of the latter, further mining events (cuts) are possible. A deformation pathway may also reflect near constant but high creep rates where normal mining cannot continue safely and which results in final collapse.

Post collapse behaviour patterns (stage 4) essentially describe the behaviour of the rock mass after collapse. In post collapse scenarios where the rock mass has maintained its integrity (i.e. not disintegrated), complex deformational behaviour of the collapsed rock mass can occur. Six principal post collapse deformation modes have been identified. These are;

1) Disintegration.
2) Partial recovery and gradual deceleration to creeping.
3) Full recovery, velocity almost completely stops.
4) Partial recovery followed by another final collapse.
5) Ratchet mechanism.
6) High creeping rate and probably accelerating.

Deformation modes may alternate between any one of type 2 to 6, in which case the overall mode is referred to as complex. The time frame this period encompasses can vary considerably especially in the case of creeping rock masses or ratchet mechanisms. The deformation pathways in Figure 3 illustrate that whilst entering this stage as progressive behaviour, deformation can change into regressive behaviour again, and can ultimately flip flop between regressive and progressive behaviour any number of times, depending on transient factors.

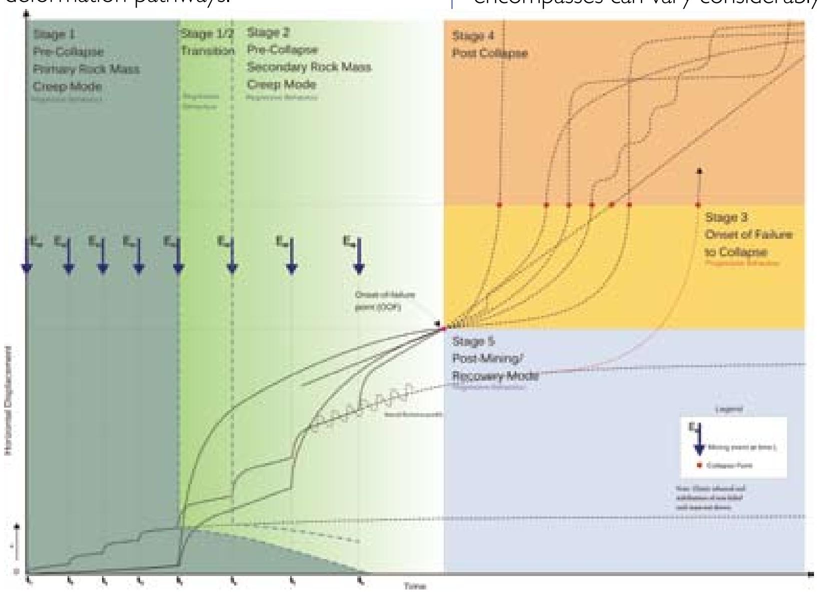


Figure 3 Generalised time and event dependent rock mass deformation model – modes of possible deformation behaviour for horizontal displacement

A post mining or recovery mode of deformation (stage 5) can be expected to be entered whenever no further mining events or collapses are influencing deformation behaviour. Long term stabilisation of the rock mass is expected however, eventual failure of rock is possible under constant stress conditions as a result of the phenomenon of the time dependency of the peak and residual rock mass strength parameters. Consequently, deformation pathways which show a transition from stage 5 back into stages 3 and 4 are considered possible.

Concluding comments

Time dependent deformational behaviour of rock slopes both during and after excavation can be extremely complicated. Up to now there have been no methods or models that have adequately addressed the range of behaviour that is possible for different slope configurations and failure mechanisms in different geological environments. This research project has significantly expanded the understanding of time and event dependent deformational behaviour of rock slopes and provided a basis for both the interpretation of monitoring results as well as forecasting of deformational behaviour. It is envisaged that ongoing development and application of the model will amongst other things, lead to the more accurate establishment of threshold limits for both deformation rates and magnitudes for use with all types of slope monitoring.

Ken Mercer,
BHP Billiton

Canadian and Australian ground support practices in high deformation environments

By Mike Sandy and William Gibson, AMC Consultants Pty Ltd, and David Gaudreau, BHP Billiton Nickel West

Introduction

Many Australian mining projects involve some exposure to low strength, foliated rocktypes, including ultramafics (especially talc-chlorite schists) and micaeous metasediments or metavolcanics. The pre-mining stresses in Western Australia's Yilgarn Craton are acknowledged to be amongst the most aggressive in the world. Stresses in Eastern Australia are comparable with the Canadian Shield. The combination of high stresses and weak rocks can result in adverse mining conditions.

The consequences of poor sequencing and layout in weaker rock materials can be severe, progressive degradation of development conditions associated with large deformations, which can lead to premature loss of access and reserves. In extreme cases, development closure of 30-50% has been experienced. This high-deformation style of ground behaviour has been observed in a number of Australian and Canadian mines.

Managing high deformation conditions has proved challenging. While there are various options for modifying the properties of support components to allow for large axial displacements, the significant shear displacements that are known to occur in the excavation walls are more difficult to accommodate.

Australian experience with high deformation conditions

The lead author's understanding of the mechanisms controlling deformation in foliated ground was initially based on observations at the Big Bell gold mine in the mid 1990s (Sandy and Player, 1999). At that time, the underground mine was being redeveloped, having closed in 1955. By chance, some of the new trackless levels were developed at elevations that allowed the backs of the old rail haulages to be scrutinised (Figure 1). This provided a relatively rare opportunity to examine the fracturing styles and intensity of stress-induced damage.

From these observations, it was clear that intense, stress-induced fracturing had developed above the backs of the haulage drives. Shearing on the stress-induced fractures had been accompanied by significant dilation or 'bulking'. The fractures had developed initially parallel to the drive backs, but then 'rotated' somewhat presumably as the failed ground had shed stresses deeper into the backs. Stress-induced fracturing had 'stabilised' once fractures had developed parallel to the local major principal stress (sigma 1).

The overbreak profile at a number of rockfall locations matched these observations, suggesting a similar mechanism of failure.

Offsets observed in blastholes drilled through the backs confirmed that significant shear was occurring on the stress-induced fractures. Similarly, shearing was observed in sludge sampling holes drilled in the ore drive hangingwalls and footwalls.

Observations at a several underground operations in Western Australia and New South Wales confirmed the initial model for ground behaviour, with some refinements. The common features of these operations were the presence of foliated or thinly laminated rocks of low to moderate strength and the existence of sub horizontal, elevated stresses at a high angle or orthogonal to the drive axis.

Consistent observations included:

- Shearing of foliation in the drive footwall and hangingwall leading to offsets in drillholes and 'guillotining' or truncation of the support elements.
- Stress-induced fractures sub-parallel to the drive backs and floors, leading to significant 'bulking' as the fractures shear and dilate (Figure 1). This in turn results in deformation and closure between the floors and backs of the drives, and contributes significantly to the shearing in the walls.
- The initial indication of significant bulking above the backs is usually

Figure 1 Stress-induced fracturing above the backs of 1950s haulage drives at Big Bell

the development of an open crack where the backs meet the hangingwall. Support elements in this location are often the first to become trapped in shear, indicated by the loss of the faceplate. Where meshing or fibrecreting are employed, the development of this crack may be difficult to observe.

- Buckling of the drive walls may occur if shearing is prevented. As a result of the confinement provided by the drive floor and the beneficial effect of reinforcement in the upper part of the walls, buckling tends to be most commonly developed in the lower part of the footwall.

Shearing in the footwall and hangingwall is promoted by local rotation of the major principal stress as the stresses redistribute around the opening. It should be recognised that the role of stress redistribution and rotation in terms of promoting shear in foliated rocks was identified in the late 1970s in the Lead Mine at Mount Isa (Lee and Bridges, 1981).

A summary of the key mechanisms that have consistently been observed in mines exhibiting the high deformation, foliated ground behaviour is presented in Figure 2.

A more recent example of observations of fracture development above the backs of an oredrive is presented in Figure 3. An example of a drive exhibiting an advanced stage of deformation, in which serviceability has been compromised, is shown in Figure 4.

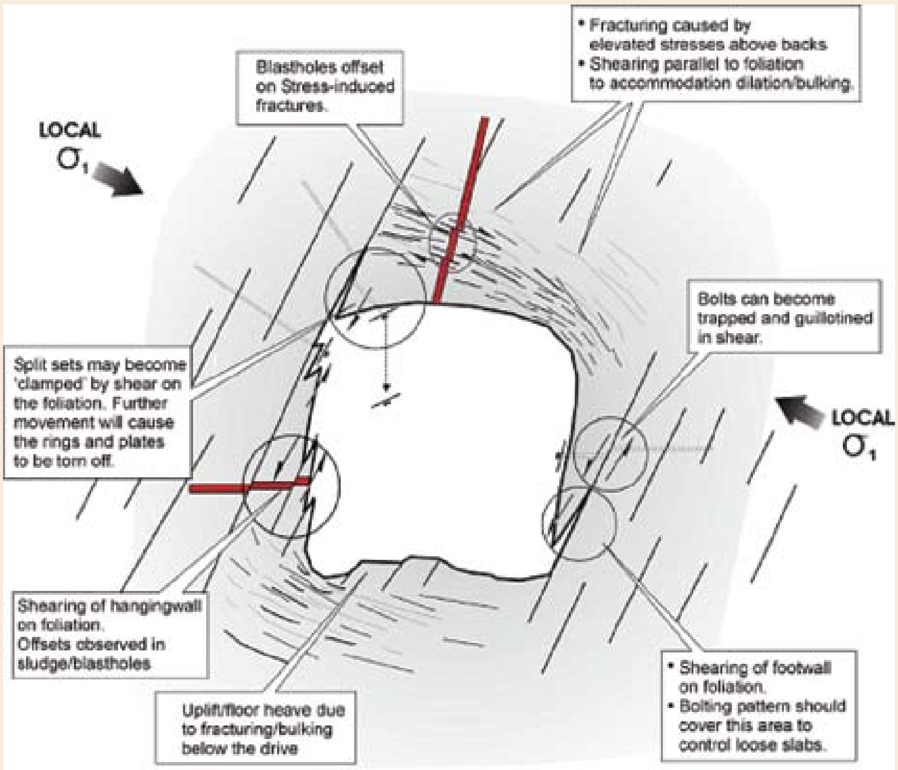


Figure 2 Summary of observed deformation mechanisms (after Beck and Sandy, 2003). Note the sense of shear at various locations around the opening

Canadian experience with high deformation conditions

Canadian experience is very similar, although high deformation behaviour is generally seen only in very deep mines due to the more moderate stress versus depth gradients that apply relative to the very aggressive conditions present in Western Australia (Lee et al., 2001).

For example, the degree of damage and deformation seen in the lower levels at the LaRonde mine, i.e. at depths of 2400 m below surface, are practically identical to those seen in the Yilgarn Star mine at 400 m below surface.

The very weak rocks at Yilgarn Star (typical uniaxial compressive strengths in the ore range from 40-60 MPa) only partly account for this – the pre-mining major principal stress in many Yilgarn Craton mines has been shown to increase at typically 0.07 to 0.09 MPa per metre depth, i.e. 70-90 MPa at 1000 m depth. This is almost twice the stress that would be expected at comparable depth in Canadian Shield mines.

Managing deformation – implications for support

Debonded or yielding ground support is required to maintain serviceability in high deformation conditions, with the additional challenge presented by shearing, which may trap or cut the support elements.

Figure 3 Stress-induced fracturing above the backs of an oredrive at the Yilgarn Star gold mine

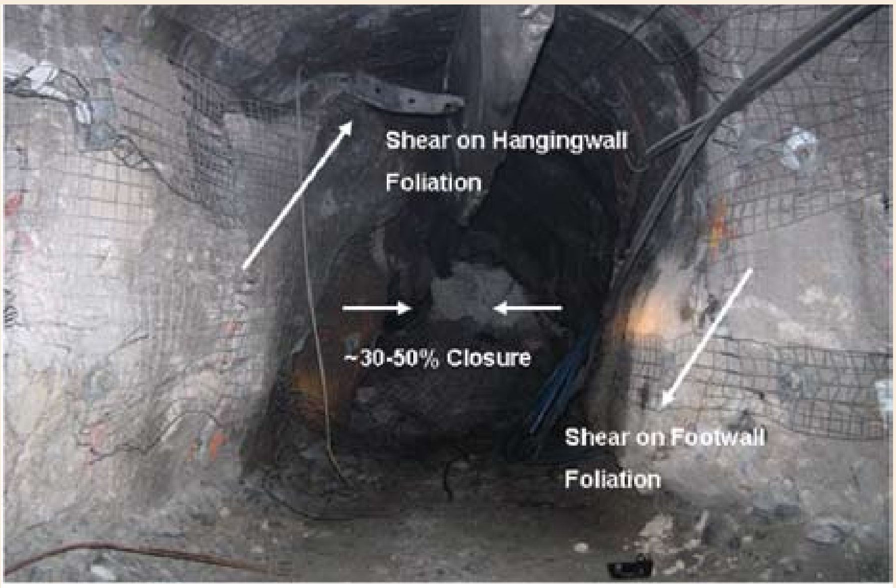


Figure 4 Drive exhibiting advanced stage of wall deformation. Serviceability has been lost

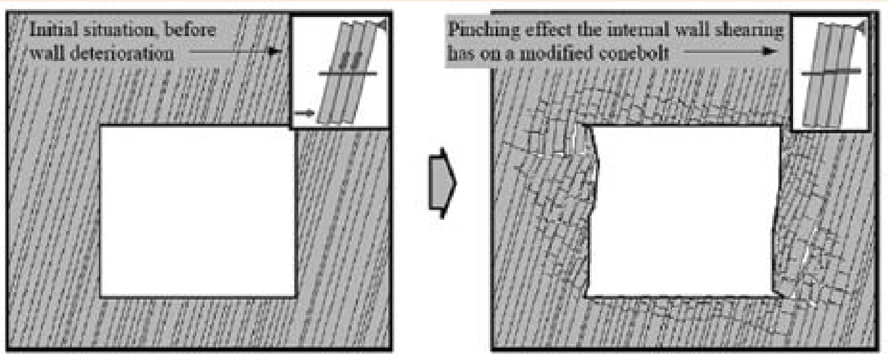


Figure 5 Observed ground behaviour in Canadian mines and interpreted mechanism of support entrapment (after Simser et al., 2006)

Often several phases of support rehabilitation are required in development with an extended service life, and this can involve substantial cost.

Where deformations have been monitored over an extended period, it is clear that there is significant time-dependent behaviour in these weaker rocks once stress conditions have been attained that are sufficient to induce fracturing. In some mines, this has been exploited by deferring development in the weaker rock as long as possible without otherwise compromising the mine plan.

In most operations the response to increasing levels of deformation has been to increase the intensity of the support in terms of both bolt density and bolt length. For example at Mount Isa in the deep copper orebodies, initial support based on split sets and mesh is followed by fibrecrete and cables. A typical design is shown in Figure 6. In addition to upper sidewalls and backs support, cablebolts are installed into the lower parts of the sidewalls, angled downwards, to control deformation in this area.

Observations in mines that have only installed support to the shoulder or the gradeline suggest that severe damage is commonly developed where the lower sidewalls are not adequately reinforced. Where fibrecrete has been used for surface support, inadequate control of lower sidewall deformation results in 'lifting' of the fibrecrete shell, often accompanied by severe unravelling of broken ground from behind the fibrecrete. Repair costs after this are always substantial and drive closure may lead to loss of serviceability.

The same approach is seen in Canadian mines, with intensive reinforcement directed at the lower sidewalls. As would be expected, the potential benefits of using yielding support in these situations have been recognised by several authors, both for accommodating ongoing deformation and in seismically active mines as a means of controlling material subject to seismic accelerations. However, the entrapment of support elements by shearing on structures and stress-induced fractures has now been recognised as severely limiting or preventing yielding bolts from operating as designed (Simser et al., 2006).

Canadian studies of the mechanisms responsible for the deformations come to similar overall conclusions, e.g. Simser et al., 2006 (Figure 5). The observations of the shear couples responsible for trapping support elements in the footwall are consistent with Australian experience, although the interpreted underlying mechanism is somewhat different. In the lead author's experience, it is important when interpreting ground behaviour to carefully review the observed shear couples to ensure that they are compatible with the mechanisms being proposed.

The amount of stress induced fracturing is not widely appreciated. Similarly, the timing, location and amount of shearing occurring on both stress induced and natural structures may not be widely recognised. Modern support practices, particularly meshing, make observation more difficult, as broken rock accumulates in the mesh. Shotcrete also tends to obscure ground behaviour from detailed observation. As a result reliable, clear observations are difficult to obtain in many mines.

Field deformation monitoring tends to focus on axial displacements – a better understanding of the shear component would assist in specifying laboratory tests and in support design. This could be obtained by drilling a series of observation holes in the drive backs and walls.

Redrilling holes may be necessary as shear displacements can be larger than typical hole

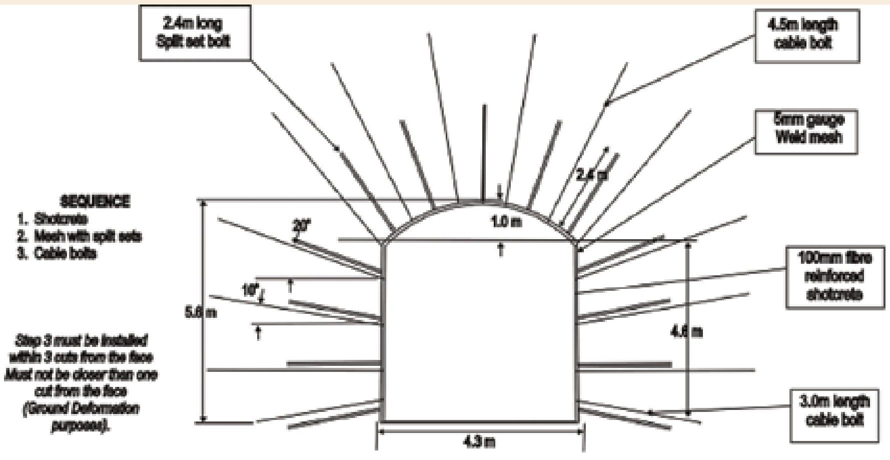


Figure 6 Support standard for high deformation conditions at Mount Isa (Guilfoyle et al., 2006)

diameters, and displacements may continue for an extended period. The objective of this work would be to better understand the timing and degree of shear displacements.

The observed deformations often involve localised shear in excess of typical support hole diameters. Trapping and 'guillotining' (truncation) of the bolts is inevitable. As observed in many Australian mines, once entrapment has occurred, the bolts are effectively locked-up, and ongoing deformation between the trapped section and the collar leads rapidly to excessive loading and failure, usually of some locally weaker part of the system at the collar.

In addition to ongoing efforts to develop bolts that can endure the large deformations and shearing within the rock mass, another significant challenge is presented by the surface fixtures that provide the connection between the bolts and surface support. In many mines, the weakest aspect of the system may be the collar fixtures and often their failure can lead to loss of connection between adjoining mesh sheets. Broken rock may spill out presenting a serious hazard.

Some Canadian mines install 'zero gauge' weld mesh straps along the overlaps between mesh sheets with additional bolts to improve the durability of the connections. Similar practices have been adopted in Australian mines although the most commonly used straps are made from galvanised steel plate. These are less flexible in terms of collaring locations and have been seen to tear under ongoing deformation.

More recently, a South African development known as an OSRO strap has been applied in a seismically active Western Australian mine to improve the durability of the surface support at the mesh overlaps. With this mesh strap, the cross-wires are attached to the longitudinal strands by means of a tightly wound 'pig tail'. This allows the strand to slip under load, and to distribute loads across several bolts. It may provide superior performance under ongoing deformation than either the zero gauge weldmesh or steel plate straps.

In mines experiencing extreme deformation, drive serviceability can be lost. One option at this stage is to strip out some of the damaged material to regain serviceable drive dimensions. The resultant large excavations are often then very difficult and expensive to re-support.

In areas where the backs have been damaged and tendon support is considered unlikely to be effective, an alternative approach is used at the Leinster Nickel Operation (Gaudreau, 2006). In areas requiring rehabilitation, limited stripping of damaged material is undertaken on one side of the drive only. After resupporting the walls with bolts, mesh and fibrecrete, shotcrete arches are installed at typically 3 m spacing. These appear to be more effective than grouted, tendon based systems in areas that have experienced deep-seated damage.

Conclusions

In high deformation environments, there is widespread acceptance that the ability to yield whilst retaining capacity is an important characteristic of support systems. A better understanding of failures in shear and interaction between support and the rock mass would be beneficial to design

Field deformation monitoring focusing on shear rather than axial displacements would provide a better understanding of the impact of shear on bolt performance. This could be obtained by drilling a series of observation holes in the drive backs and walls. Redrilling holes may be necessary as shear displacements can be larger than typical hole diameters, and displacements may continue for an extended period. This information would assist in specifying laboratory tests and aid in the design of shear resistant support systems.

Managing high deformation requires a combination of appropriate support systems, and the use of sequencing where possible. Rehabilitation costs and impacts on the schedule can be significant in operations experiencing high levels of deformation.

Acknowledgements

The authors would like to acknowledge the assistance of their colleagues at AMC Consultants and BHP-Billiton Nickel West for their support in preparing this paper, particularly Frans Basson and John Albrecht. Discussions with Brad Simser (Xstrata) and Frederic Mercier-Langevin (Agnico-Eagle) were very helpful in gaining some insight into Canadian experience.

Article references are available on request from the ACG. The full paper is available from the ACG's 4th International Seminar on Deep and High Stress Mining proceedings.

Mike Sandy, AMC Consultants Pty Ltd

Mine Closure 2007

By Jacques Wiertz, adjunct professor, University of Chile, Chile

Recently held in Santiago, Chile, the Second International Seminar on Mine Closure consolidated itself as an event of great impact that clearly responds to a growing concern of the mining industry and community about the different environmental, social and economic aspects related to closure. Over 430 attending delegates from 28 countries demonstrated the commitment of the mining community to the sustainability of its activities, of which mine closure, without a doubt, is one of the most important parts.

Mine closure planning plays a fundamental role in any new mine design

Though not the first mine closure event held in Chile, the seminar was very different from its predecessors. What marked the difference was, first of all, its truly international character and spirit. The seminar gathered over 200 foreign delegates coming not only from Latin America (Peru, Brazil, Argentina, Ecuador, Mexico, Costa Rica, Venezuela and Honduras), but also from Africa, Australia, Canada, United States and Europe. Another important characteristic was its multidisciplinary nature with presentations covering the regulatory, economic, technical and social aspects of closure. Presentations and case studies from BHP Billiton, Freeport McMoran, Barrick, Anglo American, Rio Tinto, Codelco and Alcoa offered a unique opportunity for the attending professionals to learn more about the closure criteria used by these global mining companies. Major engineering and consulting companies which offer services to industry in planning, developing and monitoring of closure activities were also present at the seminar.

The new research developments of cover for mining waste deposits, tailings or sterile dumps, generated the most interest at the event. Cover design and engineering should be adapted to specific site conditions and attention needs to be paid to the long-term evolution of cover characteristics and performances. Mine closure under extreme conditions, cold or arid climates, presents unique challenges that were addressed in one seminar session. Revegetation and phytostabilisation of mining waste deposits is another topic that was intensely discussed. As far as revegetation is concerned, it's fundamental to clearly define its objectives and to understand that to revegetate is much more than to simply grow some plants. Biodiversity, the physical integrity of covers, the long-term evolution of growing vegetation, along with the new opportunity for a

Barrick's El Indio mine is currently undergoing closure

Mine Closure 2007 attracted more than 430 delegates from 28 countries

revegetated mining area to enter into the carbon bonds market, were also explored. Water management and effluent treatment, in particular acid waters, was analysed in several technical sessions, with emphasis on passive treatments and processes to control any effluent leaks. Environmental monitoring, either on the diagnostic stage or as a control of effectiveness of the closure programme, is another topic that sparked great interest.

Social aspects associated with mine closure are high priorities for companies which, in a globalised context and with growing community expectations, need to maintain their "social license to operate". Community involvement in the design and development of the closure planning is nowadays a necessary strategy for which many companies are not yet prepared. Social impact assessment is a developing tool of an increasing use, but it requires the participation of social science professionals and should start from the first stage of closure planning.

Mine closure planning today is considered a major part of any new mine design. Closure planing is a fundamental tool to minimise the risks and costs associated with this unavoidable stage of any mining project. It must be permanently updated, integrating new technical developments and best practices and responding to new regulatory requirements. It must be supported by a responsible and reliable monitoring programme. Mine closure is, without any doubt, a subject that will be regarded with more and more attention in the context of growing regulatory requirements and local community expectations.

Jacques Wiertz, University of Chile

Technical visits

Two post-seminar technical visits were offered to the delegates: Barrick's El Indio mine and Pudahuel Mining Group's Lo Aguirre Mine. Barrick's planes took the participants to the El Indio mine, located in the Elqui Valley (Coquimbo Region) at an altitude of 4 000 m. The mine was operating from 1979 to 2001 and is now undergoing closure. This is a pioneer initiative in Chile, with an investment of over US$ 55 million to date. A comprehensive environmental follow-up programme was designed in collaboration with the public services and valley representatives, which considered the monitoring of the physical and chemical stability of the Malo River water and the physical stability of the mining structures in the rehabilitated sector of the valley as its main objectives.

Others visited the Lo Aguirre mine, one of the first closed copper mines in Chile. The peculiarity of this mine is its exposure to heavy rainfall during the autumn and winter months. In order to avoid percolation and acid generation, the tailings dams and leached heaps were covered with clayey materials, whose hydraulic conductivity is equal to or less than 10-6 cm/s. The applied technique yielded good results an average 90% efficiency rate (with rain water infiltration into the heaps no greater than 10%). It is interesting to note that almost all closure efforts were financed by sterile dumps used for construction materials and by the recycled dissolutions that still contained copper. The recovery of copper precipitate by adding scrap iron, without adding acid, resulted in significant resource sustainability.

Mine Closure 2007 proceedings

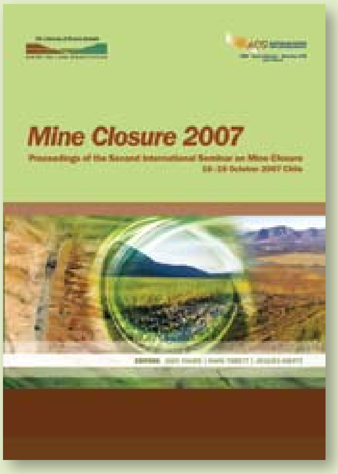
Industry's enthusiastic support of the Mine Closure 2007 Seminar denoted the high degree of interest that exists throughout the world. The challenge that raises the stage of closure, when the mine has reached the end of its economic life, is becoming increasingly more important and relevant for mining companies. This is not only related to the demanding regulations applied by different countries, but also to industry's own motivation to reach higher standards of health, safety and environmental protection.

The selected papers presented in these proceedings reflect the efforts of the universities, mining and engineering companies, governmental and non governmental agencies towards an improved sustainability of the mining industry through the design and application of advanced criteria, innovative methodologies and new technologies for a responsible mine closure process.

The hardbound proceedings contain 89 peer reviewed papers and almost 900 pages. Topics include:

- Legal and regulatory requirements
- Social issues
- Criteria for closure
- Mine closure planning
- Costs and financing
- Mine site reclamation and rehabilitation
- Revegetation and phytostabilisation
- Water and acid water management
- Mine waste management and cover design
- Closure under extreme environmental conditions
- Monitoring
- Mining heritage and tourism

To order your copy of the Mine Closure 2006 and 2007 Seminar proceedings, please email neskudla@acg.uwa.edu.au.



MINECLOSURE 2008

14 – 17 October 2008
Johannesburg, South Africa

The Third International Seminar on Mine Closure's theme is "From Waste to Resources: Revaluation of Mining Operations, Land and Residue Deposits in a Changing World".

Seminar topics

Mine Closure 2008. From waste to resources: revaluation of mining operations, land and residue deposits in a changing world

- Policy regulation and finance for mine closure
- Planning, modelling and monitoring tools for mine closure
- Design and construction for mine closure
- Mining legacies
- Reclamation, remediation, rehabilitation and restoration
- Opportunities from mine closure

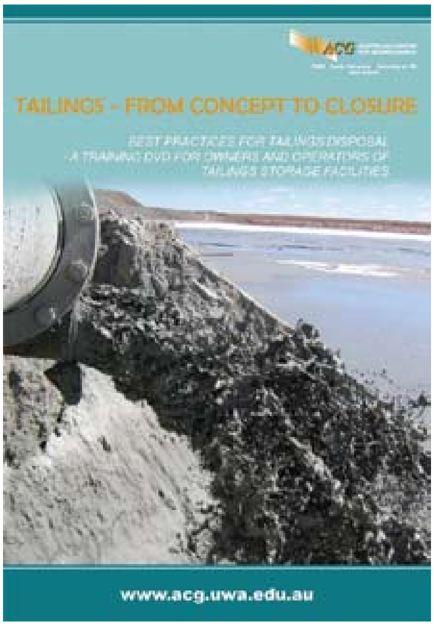
Intending authors are invited to submit their abstracts to the University of the Witwatersrand, South Africa by 31 March 2008. Please visit www.mineclosure2008.org.za or email info.mineclosure2008@wits.ac.za or Lesley.Stephenson@wits.ac.za for further information.

The economic, environmental and social acceptability of mine closure is one of the greatest challenges facing the mining industry in this new century

Tailings – From Concept to Closure

By John Phillips, senior manager, GHD Pty Ltd

It is frustrating that despite modern engineering, tailings storages continue to wreak havoc through failures or spillages. Very few of these incidents were due to poor design or highly complex technical difficulties. The majority were due to simple causes, were preventable and should never have happened.



In a study of 221 such incidents, the International Congress of Large Dams (ICOLD) found that the majority were due to slope or foundation stability (33%) or poor water management (14%). Many stability problems were in turn influenced by lack of seepage control, which together with other seepage issues would make seepage one of the main issues in tailings storages. Earthquake damage occurred in 14% of cases but the statistics are influenced by multiple failures from a single earthquake in one country (ICOLD Bulletin 121, 2001).

What is being done to correct the mistakes and poor management?

Commonly, mine management regard tailings as an unwanted nuisance. Tailings operations are relegated to available staff who may not have been trained in the skills necessary to deal with the many engineering facets of tailings disposal. They confuse risk with consequence. They feel the risk is low, which generally it is, but the consequences are enormous. Failures or spillages in recent years have led to stopping of production, multi million dollar clean-ups, some loss of life and major impact on company credibility and share value.

The Australian Centre of Geomechanics (ACG) has made a very significant contribution by preparing a DVD: *Tailings – From Concept to Closure*. This is a timely tool for lifting the standards and training associated with tailings disposal. Scripted by Dr Andy Fourie of ACG, the DVD was reviewed by seven leading exponents of tailings systems representing the major international and Australian mining companies. This DVD represents not only the latest safe practices but is also pragmatic in its approach, showing real life situations. Whilst the majority of examples are Australian and many are in dry climates, there are a number of examples of tailings disposal in wet climates. The principles described and the variety of situations makes this DVD suitable for many countries.

The DVD is an essential training tool for all mines or processing plants that have tailings storage facilities (TSFs). Before describing the features of the DVD, it is worthwhile to define what it is not. It is not a substitute for a design manual, nor is it an operations manual. It is not a training tool for the designer, but it is very useful for new design staff or those staff working on one aspect of a design so that they can get an appreciation of the interaction between the different aspects of tailings disposal.

The DVD is easily operated and is based on five "titles" or sections as follows:

- TSF overview,
- TSF operations,
- Water management,
- Monitoring and response, and
- Closure and rehabilitation.

Each "title" is broken into a series of chapters covering different topics. The DVD can be operated to play continuously (not recommended as it is one hour long and the comprehensive

Closure and rehabilitation are essential components of a mine's concept and design information would cause mental overload), on each title or individual chapters can be selected when wanting to focus on one particular aspect.

The TSF overview section is regarded as essential viewing for all staff involved in mine or plant operations. It should follow soon after the initial site and safety inductions. It is imperative that everyone on site has a feeling for the major damage that can be caused by tailings incidents and that as many pairs of eyes as possible be alert to signs that can give early warning that action is required. This 11-minute section shows the consequence of some failures and emphasises that there were always some tell-tale signs before the failures. The broad concepts of tailings disposal are described and due emphasis is given to the importance of operations manuals, water management and monitoring. Closure and rehabilitation is described as being an essential part of the original concept and design, rather than an afterthought at a time when funds are in short supply.

The second section on TSF operations is 12 minutes long and gives a comprehensive outline on the nature of tailings, their transport and deposition techniques. Due emphasis is given to potential environmental impacts of the tailings themselves and the water associated with tailings disposal. Potential problems are outlined and factors influencing choice of deposition method and its impact on the behaviour of tailings after deposition are described. Diagrams are used to illustrate the various points, with footage of a variety of tailings systems giving the viewer a clear understanding of how the principles are put into practice. The factors influencing the behaviour of tailings on the beach and their impact on the strength and other tailings properties are clearly covered with sufficient detail to allow the viewer to see the impact of various decisions. A number of examples of good practice shows where improvements may be possible at their own facility.

The section on water management is the longest at 20 minutes, but this is appropriate given the significance of this topic and the fact that most tailings incidents have arisen from poor practice in this area. Vivid illustrations are given of relatively recent major failures at Stava, Merriespruit and Baia Mare, with pointers as to why they occurred and what measures might be taken to prevent future incidents. These dramatic pictures are mixed with views of very practical and well operated decant systems. This section is the most detailed and shows with diagrams the principles involved in water balance, the importance of controlling the decant pond position and the control of freeboard. Seepage behaviour and its potential to cause piping failure, stability failure or liquefaction is well illustrated. It is demonstrated that pond control is one of the factors in determining wall raising methods. The various wall construction methods are described along with schematics that cover the relevant issues.

The important topic of monitoring is given due emphasis, an important factor that is not given adequate attention at many mines. This 11-minute long section describes routine inspections, the annual auditing process and provides checklists. Appropriate guidelines are described to help establish the inspection regime. This section highlights the critical relevance of an operations manual that is mentioned several times earlier in the DVD. The value of monitoring is diminished if observers do not know how to identify critical situations and the appropriate response. These topics are well covered, with an exhortation to have clear trigger levels for initiating a response and to have clear written instructions on what that response should be. Again there is a graphic warning of what can go wrong and why it is important to have clear and rapid responses.

The final section on closure and rehabilitation appears to carry less emphasis, being only four minutes long. It is not appropriate to outline all the possible end land uses and methods

This training DVD will provide guidance to personnel involved in the management and operation of TSFs that will facilitate the adoption of accepted best practices for mine tailings management

of achieving the desired outcomes for different climates. The DVD wisely stays with broad principles only, but nevertheless hammers home the key message that closure must be considered in the concept stage for the TSF. It stresses the need to plan ahead and the benefits of progressive closure. Warnings are given about the significant cost implications and the effect these have on cash flow. It is fitting that the DVD closes with views of how a well managed TSF can be returned to aesthetic and stable land forms.

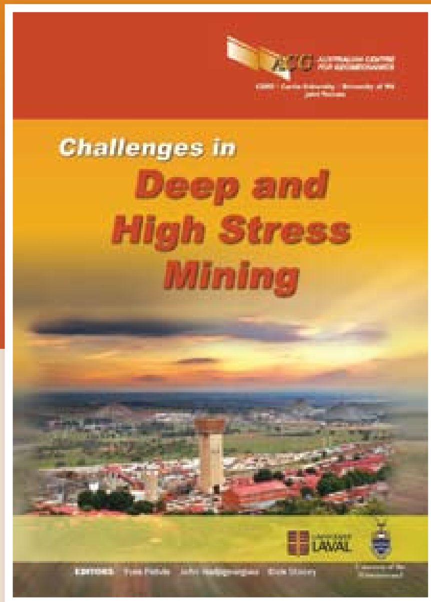
Overall, video ranks as one of the most useful training tools in this field. Again it is stressed that TSFs have such potential for damage that all staff should at least see the overview section as part of their basic site induction.

Please contact the ACG to order your copy of the *Tailings – From Concept to Closure*, best practices for tailings disposal – a training DVD for owners and operators of tailings storage facilities.

John Phillips,
GHD Pty Ltd

Challenges in Deep and High Stress Mining

The ACG's newest publication entitled "Challenges in Deep and High Stress Mining" was launched by the ACG chairman Ian Suckling at the 4th International Seminar on Deep and High Stress Mining dinner in November 2007.



This publication features a collection of the most relevant papers presented at the series of biennial International Seminars on Deep and High Stress Mining held in Perth (2002), Johannesburg (2004), and Quebec City (October 2006). One hundred and twenty papers were presented at the three seminars producing the most complete and current compilation of literature on this highly topical subject.

The engineering challenges associated with mining in a deep and high stress environment are diverse and significant. Deep and high stress mining requires sound strategic mine planning approaches as well as good tactical reactive systems. The development of the underground infrastructure required for the exploitation of deep reserves needs to be carefully designed. The complex logistics associated with the transportation of material and human resources is omnipresent throughout a mine's operating system. Transporting fresh air several kilometres under the surface of the earth and exhausting the fumes created by blasting and diesel equipment is another daunting aspect of deep mining. Rock temperatures can easily exceed 50°C in deep mines, creating a high dependency of the operation on efficient refrigeration systems.

Engineers and mining professionals from throughout the world share their experiences in *Challenges in Deep and High Stress Mining*. This unique resource aims to assist mine personnel dealing on a day-to-day basis with the challenges of mining in deep and high stress conditions.

Book sponsors

The editors acknowledge the outstanding contribution of the authors of the 75 papers featured in the publication and industry sponsorship from Newmont Asia Pacific and Xstrata Copper.

Contact the ACG to order your copy.

Sixth International Symposium on Ground Support in Mining and Civil Engineering Construction

31 March – 3 April 2008
Cape Town, South Africa

This symposium will be the sixth in a series dealing with the specialist subject of ground support for mining and civil engineering excavations. These symposia have been organised on an ad hoc basis in different parts of the world, previous symposia having been held in 1983 in Luleå, Sweden; in 1992 in Sudbury, Canada; in 1997 in Lillehammer, Norway; in 1999 in Kalgoorlie, Australia; and in 2004 in Perth, Australia. The 6th Symposium is being organised jointly by the Southern African Institute of Mining and Metallurgy (SAIMM) and the South African National Institute for Rock Engineering (SANIRE).

Ground support is used extensively in both civil and mining environments, and hence South Africa is a great location for the symposium; it is a country with a strong mining tradition and a rapidly developing civil infrastructure.

Commonly there is insufficient interaction between these two disciplines and the symposium will provide a forum for good interchange of ideas. In both fields significant developments in ground support take place regularly, and miners have a lot to learn from their civil colleagues and vice-versa.

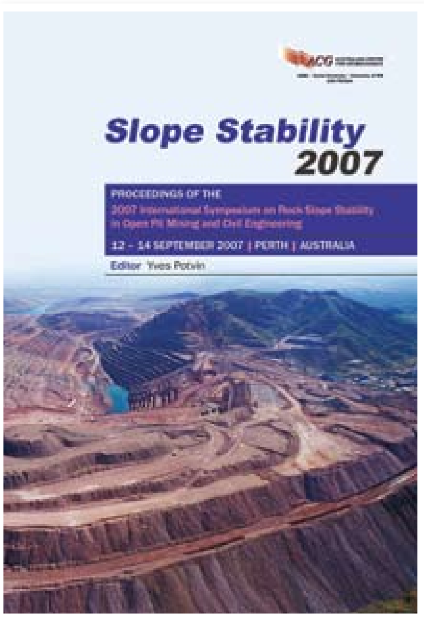
More than 50 abstracts were received for Ground Support 2008. For more information, please visit www.saimm.co.za.

ACG 2007 international events

2007 has been a remarkably busy year for the ACG team with more than 585 mining professionals attending our international events: 10th International Seminar on Paste and Thickened Tailings, March 2007, Perth; 2007 International Symposium on Rock Slope Stability in Open Pit Mining and Civil Engineering, September 2007, and the 4th International Seminar on Deep and High Stress Mining.

These attendance figures indicate that industry finds the content, format, quality and networking opportunities of the ACG's international events to be of tangible benefit and value.

As industry continues to evolve at a rapid rate many engineers and mining practitioners are asked to explore new ways of enhancing their performance and contributions. The ACG's specialised publications and event proceedings can assist industry personnel to maintain and develop their skills, knowledge and capabilities.

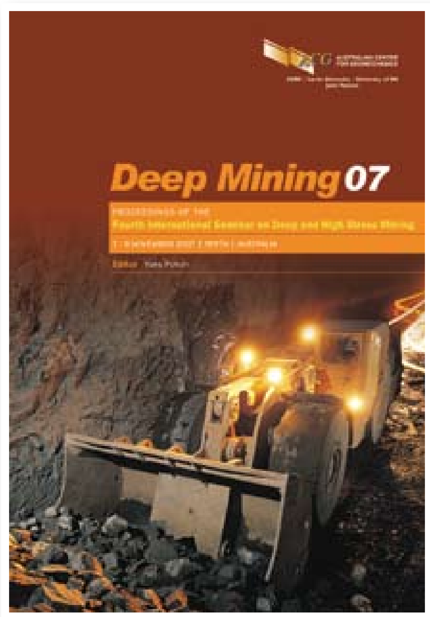


ACG's specialised events provide industry with excellent learning and networking opportunities

The 2007 International Symposium on Rock Slope Stability in Open Pit Mining and Civil Engineering was attended by almost 200 mining and civil engineering professionals reflecting industry's keen interest in the novel and rapidly evolving slope monitoring and design technologies. This interest is fuelled by the challenge to design new open pits in deep and high stress conditions. The ACG was able to host this symposium with the generous support of its sponsors, including: AngloGold Ashanti Australia, BHP Billiton Nickel West, Rio Tinto and AMC Consultants.

The symposium hardbound proceedings feature 40 technical papers covering the following themes:

- Slope design
- Numerical modelling
- Slope failure mechanisms
- Risk analysis
- Rockfalls
- Slope dewatering



Almost 130 delegates attended the 4th International Seminar on Deep and High Stress Mining held in Perth in November 2007. As the mining industry matures in many regions of the world, the focus for both exploration and production is migrating towards deeper levels and, inevitably, towards an environment where the stress regime is high. It is undeniable that stress increases with depth, although the relationship between stress and depth can be complex. High horizontal stress gradients are experienced in many of the world's most productive mining areas.

The objective of this series of seminars is to promote the documentation and dissemination of the latest technologies and experiences in deep and high stress mining, Historically the seminars have had a strong focus on geomechanics issues, including mine seismicity, ground support and numerical modelling. Recent advances include broader topics such as mine planning, ventilation, blasting, economics and risk management.

The ACG was delighted to host Deep Mining 2007 with the support and encouragement of industry sponsors, including Itasca, Macmahon Underground and Stratacrete.

The hardbound seminar proceedings feature 39 technical papers.

The 5th International Seminar on Deep and High Stress Mining will be held in Chile in November 2009. Please contact Professor Michel Van Sint Jan, University of Chile via vsintjan@ing.puc.cl for details.

For more information about our publications, please visit acg.uwa.edu.au/publications.

Paste 2008 — Eleventh International Seminar on Paste and Thickened Tailings

Workshop: 5 May 2008
Paste 2008: 6 – 8 May 2008
Site Visit: 9 May 2008
Kasane, Botswana

Mining operations need large quantities of water to extract the valuable minerals from the ore that is mined. Due to the competition for this scarce resource and, more importantly, to sustain mining operations in the long term, companies must find technologies that will reduce the quantities of water required for their operations. Almost all of the water used is locked up in the final residue after extracting the valuable minerals. When water is extracted from the final residue for reuse or recycle, less new water is required. Therefore, the focus is to find technology that will extract more water from the final residue, hence the interest in paste and thickened tailings. Besides, saving water, the surface area required to store the mining residue will decrease as more water is extracted from it. The drier material can be used to fill up the previously mined out excavations. Additionally, this material is easier to rehabilitate. The immediate and long term environmental benefits are obvious.

Mine owners, legislators and environmentalists have long been concerned about the environmental impact cause by mining. All parties have to work together to find solutions that effectively reduce these impacts in a cost effective manner.

A production prototype paste thickening plant at Orapa Mine

The Paste 2008 seminar programme features more than 35 technical papers. To view the seminar programme and registration brochure, please visit www.paste08.com or email paste@paste08.com.

To order your copy "Paste and Thickened Tailings – A Guide (Second Edition)" or for the proceedings of past Paste Seminars, please contact the acg via neskudla@acg.uwa.edu.au.

Paste 2008 will promote technology that will reduce the water used by the mining operations as well as to advance the use of environmentally superior management of mine residues to reduce the resultant environmental impacts.

Eastern Australian Ground Control update

The EAGCG biannual meeting was held in Adelaide in November 2007. A wide range of representatives from site based and consulting geotechnical practitioners, students, researchers and industry suppliers were in attendance. Sponsored student attendance has been a continued initiative from the Townsville meeting with five students attending and presenting a summary of their work.

The next meeting of the EAGCG is planned for April 2008 at a regional mining centre in NSW, to be confirmed. The theme will be "Stress Measurement, Modelling Techniques and Monitoring and their Design Application". If people are interested to present, please contact Marnie.Pascoe@BHPBilliton.com or Andrew.Campbell@maunsell.com.

ACG 2008 Event Schedule*

Title	Place/Date
Planning for Stable Landforms Workshop	Perth, 4 March 2008
First International Seminar on the Management of Rock Dumps, Stockpiles and Heap Leach Pads	Perth, 5 – 7 March 2008
Geotechnical Engineering for Open Pit Mines Seminar	Perth, 6 – 8 May 2008
Coal Tailings Impoundments: Risks, Responses and Alternatives Seminar	Sydney, 14 – 15 May 2008
From Rock Mass to Rock Model Workshop	Perth, 15 September 2008
First Southern Hemisphere International Rock Mechanics Symposium	Perth, 16 – 19 Sept. 2008
Blasting for Stable Slopes	Perth, 23 – 24 October 2008
UNDERGROUND MINING SHORT COURSE SERIES	
Underground Blasting (One-day Development Blasting, and one-day Stope Blasting)	Perth, 3 – 4 November 2008
Ground Support in Underground Mining	Perth, 5 – 7 November 2008
Tailings Management for Decision Makers	Perth, 3 – 4 December 2008

**The ACG event schedule is subject to change. For event updates, please visit www.acg.uwa.edu.au/events_and_courses*

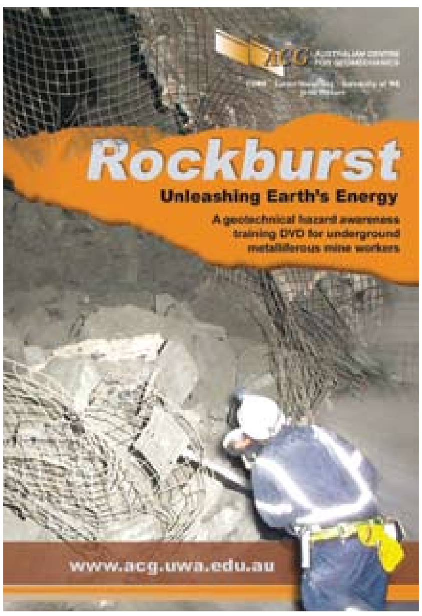
Rockburst – Unleashing Earth's Energy

A geotechnical hazard awareness training DVD for underground metalliferous mine workers

Understanding the complex issue of mine seismicity and rockburst is one of the biggest technical challenges facing the Australian mining industry. As local and global operations push deeper, activity associated challenges are becoming more common. There is an urgent need for industry funded and supported research projects to effectively manage these geotechnical challenges. Mine workers need to be aware of these hazards, including understanding the difference between natural seismicity and mine induced seismicity, what makes a mine seismically active, the pre-cursors, and how to control seismic hazards. With industry support the ACG is delighted to launch early next year a new training DVD for mine workers that explores the rockburst phenomenon.

Topics include:

- What are seismic events and rockbursts?
- How do seismic monitoring systems work?
- How to manage seismic risks.



Project Sponsors

anglogold Australia

BARRICK AUSTRALIA PACIFIC

LIGHTNING NICKEL PTY LTD

bhpbilliton Nickel West

Festive Season Wishes

The ACG staff and Board of Management wish you and your family a safe and merry Christmas and happy New Year.

We are appreciative of your support and encouragement of our activities to advance mine safety throughout 2007 and look forward to another rewarding year ahead.

Our office will be closed from Friday 21st December 2007, reopening Monday 7th January 2008.

Australian Centre for Geomechanics PO Box 3296 – Broadway, Nedlands, Western Australia, AUSTRALIA 6009
Ph + 61 8 6488 3300 Fax +61 8 6488 1130 acginfo@acg.uwa.edu.au www.acg.uwa.edu.au