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Newmont Asia Pacific's Jundee Operation. Photograph by Tony McDonough of Raw Image.

An interpretation of ground support capacity submitted to dynamic loading

by Winthrop Professor Yves Potvin

Introduction

The trend towards exploiting deeper mineral resources is a natural evolution of underground mining worldwide as near surface reserves become progressively depleted. Notably, South Africa has several mines operating between 3 and 4 km below surface while some Canadian mines are operating at a depth exceeding 2 km (Potvin et al., 2007). The challenges associated with deep mines are numerous but perhaps the prime risk and concern in many of these mines is rockbursting. However, rockbursting is not confined to deep mines. Relatively shallow mines, for example in Western Australia, can also experience high stress (Lee et al., 2006) and must address the risks associated with rockbursts. Rockbursting is undoubtedly an increasing problem in the mining industry.

There are a number of measures that can be implemented to mitigate rockburst risks, including reducing exposure of personnel and changes to mine design, layout and extraction sequences. A mine which experiences significant seismicity, to the extent where rockburst damage is caused to underground workings, should generally implement ground support designs which account for the possibility of dynamic loading. This is an area where rock engineering science is still developing. More specifically, the dynamic capacity of ground support has been the object of significant research during the last two decades.

In this work, the dynamic load applied to reproduce rockburst loading involved either some form of drop tests or blasting tests. Stacey (2012) rightly argued that neither of these is '... truly representative of rockburst loading, in a similitude sense'.

The above research is nevertheless very important to understand the behaviour and compare the performance of different support elements under dynamic loading (even if the loading is not truly representative of a seismic stress wave).

Dynamic capacity of ground support systems

In mechanised mining, most ground support systems are comprised of reinforcement elements such as rockbolts as well as surface support which is, most commonly, mesh or fibre-reinforced shotcrete (FRS).

The surface support is installed on the surface of the rock and its primary aim is to contain the rock mass in between the reinforcement elements or prevent unravelling of the skin of the excavation. It is interesting to note that under static conditions, the functions of the reinforcement and surface support are distinct from each other and the need for them to work in unison as a system is minimal. In fact, shotcrete is sometimes applied over the reinforcement resulting in little interaction between the surface support and reinforcement. This is often reflected in the static design process where the demand is matched to the capacity of the reinforcement alone, with little consideration in the calculations given for the contribution of the surface support.

The weakest link

Under dynamic loading, it is expected that the load is transferred from the rock mass to the surface support during the processes of rock fracturing and ejection brought about by a seismic event. This transfer will occur via the plate and terminating arrangements (split set ring, nuts, etc.) of each reinforcing element. When either the surface support, the plate or the terminating arrangement fails, the load is no longer transmitted to the reinforcement, and the rock will likely be ejected from in-between the bolts. In this scenario, the reinforcement will only be submitted to a fraction of its dynamic load capacity.

Therefore, to withstand the dynamic loading generated during a seismic event, the ground support must work as an integrated system and will only be as strong as its weakest link. This is evident in work done by Heal et al. (2006), who have also demonstrated this principle with the study of 254 cases of rockburst damage showing that the weakest link in the ground support systems used in mines was often the surface support or connection between the surface support and reinforcing elements (plate and terminating arrangement). Only 30% of the rockburst damage cases from this database were due to reinforcement failure (Figure 1). The implication for estimating the ground support capacity under dynamic loading is that the capacity must be assessed as a system rather than as individual support elements. Using the dynamic capacity of the reinforcement alone for design purposes would likely overestimate the capacity of the system as Heal et al. (2006) have shown through their database that surface support and connections often fail before the reinforcement capacity is mobilised.

Dynamic capacity of ground support estimated from drop tests

In the last 15 years a number of test facilities have been constructed in South Africa, Canada and, more recently, in Australia. All facilities rely on gravity (or weight) drops to generate energy to be applied to ground support. However, all testing facilities have significant differences which make the comparison of their results somewhat difficult.

The Western Australian School of Mines (WASM) rig, which is the most recent and best instrumented facility, relies on a drop weight deceleration of the support element being tested, also known as the momentum transfer mechanism (Player et al., 2004), whilst the other rigs use the kinetic energy from the impact of the falling weight onto the support element itself. When testing surface support the South African rigs, SRK and the Safety in Mines Research and Advisory Committee (SIMRAC) distribute (and also attenuate) the impact by dropping the weight on a pyramid of bricks laid over the support system whilst the Canadian rigs, Geomechanics Research Centre (GRC) and Mining Innovation Rehabilitation and Applied Research Corporation (MIRARCO) drop the weight directly onto the surface support tested. The GRC and MIRARCO systems (no longer in operation) were extremely stiff as the surface support was mounted directly onto steel/concrete pillars sitting on a concrete floor. Presumably, a higher proportion of the energy is transferred to the floor through these stiff pillars.

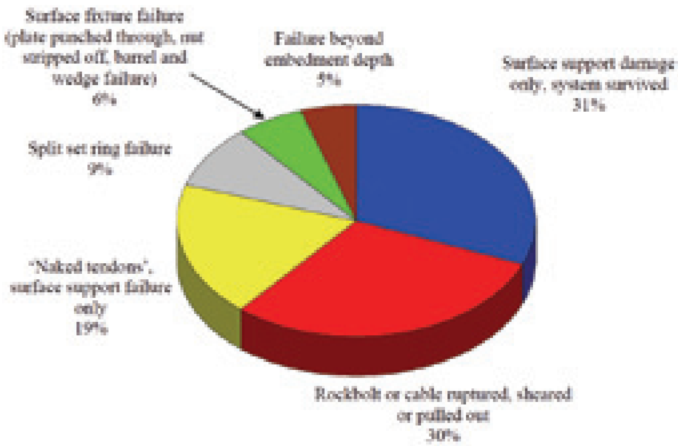

Figure 1 Breakdown of the components of ground support system failures from 254 rockburst damage observations (after Heal et al., 2006)

Only the SRK drop weight test facility was capable of testing a complete support system (rockbolts and mesh or FRS together). However, most published results from this rig focused on the capacity of surface support only, rather than on support systems. The results are also presented in terms of the input energy into the system rather than the portion transmitted to the support element. The WASM rig can also test both reinforcing elements and surface support, but at this stage cannot test them together as an integrated support system.

Compilation of published results from drop testing

Given the high cost of constructing, commissioning and running drop testing facilities, it follows that researchers working on individual facilities have not published significant bodies of test results, and most of the rigs are no longer active, except for the SIMRAC prop testing, the Noranda Technology Centre-Canada Metal (Pacific) Ltd (NTC-CANMET), and the WASM facilities. As the SIMRAC rig is not designed to test bolts, mesh or shotcrete, the WASM and the NTC-CANMET rigs appear to be the only facilities currently contributing to growing the public database of dynamic tests. Given that there are a wide variety of ground support systems used in mines, and the fact that practitioners are frequently required to design dynamic resistant support systems, there is an incentive to compile all results from the different rigs such that the status of the current knowledge from the various drop testing campaigns can be assessed.

An attempt is made here to compile the results from as many published tests as possible. However, as mentioned before, there are difficulties in comparing the results obtained from the different rigs due to their different testing arrangements and protocols. It is noted that a very small percentage of 'abnormal' test results from the various published sources of data were ignored, when explanations for the deviation could not be found.

Reinforcement results

Figure 2 is a compilation of drop test results for reinforcement elements from the work of Ortlepp and Stacey (1998)

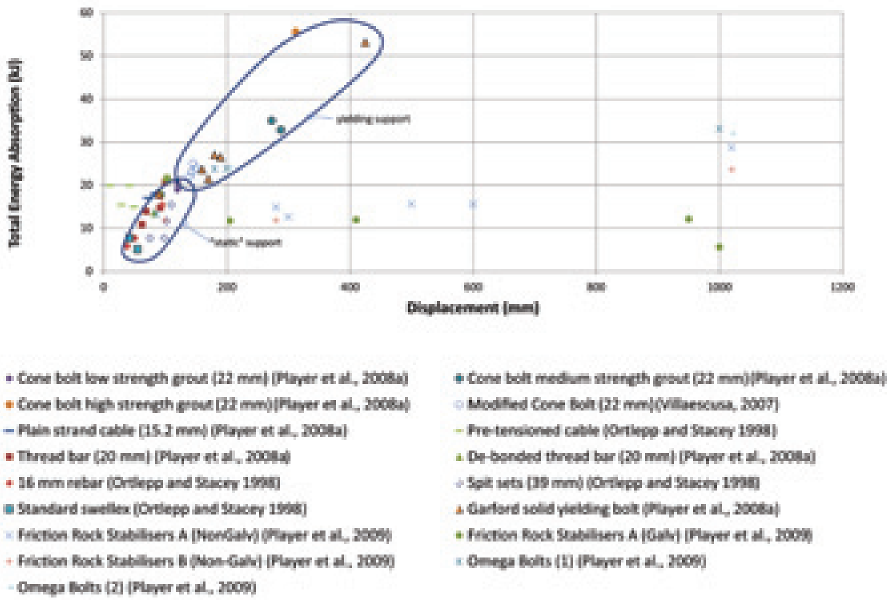

Figure 2 Compilation of drop tests performed on various reinforcement elements and reported by the following authors: Ortlepp and Stacey (1998); Player et al. (2008a, 2009)

on the SRK rigs in the 1990s, and the WASM publications by Player et al. (2008a, 2009). The total energy absorbed is plotted as a function of the displacement.

Figure 2 includes results from 70 tests grouped under 17 datasets, represented by different symbols. Each dataset represents a different reinforcement element or a variation in the size of the bolt, the grout or the embedment length.

Considering that a wide variety of bolts were tested using two different rigs, the compiled datasets show a very clear 'quasi-linear' trend. A large cloud of data plots in the area defined between 7 and 27 kJ of total energy absorption and between 25 and 200 mm displacement. The trend of energy increasing with displacement is to be expected as the energy is a product of the force and displacement. The bottom half of the cloud (i.e. energy between 7 and 18 kJ and displacement between 25 and 100 mm) is dominated by reinforcement commonly used in mines dealing with mostly static loading conditions, whilst the top half of the cloud (i.e. energy between 18 and 27 kJ and displacement between 100 and 200 mm) is dominated by yielding bolts.

The energy absorption for encapsulated (fully grouted or partly de-bonded) bars is generally dissipated mainly by bolt elongation combined with gradual breaking of the bolt/grout bond and limited slippage in the case of grouted solid bars. Cone bolts generally allow for more displacement and energy absorption as the energy is dissipated by a combination of steel elongation and friction generated by the bolt ploughing through the grout. Some of the more recently developed yielding bolts allow for extended elongation through mechanisms other than steel stretching.

Generally, thicker bars and yielding bars provide better energy absorption and displacement capacities as they stretch more and offer more resistance than thin bars. This is reflected in the data in Figure 2. There are four higher energy absorption data points, all from yielding bolts. These exceptional performances seem to be isolated cases. These points follow the general energy displacement trend, however, with very high values of energy absorption and displacement.

The friction bolts show a very flat trend, which means that there is virtually no increase in energy absorption once a certain energy and displacement has been reached. The laboratory response observed by Player et al. (2009) shows that an initial frictional resistance to movement dissipates most of the energy. The very flat trend in the energy absorption with displacement suggests that there is a reduction in the friction resistance with displacement.

Reinforcement in general can dissipate energy through bond breaking, steel deformation, friction or a combination of the above. The bi-modal behaviour depicted in Figure 2 can be interpreted as most reinforcement systems appear to dissipate energy by bond breaking and steel stretching and as such follow the quasi-linear increasing trend. The friction bolts, however, absorb most of its energy by overcoming the original frictional resistance and then slide without dissipating much energy, producing the flat trend on the energy displacement graph.

Most of the omega (inflatable) bolt results (Player et al., 2009) also fit the general quasi-linear increasing trend. Although they use a friction bond, the mechanism involved when inflatable bolts are submitted to dynamic loads is more akin to grouted bolts and this is reflected by the test results.

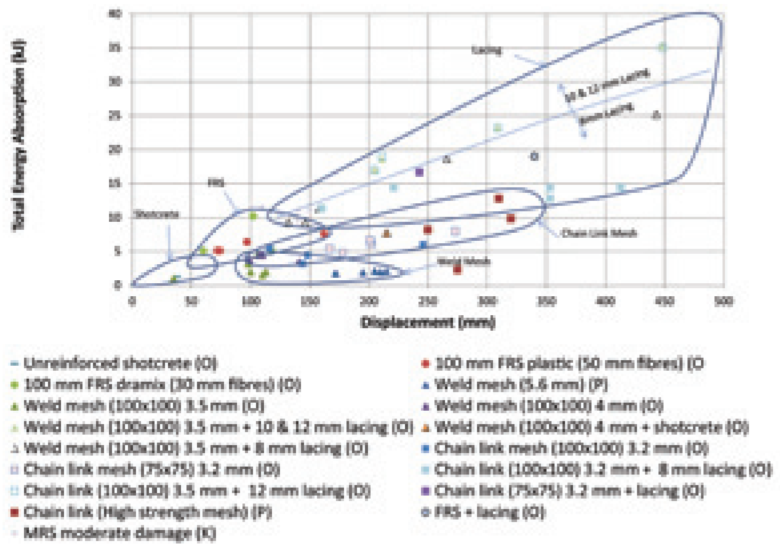

Figure 3 Compilation of drop tests performed on various surface support elements and reported by the following authors: Kaiser et al. (1996) (K); Ortlepp and Stacey (1997) (O); Player et al. (2008b) (P)

Surface support results

Figure 3 is a compilation of surface support results from drop tests, where the total energy absorbed is plotted as a function of the displacement. The compilation includes tests from three different rigs and was sourced from Kaiser et al. (1996); Ortlepp and Stacey (1997); Player et al. (2008b).

It is noted that the surface support energy results published by Ortlepp and Stacey (1997) are input energy, and a significant part of this input energy was dissipated in the brick pyramid, with the remainder transmitted to the surface support element tested. The fraction of the energy absorbed by the bricks is unknown and the tests were originally intended for use as a comparative assessment of the performance. To enable comparison to other tests we will assume that about half of the input energy is lost due to the brick arrangement. This is based on an estimation by Human (2004) for the SIMRAC test facility. Although simplistic, this assumption yields results which are comparable to other tests.

There are 65 test results from 16 datasets shown in Figure 3. The data is relatively scattered, but when regrouped according to individual surface support elements (areas delineated by the blue lines), the relative performance of the different surface support methods becomes evident. The expected general trend of increasing energy with displacement can be observed. The lowest performing surface support against dynamic loading is plain shotcrete, which is expected due to its low tensile strength and deformation capacity in addition to its very low post-peak strength. The best performance was from surface support involving cable-lacing, which exhibits a high deformability and high energy absorption capacity. Other surface support systems (with no lacing) generally have energy absorption capacities under 10 kJ. According to Figure 3, FRS and chain link mesh have similar energy absorption capacity but the mesh exhibits larger deformability. The weld mesh alone has only achieved energy absorption capacity of up to 5 kJ.

Even when looking at the results for individual surface support elements, significant scatter exists within each dataset. This is a reflection of the variety of the products tested. For example, it is noted from Figure 3 that thinner wire-mesh (which varies from 3.2 to 5.6 mm wire) and wider aperture (100 × 100 mm) generally have lower energy absorption and displacement capacity. Thicker wire-rope lacing and high-tensile chain link mesh also perform in the upper region of their respective group. These results are all according to expectations and largely explain the scatter within each type of surface support.

As a general conclusion on the overall database, unless rope lacing or other high energy absorption surface support elements such as heavy gauge mesh straps or high tensile strength mesh are utilised, the weakest link will likely be the surface support and the overall support system will likely fail at energy levels

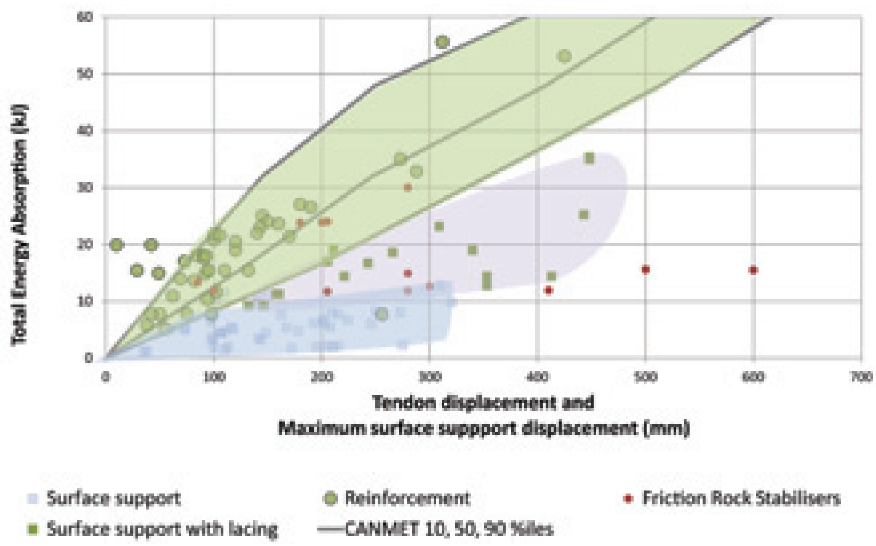

Figure 4 Total energy absorption and displacement of reinforcement and surface support dynamically loaded using drop weight tests

lower than 10 kJ, which is at the lower end of the reinforcement capacity results (Figure 2). In this scenario, the full capacity of most commonly used reinforcing elements would not be engaged during dynamic loading, resulting in surface support failure with only low loading applied to the reinforcing elements. Historically, this has been a common occurrence in seismically active mines, based on the case history data described in Heal (2010) and Heal et al. (2006) (Figure 1).

The drop tests provide results from individual support elements that somehow need to be combined for the purpose of designing a complete support system. As an initial step, it is useful to take the results from the reinforcement and the surface support (Figure 3) and compile them on the same graph (Figure 4).

In Figure 4 three shaded zones are delineated; the top zone is an approximation of the quasi-linear trend from testing reinforcement elements, the bottom zone includes most surface support results excluding rope lacing, which are re-grouped in the middle zone of the graph. It is readily apparent from this that the weakest link will be the surface support, which has only a fraction of the energy capacity of the reinforcement.

Summary and conclusion

A number of research initiatives involving laboratory drop tests were undertaken during the last two decades on the premise that the calculation of the capacity of ground support systems submitted to dynamic loading can be assisted using the results from such tests. However, no clear guidelines have yet emerged from this research. Observations from rockburst damage have shown that the weakest link of support systems submitted to dynamic loading is often the surface support or the connection between the surface support and the reinforcement. Considering that a system is only as strong as its weakest link, a conservative assumption would be to use the energy absorption capacity of the surface support as the capacity of the overall support system. This assumes that the amount of energy absorbed by the reinforcement is negligible and is seen as a conservative assumption. Figure 3 provides a compilation of published energy absorption results from drop testing different surface support. Most surface support systems, with the exception of cable lacing, have an energy absorption capacity of less than 10 kJ.

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Dr Yves Potvin,
Australian Centre for Geomechanics

Mine seismicity and rockburst risk management project – phase V

by Dr Johan Wesseloo

MSRRM project

The ACG Mine Seismicity and Rockburst Risk Management (MSRRM) project commenced 13 years ago as a MERIWA sponsored project and is now in its fifth phase. The project continues to focus on improving the methods for managing the risks that mine-induced seismicity presents to personnel safety and financial investment. This is achieved, broadly speaking, by tackling the problem at two fronts. The first being the understanding of the rock mass response to mining, the second, being the design of dynamic support.

The MSRRM project started under the leadership of Associate Professor Marty Hudyma, Laurentian University, Canada who lead the first two phases of the project. Dr Dan Heal, BHP Billiton, Group Resource and Business Optimisation, Mineral Resource Development lead the project during its third phase and the ACG's Dr Johan Wesseloo is currently leading the project.

The fifth phase of this MERIWA sponsored project now focuses on three key areas: probabilistic seismic hazard assessment, re-entry protocol and support design.

The human capital

The development of human capital is one of the ways industry continues to benefit from this project. Since 1999, many postgraduate and undergraduate students have formed part of this project team. An incredible 5 PhD theses, one Master thesis and many undergraduate projects have been accomplished during this time.

Through highly valued industry sponsorship of the project, we can continue this good tradition of developing relevant skills and knowledge for industry by expanding the project team with more bright minds from Australia, Chile and China. Our current students are Kyle Woodward, UWA and Juan Jarufe from Codelco Chile. In 2013, Longjun Dong from China will be joining the team for a year and Dan Cumming-Potvin, UWA will also come onboard as a postgraduate student. Wei Duan, a UWA fourth year student, joined the team this year. After completing his undergraduate studies, Wei will be a project research assistant.

Kyle's research focuses on the seismic response to blasting. Juan's efforts are focused on understanding and effectively modelling major shearing events in mining environments. These two projects fall into the project's first key area: the understanding of the seismic response.

MS-RAP

Undoubtedly one of the major benefits to the 19 current project sponsors is the software, MS-RAP. The software was originally developed during the first phases of the project to fill an industry need at the time. It has proven to be an essential technology transfer tool as it enables the sponsor sites to implement the results of the research. For this reason, the continued development of this software is an important part of the project. The ACG recognises the remarkable achievements of Paul Harris, who came onboard as the project's software engineer in 2001, to develop and implement this world class technology. The MS-RAP software continues to be an effective tool in helping mine site staff to manage the myriad of data and respond more proactively to hazards posed by mine seismicity and rockbursts.

Dr Johan Wesseloo,
Australian Centre for Geomechanics

Paul Harris,
Australian Centre for Geomechanics

MSRRM Research Project PhD and Master Theses

Dr John Albrecht – Delineating rockburst damage to underground development subject to seismic loading

Dr Paul Duplancic – Characterisation of caving mechanisms through analysis of stress and seismicity

Dr Daniel Heal – Observations and analysis of incidences of rockburst damage in underground mines

Dr Martin Hudyma – Analysis and interpretation of clusters of seismic events in mines

Dr Michelle Owen – Exposure model – detailed profiling and quantification of the exposure of personnel to geotechnical hazards in underground mines

Marc Reimnitz – Shear-slip induced seismic activity in underground mines: a case study in Western Australia

Phase V of this research project is financially supported by:

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An economic risk-based methodology for pit slope design

by Luis-Fernando Contreras and Dr Oskar Steffen

Introduction

The traditional approach to design overall slopes in open pit mines is based on the calculation of slope stability indicators such as the factors of safety (FoS) or the probability of failure (PoF), which are compared with acceptability criteria to define the acceptable slope angles used for the mine design. This methodology is applied within a design process that starts with the definition of bench configurations, proceeds with the stack (i.e. multiple bench) and inter-ramp slope layout and concludes with the overall slope angle definition.

In this article the authors describe a quantitative risk-based approach for overall slope design, where the economic impacts of slope failures are calculated and used as the elements on which to apply the acceptability criteria for design. The proposed risk-based approach is also consistent with a design philosophy where the overall slope angles are defined in accordance with the capacity of the rock mass and structural conditions by defining a pit layout with maximum economic benefit. This process is followed by determining the inter-ramp slopes based on local conditions and ramp layouts. Finally, the appropriate bench configurations are defined based on operational factors and the influence of local structures.

The proposed methodology is currently being used on various open pit projects, although still in its infancy at the present time. The methodology is presented through a simple example and it is hoped that, as results become available from actual projects, they could be used as case studies to illustrate the process.

Proposed risk evaluation approach

The risk evaluation process has been developed to assess the economic impact of potential slope failures on a quantitative basis. The approach described by Steffen et al. (2008) is based on event tree analysis, which is suitable for safety risk evaluation, but requires a greater degree of subjective judgment when used for an economic impact analysis. Defining an optimum slope angle implies steeper slopes for greater value and greater risk. The present acceptability criteria, i.e. FoS and PoF, are based on experience and intuition and can be converted to quantifying the risk in monetary value in the optimisation concept.

The risk evaluation process in the context of overall slope design is intended to facilitate the definition of pit geometry as a result of applying project specific criteria on the quantified risk costs. The approach includes the following steps:

1. Definition of alternative pit layouts covering a wide range of slope design options in terms of judged value and risk.
2. Calculation of the PoF of the slopes for the various pit areas and key years of the mine life.
3. Quantification of the economic impacts of slope failure with reference to the loss of value as measured by the net present value (NPV).
4. Integration of the results of PoF analysis and impact for the various areas and years of each pit option to define the economic risk map of each pit layout.
5. Construction of a graph of slope angle versus value and risk cost where the optimum slope angles can be defined.

Data requirements

In addition to the conventional geotechnical data required for the analysis of stability of the slopes, the following information is required for the risk-based analysis of the overall slopes:

- Pit shell representing the base case design (balanced risk class).
- Geometry of alternative pit shell layouts reflecting conservative and aggressive risk classes, as well as the upper limit slope angle design. These may be the result of optimisation runs (e.g. www.gemcomsoftware.com/products/Whittle).
- Production profile and cash flow model of the mine plan selected for the study.
- Simplified cash flow model of alternative pit shells. The cash flow model should include the more relevant items such as mine tonnages, plant ore feed, plant metal production, revenue, capital costs, operating costs and other relevant costs. Operating costs should differentiate mining costs with an indication of their fixed and variable components.

Pit slope options

The overall slope angle defined with the traditional approach based on FoS or PoF criteria represent the base case pit layout and is considered to correspond to a 'balanced risk' class. For the risk evaluation analysis, additional slope angle options are required to define the relationship between the slope angle and

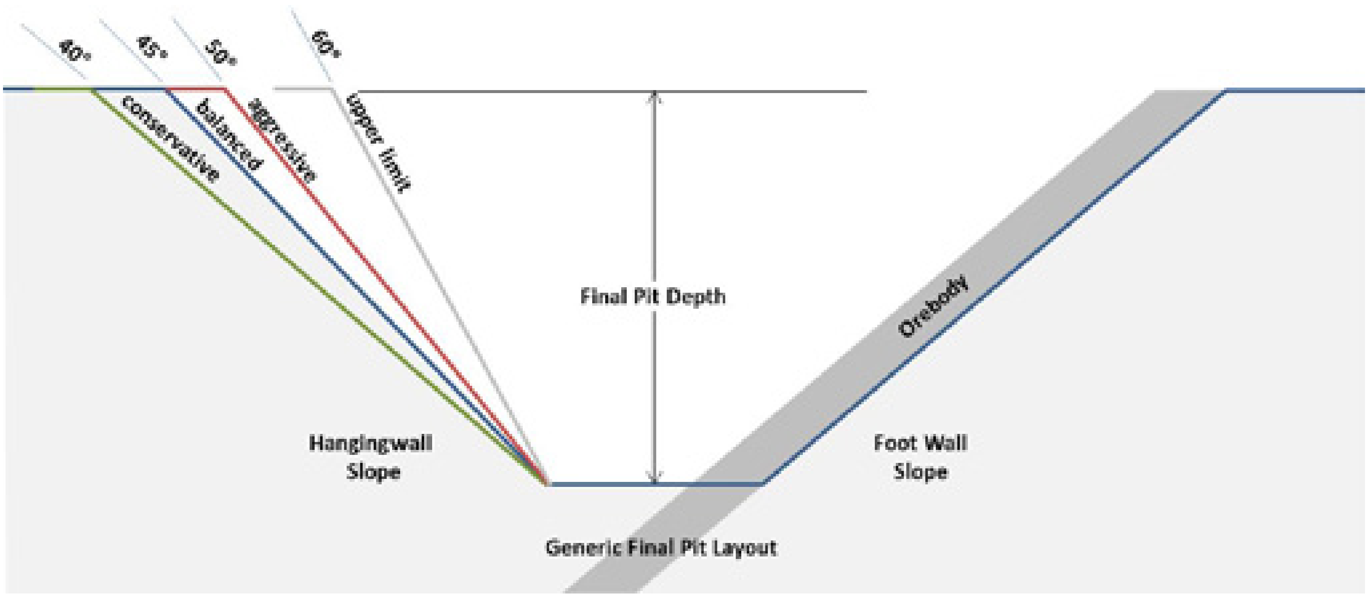


Figure 1 Typical pit slope configuration for risk-based analysis

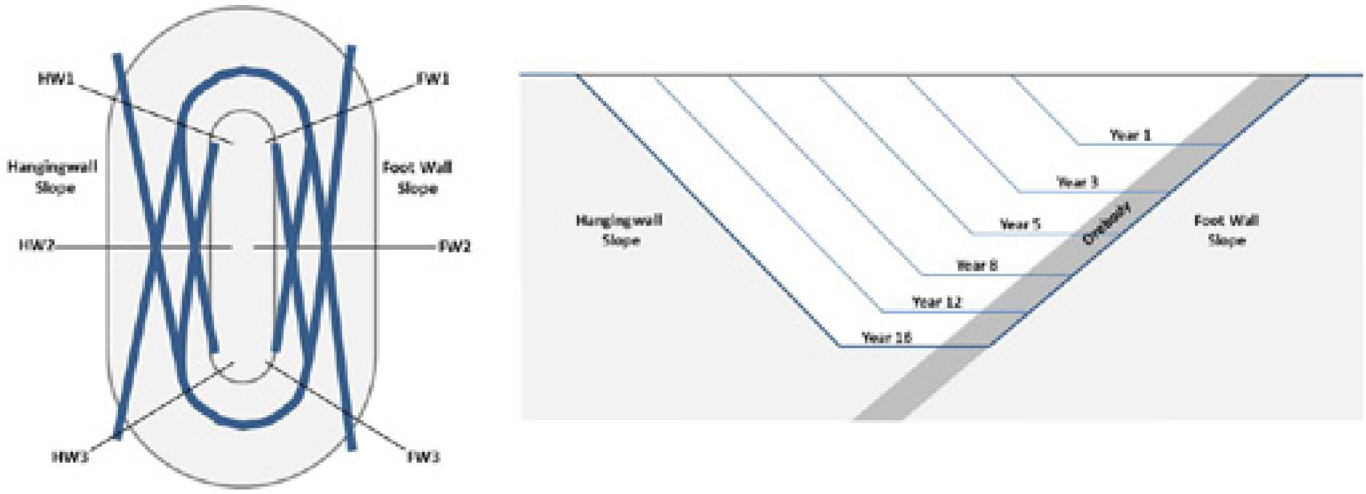


Figure 2 Schematic plan of a pit with the location of selected sections for slope analysis (left), and an illustration of conceptual pit development with slope geometries for years of analysis (right)

the value and risk condition of the pit layout. The schematic cross-section of the pit shown in Figure 1 illustrates an example of a hangingwall slope option to be considered for the risk analysis. In this case the 'balanced risk' option corresponds to a 45° hangingwall, with optional layouts of 40° and 50° to represent the 'conservative' and 'aggressive' design cases, respectively. The upper limit angle of 60° included in the section represents the steepest angle which is included in the analysis in order to define the expected upper bound conditions of value and risk of the project.

PoF of the slopes

The risk evaluation process requires the definition of a programme of slope stability analysis including the critical pit areas and years in terms of potential economic impacts of eventual slope failures. This means that besides adequate information on geotechnical conditions defining the likelihood of failures, a good understanding of the mine plan is required to identify those areas and years prone to bigger impacts.

The pit layout sketched in Figure 2 shows the sections and years of pit development used for illustration of the risk process. The six sections represent the various domains of the pit and the six years represent key periods of mine development. Therefore, the risk evaluation process includes the analysis of 36 potential failure events.

The results of the slope stability analysis are reported in terms of PoF values which are calculated with the appropriate slope stability models, in accordance with the relevant failure mechanisms in each sector. In general, programs based on limit equilibrium analysis considering either rock mass or structurally controlled failure mechanisms are used for this purpose. Most of these programs have built-in routines based on a Monte Carlo technique that enable a relatively quick calculation of the PoF values. Alternatively, the stability analysis can be carried out with more elaborate models based on stress–deformation analysis, but in these cases the calculation of PoF values requires additional steps carried out externally to the numerical models.

Judgement needs to be exercised when deciding the appropriate methods of stability analysis to be used in a particular situation in order to have a balance between practicality and rigorousness. Simple methods of analysis might be sufficient in early screening studies where general trends of stability based on geotechnical domains and slope geometry need to be defined. More thorough methods of analysis might be required for the risk evaluation of defined mine plans in the advanced stages of a study.

Economic impact of slope failure events

The measure of value of each pit option considered is based on the calculation of the corresponding NPV. The NPV is normally defined as the result of a mining scheduling and optimisation process carried out with specialised software. In general, the economic impact of a slope failure event is derived from the disruption of the planned ore feed during the time required to restore the site affected, and from the additional costs caused by these activities. One way to quantify the economic impact of a failure consists of calculating the NPV incorporating the effects of the failure event. The difference

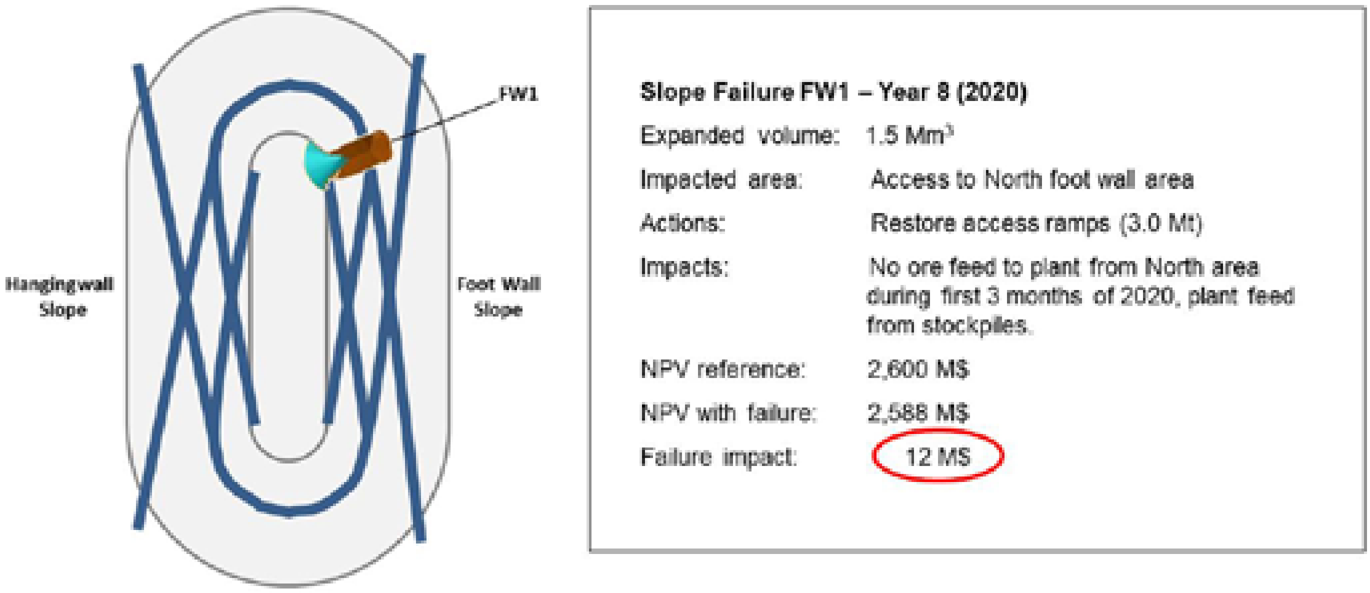


Figure 3 Illustration of the simplified estimation of the economic impact of a failure event

Table 1 Structure of simplified cash flow model for slope failure impact assessment

Description	Unit	Total	Mine Plan of Reference					Total	Mine Plan Including Slope Failure Effect				
			2013	...	2020	...	2028		2013	...	2020	...	2028
Production values (per Phases)													
Mined tons	kts												
Grade	%												
Ore tons	kt												
Waste tons	kt												
% impact on production	%		0%	0%	0%	0%	0%		0%	0%	5%	0%	0%
Production values after impact													
Tons to plant	kts												
Grade	%												
Recovery	%												
Metal tons	kt												
Tons to stockpiles	kts												
Tons to waste dumps	kt												
Revenue													
Metal Price	$/lb												
Revenue	M$												
Operation Costs	M$												
Mining costs	$/ton												
% impact on mining costs	%		0%	0%	0%	0%	0%		0%	0%	30%	0%	0%
Mining costs after impact	$/ton												
Plant costs	$/ton												
Others costs	$/ton												
Capital Costs	M$												
Net Benefit	M$		297.1	428.1	154.8	192.5	298.8		297.1	428.1	130.0	192.5	298.8
Discount Rate	%	8%						8%					
NPV	M$	2,600						2,588					
				Estimated Slope Failure Impact				12	M$				

between the NPV of reference (without failures) and the NPV with failure would provide a measure of the economic impact of the event.

The impact calculated in this way would correspond to a condition without mitigation. In a real-life situation, specific re-designs of the plan would be carried out to minimise the impact. The described approach for calculating the impacts of failures would be appropriate for a detailed risk evaluation of a defined mine plan. However, the methodology would not be practical at an early stage of study, and a simplified approach based on a simplified cash flow model is required.

The simplified approach to quantify the impact of a failure event consists of calculating the differential NPV due to the failure, using a cash flow model where the estimated failure effects on production and costs are included. The impact factors are defined in percentage terms using engineering judgement or reference calculations and are related to factors such as magnitude, location and time of occurrence of the failure, and flexibility of the mine plan to provide alternative ore feed sources. The simplified cash flow model should include production data per phase, operating and capital costs, and needs to be calibrated against the NPV of reference of the mine plan.

An example to illustrate the simplified estimation of the economic impact of a failure event is shown in Figure 3 (FW1). This case is assumed to represent a potential failure in section FW1 during year 8 of the mine layout shown in Figure 2. The structure of the simplified cash flow model used for this calculation is shown in Table 1. In this example the relatively small impact on production estimated in spite of the critical location of the failure is due to the fact that plant feed is maintained with stockpiles, with the impact being caused by the variation in the planned ore grade.

Economic risk map of pit options

The results of PoF and economic impact of individual failure events are used to construct the economic risk map per year and for the mine life. The risk map defines the relationship between the probability of having a particular economic impact and the magnitude of that impact; and accounts for different situations of occurrence of the events, including isolated, mutually exclusive and concurrent occurrences for the different possible combinations of the events in a year. The probability concepts used for this analysis are described below.

Considering that all the slope failures evaluated are independent events, it is possible to calculate the probability of occurrence (P) and the associated economic impact (I) of the different possible combinations of events in a group, which for the present analysis correspond to the events in a year. There are three possible situations for this calculation:

1. Occurrence of isolated events represented by the PoF and the corresponding impact of each event evaluated in a particular year of the mine life:

   P = PoF.

   I = economic impact of failure.

2. Occurrence of any of the events in a group of *r* events (mutually exclusive occurrence), with a probability equivalent to the addition (using the reliability concept) of the probabilities of the individual events and an impact of at least the minimum of the individual impacts:

   $P = 1 - (1\text{-}PoF_1)\times(1\text{-}PoF_2)\times\ldots\ldots\times(1\text{-}PoF_r)$.

   $I = \text{Minimum}\ (Impact_1, Impact_2, \ldots\ldots, Impact_r)$.

3. Occurrence of all the events in a group of *r* events (concurrent occurrence), with a probability equivalent to the product of the probabilities of the individual events and an impact corresponding to the sum of the individual impacts:

   $P = PoF_1\times PoF_2\times\ldots\ldots\times PoF_r$.

   $I = Impact_1+Impact_2+\ldots\ldots+Impact_r$.

A summary of the operators used for the probabilistic evaluation of likelihood and impact of combination of events per year is presented in Table 2. The 57 Number of Cases for combinations of events indicated in this table corresponds to the particular situation of six failure events per year.

The generic expression to calculate the number of combinations (N) of 2 or more events that can be obtained with a total number of events (n) is:

$$N = \sum_{r=2}^{n} \frac{n!}{r!\,(n-r)!}$$

To illustrate the construction of the economic risk map with the methodology described, values of PoF and economic impact were assigned to the six sections for the six years of analysis of the pit sketched in Figure 2

Table 2 Operators and number of combinations of failure events

No.	Time Frame of Analysis	Condition	Operator PoF	Operator Impact	Number of Cases	Number Points Risk Map
1	Year	Occurrence of individual events			6	120
2		Ocurrence of any of the events in a group	OR	MIN	57	
3		Occurrence of all the events in a group	AND	SUM	57	

Note: The number of possible combinations for a year with six events is 15 cases of two events + 20 of three events + 15 of four events + six of five events + one of six events = 57 possible combinations.

Table 3 Example of results of economic impact analysis

Year Mine Plan		1		3		5		8		12		16	
Year		2013		2015		2017		2020		2024		2028	
No.	Section	PoF %	Impact M$	PoF %	Impact M$	PoF %	Impact M$	PoF %	Impact M$	PoF %	Impact M$	PoF %	Impact M$
1	FW1	6.4%	15.0	10.5%	42.0	14.7%	23.0	10.6%	12.0	27.6%	13.0	33.6%	10.0
2	FW2	4.2%	12.0	6.7%	25.0	6.9%	17.0	11.1%	15.0	8.2%	14.0	25.6%	5.0
3	FW3	4.1%	5.0	3.4%	16.0	6.1%	12.0	13.6%	18.0	15.6%	12.0	28.3%	6.0
4	HW1	3.4%	10.0	7.7%	30.0	7.2%	20.0	9.0%	12.0	6.7%	10.0	18.2%	4.0
5	HW2	2.0%	15.0	17.6%	35.0	10.8%	16.0	18.1%	10.0	13.2%	15.0	27.0%	7.0
6	HW3	3.1%	14.0	6.0%	17.0	6.1%	9.0	6.2%	14.0	16.4%	14.0	22.9%	3.0

Note: Mine plan for 'balance design' (overall slope angle 50°); starting year of plan: 2013. NPV without risk 2,600 M$.

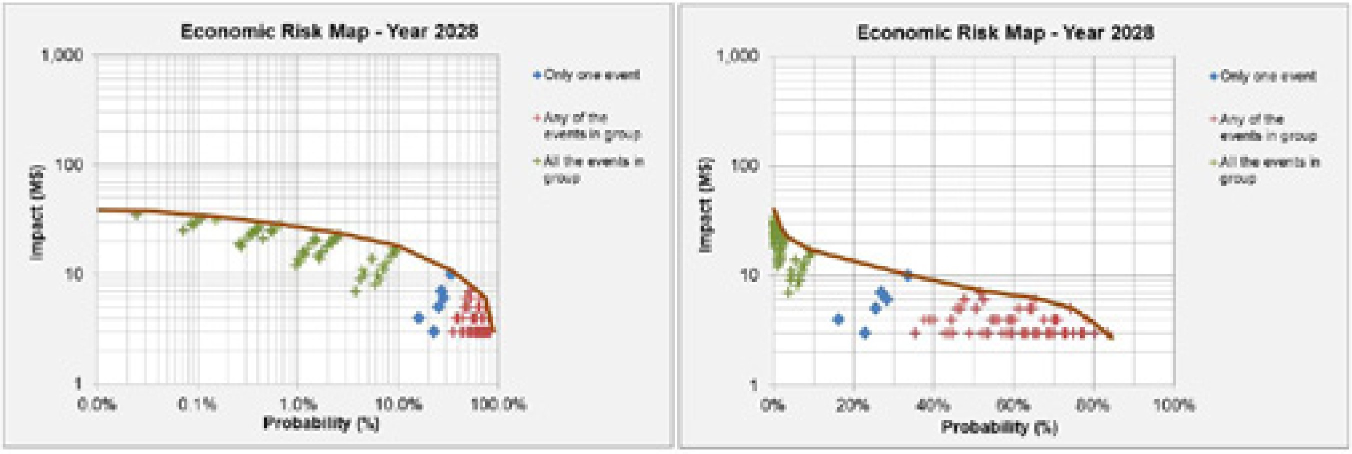


Figure 4 Construction of the envelope defining the economic risk map for year 2028 of the example in Table 3; logarithmic scale for clarity of high impacts (left) and normal scale to show detail of low impacts (right)

and summarised in Table 3. In this example the impact of section FW1 in year 8 corresponds to the case presented in Figure 3. The resulting risk map for year 16 of the mine plan is shown in Figure 4. The graphs show the relationship between the probability of occurrence of slope failure events and the associated economic impact value. The six blue dots in the graph correspond to the occurrence of individual events, the 57 red dots represent the mutually exclusive occurrence of the possible combination of events, and the 57 green dots correspond to the concurrent occurrence of those combinations of events. The probability axis in the left graph of Figure 4 is displayed in a logarithmic scale to enhance the detail of the high impact low probability occurrences. The envelope to the points plotted defines the economic risk map profile of that year.

Following this procedure for each of the years evaluated, the complete economic risk map for the life-of-mine can be constructed, as shown in Figure 5. The risk envelope representative of the life-of-mine situation is constructed by

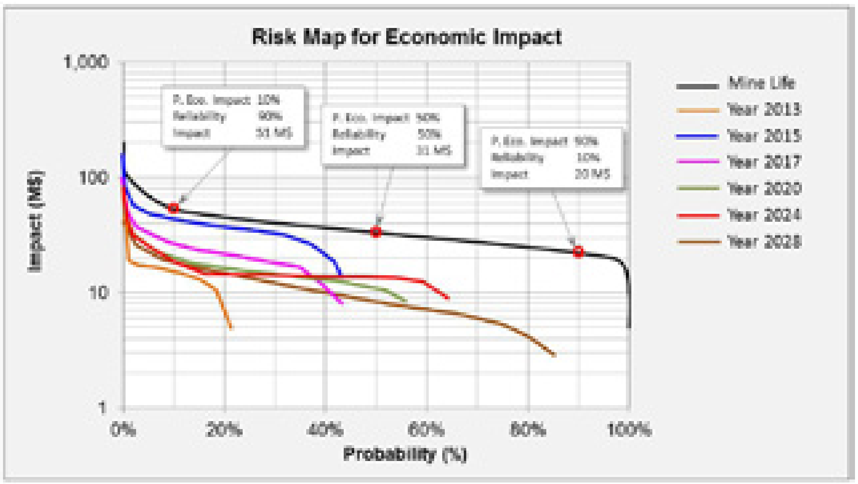


Figure 5 Risk map for economic impact based on the data of Table 4

compounding the probabilities of the various years for fixed values of impact. In this particular example the life-of-mine probability of economic impact (PLOM) for a given impact is calculated from the corresponding annual probabilities using the following expression:

$$P_{LOM} = (1-P_{2013})^2 + (1-P_{2015})^2 + (1-P_{2017})^3 + (1-P_{2020})^4 + (1-P_{2024})^4 + (1-P_{2028})$$

For this calculation it is assumed that the annual probabilities represent the situation of the periods defined by the selected years of analysis, thus accounting for the total duration of the mine, which in this example corresponds to 16 years.

Value and risk as slope design criteria

The risk map for economic impact, as described in the previous section, not only enables the identification of those years of more relevance in terms of potential economic impacts, but also provides information regarding the critical pit areas causing those risks. When the risk map is based on detailed data and thorough geomechanical and economic analysis, it can be used to optimise the respective mine plan by comparing this result with project specific acceptability criteria. The result is valuable for the definition of the areas requiring more investigation in further stages of study, and for the evaluation of mitigation strategies to reduce the risks.

In the context of overall slope design in an early stage of a project as discussed in this article, the risk map is meant to be used for a first screening of options and could be based on general input data and simplified analysis. In this context the result is used to define the risk cost of the pit options evaluated and with this information to construct the value and risk profile for changing slope geometries.

The risk cost(s) of impact of slope failures has an inverse relationship with the probability of incurring this cost, with higher probabilities of having small impacts and conversely, lower probabilities associated with the occurrence of big impacts. Therefore, the risk cost calculation requires the definition of the reliability level of the analysis, where:

Reliability = (1–Probability of Economic Impact)

The typical results of a risk-based analysis of economic impact for overall slope design are shown in Table 4 and Figure 6. These results present the variation of value (NPV) and risk cost for different overall slope angles. To illustrate the method it is assumed that the balanced design case corresponds to the example described in the sections on economic impact. Therefore, a reference NPV of 2,600 M$ and risk cost values of 51, 31 and 20 M$ for reliability levels of 90, 50 and 10%, respectively, extracted from the graph in Figure 5, have been assigned to the 50° slope angle case. The results for other slope angles were assumed for illustration purposes.

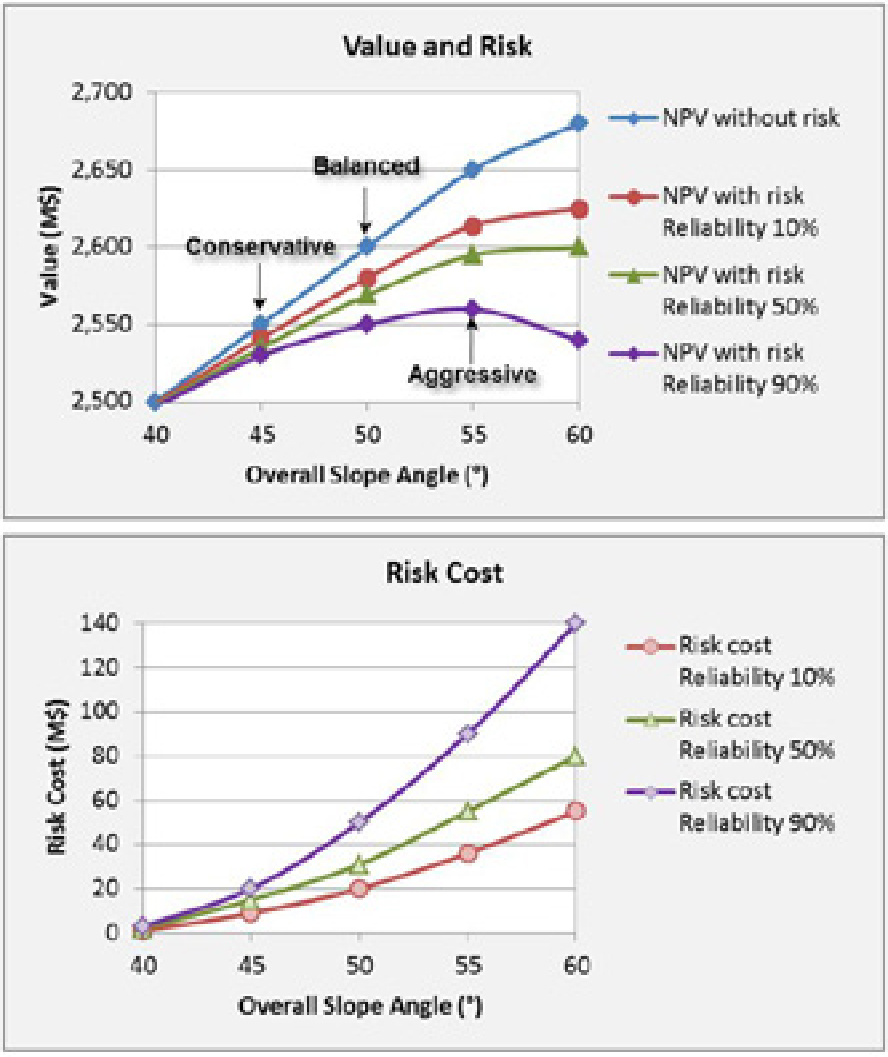


Figure 6 Typical results of risk analysis in terms of economic impact

The graph at the bottom of Figure 6 shows the typical increase of risk cost with increasing slope angles for various reliability levels. The risk cost values were used to construct the NPV with risk curves shown in the graph at the top of Figure 6. This graph shows a rapid increase in NPV with increasing slope angle when no risk aspects are considered. However, once the risk cost is included in the analysis, the rate of increase of value reduces for slope angles steeper than 55° and the NPV could reduce as in the case for the 60° slope with 90% reliability.

Information, such as that included in Figure 6, constitutes a valuable tool to optimise the pit design and to bracket the overall slope angles for further phases of study.

Table 4 Example of risk-based slope design data

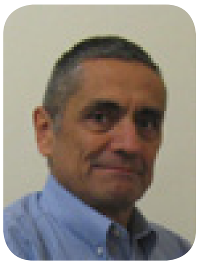
Case No	Slope Angle (°)	Design Class	NPV (M$)	Risk Cost (M$)			Risk Cost (%NPV)			NPV with risk (M$)		
				Rel 90%	Rel 50%	Rel 10%	Rel 90%	Rel 50%	Rel 10%	Rel 90%	Rel 50%	Rel 10%
1	40	minimum	2,500	3	2	1	0.1%	0.1%	0.0%	2,497	2,498	2,499
2	45	conservative	2,550	20	15	9	0.8%	0.6%	0.4%	2,530	2,535	2,541
3	50	balanced	2,600	51	31	20	2.0%	1.2%	0.8%	2,549	2,569	2,580
4	55	aggressive	2,650	90	55	36	3.4%	2.1%	1.4%	2,560	2,595	2,614
5	60	maximum	2,680	140	80	55	5.2%	3.0%	2.1%	2,540	2,600	2,625

Note: Rel: Reliability = (1-Probability of Economic Impact from slope failure).

Conclusions

The methodology presented provides a rational approach to define at an early stage of a mine, the main features of pit geometry reflecting the appropriate balance between value and risk, in accordance with the specific conditions of the project. The process considers both the likelihood of occurrence of individual slope failure events and the resulting economic impacts from all possible combinations of occurrence of these events on an annual basis and for the mine's life. The economic risk maps constructed for each pit slope option evaluated, permits the quantification of the risk cost for a defined reliability level. Risk cost estimations enable the determination of project value variations, including risk with changes of the slope angle, and provide an adequate tool to define the optimum geometry for mine design.

Please click here for article references.



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Tailings: dammed, damned or damless

Tailings dams are long-term hazards, and must remain stable in the landscape long after we are no longer there to monitor and maintain them writes Andy Robertson.

The dragon's message is becoming increasingly clear – 'become damless or get out of dodge – and no, you cannot have our water either'. Photo by Andy Robertson

Dammed tailings

The largest mines have increased their production, tons milled per day, by an order of magnitude every 30 years, for the past 120 years. In the late 1800s the largest mines milled a few 100s of tons of ore per day. Today our largest mines mill a few 100,000s of tons per day. Quantities of tailings have grown in proportion, and to store them our largest tailings dams have had to increase in volume from a few millions of tons capacity to several billions. Areas occupied by individual dams have increased from a few hectares to many square kilometres. Maximum dam heights have increased from less than 20 m to approaching 300 m – giants on the landscape.

Damned tailings

In constructing these tailings dams we are no longer merely doing earthworks – we are terraforming, or changing the face of the earth with gargantuan structures that will remain on our landscape in perpetuity. These huge structures store vast quantities of water and liquefiable solids that could flow if the dams breach. They are long-term hazards, and must remain stable in the landscape long after we are no longer there to monitor and maintain them. In the view of the downstream communities, we are not terraformers, but terror fermenters. And to add insult to potential injury, we steal their water and pollute their environment. In metaphorical terms 'we have tickled the dragon' of society. The dragon is waking and is becoming hostile to the threats we pose. Our tailings dams are increasingly 'damned' and our water usage and seepage abhorred.

Damless tailings

The dragon's message is becoming increasingly clear – 'become damless or get out of dodge – and no, you cannot have our water either'.

Lessons in damlessness

Our weapons for survival are filtered paste and thickened tailings, as well as mechanically and hydraulically stacked tailings – all technologies that may offer opportunities to eliminate or reduce the sizes of containment dams, reduce water use and seepage and produce dry, stable landforms at closure. From 16–19 June 2013, our specialists, and those seeking specialists in these defensive technologies, will meet at Paste 2013 in Belo Horizonte, in the State of Minas Gerais, Brazil, to share knowledge and experience to better address tailings disposal with reductions in the need for dams and minimisation of water usage.

The state of mines (and tailings)

The seminar setting is unique, in Belo Horizonte, the capital city of a state named 'General Mines' (Minas Gerais or MG) with a history of extensive mining that dates back to the late 1600s. In the early 1700s, nearby Ouro Preto was the capital of the state, the centre of a gold rush to the 'Eldorado' of the Portuguese Empire and a flourishing city with churches painted by the leading religious painters from Europe. Since then, the state capital has moved on to Belo

'And to add insult to potential injury, we steal their water and pollute their environment'

Horizonte; while Ouro Preto has remained, with the period architecture, complete with the churches of the early 1700s, a rich mining culture and the leading mining university in Brazil. A UNESCO primary heritage site, Ouro Preto is one of the best preserved monuments to the economic and cultural benefits of mining. Ouro Preto is a three hour drive from Belo Horizonte and is the destination for one of the site tours.

MG is blessed with rich iron ore bearing formations, which have given rise to a large number of open pit iron ore mines. These mines, located mainly in an area named the Iron Ore Quadrilateral, within three hours' drive from Belo Horizonte, have provided the prosperity that makes MG one of the 'have' states of Brazil and a focus for mining and industrial development.

Across the rich minefields of the Iron Ore Quadrilateral, there has developed a patchwork of open pit mines, tailings dams and waste dumps amongst suburbs, towns and villages that share the prosperity derived from mining. Recent intensive development of mines, resulting from the sustained 'super boom' in mined resources, has led to intense competition between mines needing land and water for mine development and increasingly affluent communities seeking to preserve their natural environment. This has forced mines to develop tailings facilities on less favourable sites, and to adopt technology that minimises impacts and risks to the downstream population, and also to consume and/or contaminate less water. One new methodology is to cyclone split the sand and slimes and then place the sands in hydraulically deposited sand stacks which can be drained and cease to be dams, while containing the slimes in smaller dams or disposing of them in exhausted mine pits. The future of iron ore mining in this region increasingly depends on finding solutions that further develop and adopt dam reduction and water conserving technologies.

The bauxite and aluminum industries of the Brazilian north (Amazonia) produce very fine tailings that settle to high void ratios and occupy large volumes. Filtering of these fine tailings has been found to be remarkably effective, allowing mechanical transport and stacking. There is currently a substantial swing in the industry towards this form of tailings management.

With the advances being made in the various methods of tailings dewatering using thickeners and filters, and the distribution and placement methods for paste, thickened and filtered tailings, it is only a matter of time before there is more extensive use of these technologies. A substantial number of evaluations have been made or are underway. This interest is likely to intensify.

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Paste 2013

The 16th International Seminar on Paste and Thickened Tailings will be held in Belo Horizonte, Brazil in June 2013. Visit www.paste2013.com or email paste2013@infomine.com for further information.

Germano Jusante, Samarco Mining Co., example of sand stacking. Photo courtesy of the Brazilian Commission on Tailings Dams (CBDB)

A practical study of the Movement and Surveying Radar in mining

by Alex Pienaar

Slope failures are an unfortunate reality of open cut mining. A seemingly arbitrary combination of uncertain stresses, strains and volumetric changes could potentially be catastrophic even in mines with the most conservative of slope designs.

Gone are the days where geotechnical engineering was limited to the confines of the design process and only seen as a consultation device. Safety and productivity in modern day open pit mines greatly depend on the notion that geotechnical engineering should be an integrated approach, with the most important attribute being the monitoring of rock slopes and the interpretation of measured data.

The utilisation of radar technology within the mining industry, when compared to other technologies, is a relatively new concept. It has, however, already proven to be setting a new standard in terms of geotechnical monitoring. The Movement and Surveying Radar (MSR) uses state-of-the-art radar technology to accurately track movement to within less than 1 mm over distances up to 2500 m. Measured data is provided to the geotechnical engineer in near real-time on a 24/7 basis and more often than not, in the harshest of atmospheric conditions.

In this article the effectiveness of the MSR, both as a safety measure and also as a productivity tool, is demonstrated by means of real-world exhibits and case studies taken from across the globe.

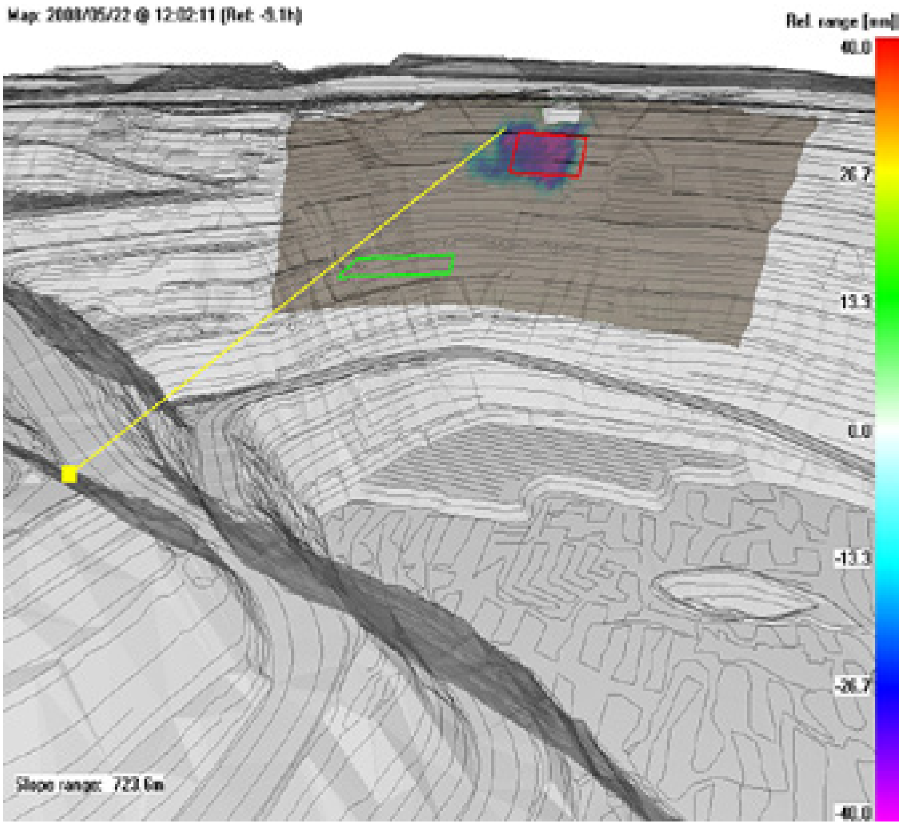


Figure 1 The mine's DTM fully integrated with the radar's synthetic map providing all weather, 24/7 functionality

Application of the MSR in mining

The MSR was designed to specifically operate reliably under harsh mining conditions and provides fully geo-referenced data accurately. This allows on-system integration of the radar's synthetic map with the Digital Terrain Maps (DTM) of the mine, which in turn enables the system to function without the dependence on light, visibility or any other unfavourable atmospheric condition (Figure 1).

Data regarding the different digital model layers on a site can be imported to allow correlation of radar-based displacement data for specific material types, joints and faults located in the mine slopes (Figure 2). This ensures accurate monitoring and facilitates rapid response to any anticipated slope failure.

Seamlessly integrating radar data with established slope monitoring systems and methodologies (e.g. prism monitoring) plays a pivotal role in assisting geotechnical engineers to understand overall slope behaviour. The functionality to directly interface with data from an Automatic Total Station database is one example of such integration. As a result, the geotechnical engineer is able to quickly review and identify changing slope conditions (Figure 3).

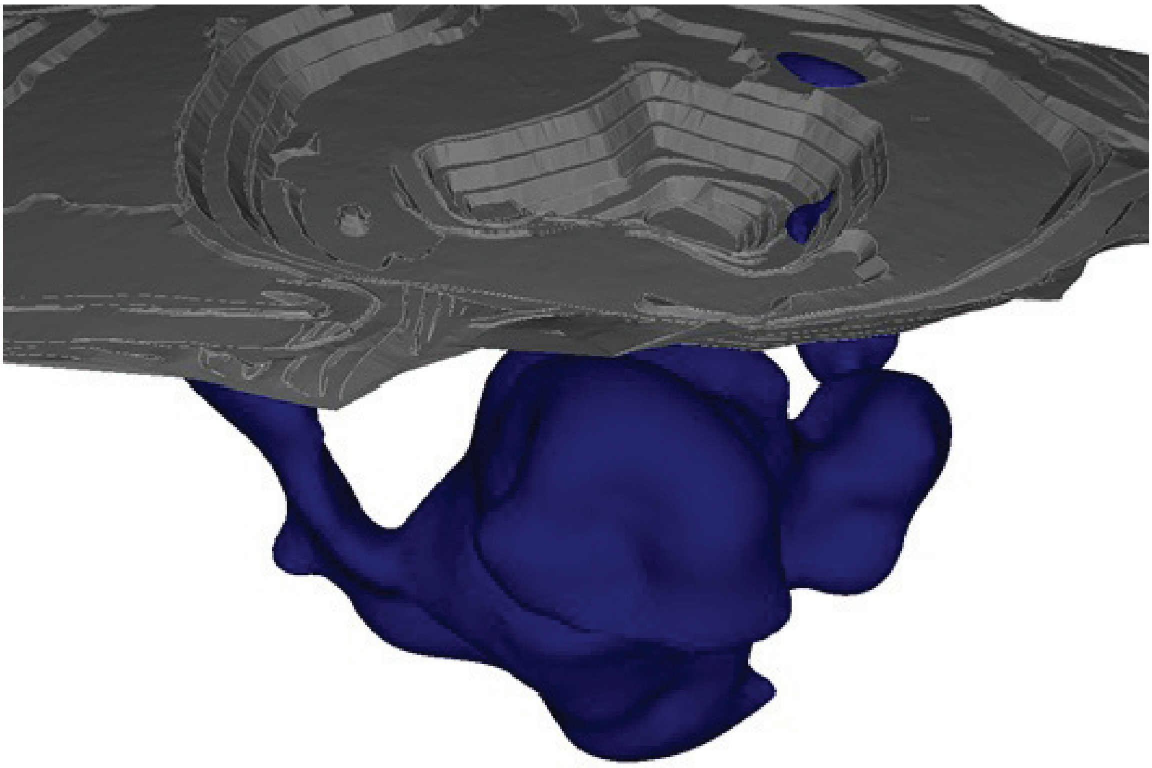


Figure 2 Imported DTM correlated with a model of a weak rock mass. Area of intersection between the rock mass and the slope face combined with measured data would typically prompt more conservative mining activity

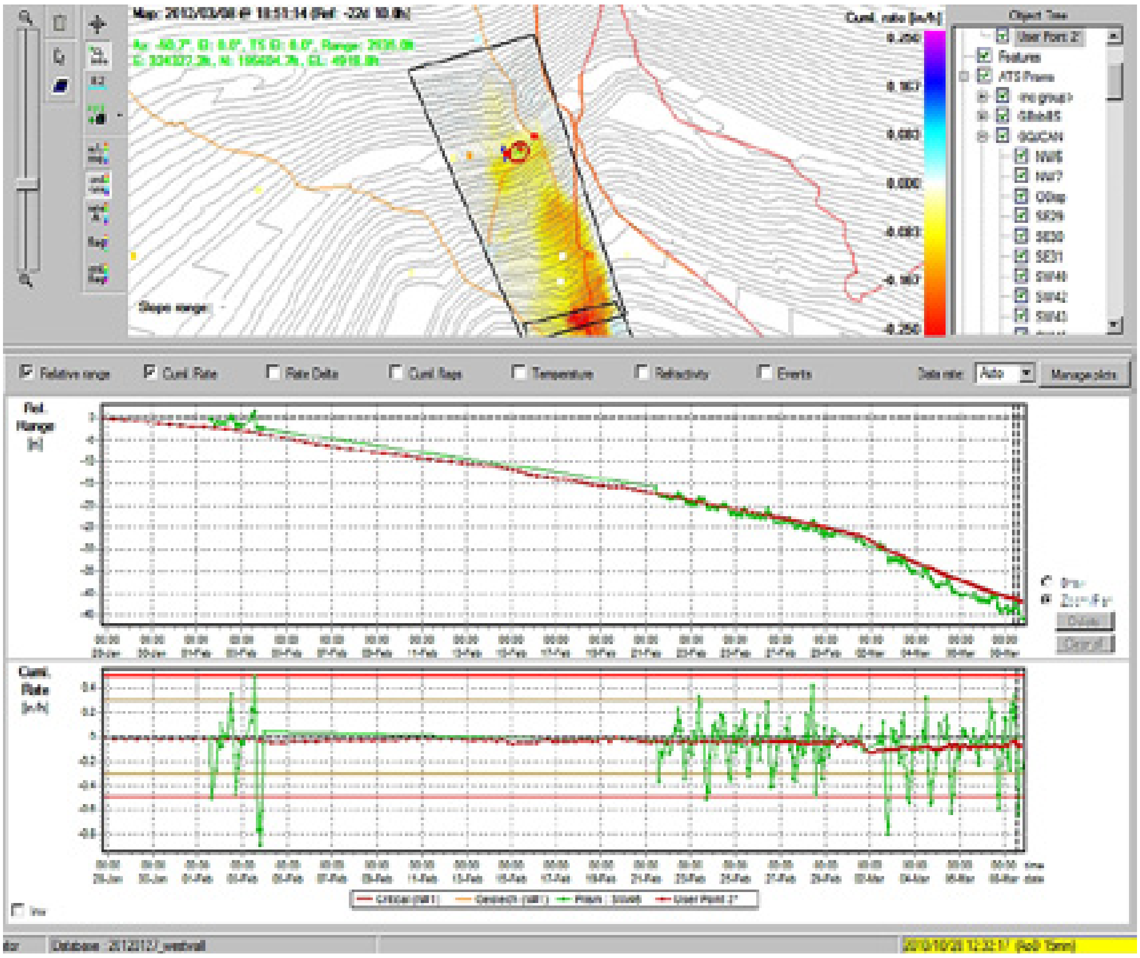


Figure 3 MSR screenshot showing prism points that are colour-coded based on the radar data scale. The red trace represents the radar data and the green trace represents the prism data

Case studies

Each of the subsequent mining operations that were studied made use of a MSR system that was responsible for monitoring the relevant slopes on a 24/7 basis. The case studies demonstrate how critical alarms were triggered as a result of movement exceeding pre-determined thresholds set up by the user, giving enough warning time for the evacuation of personnel and equipment in the affected area.

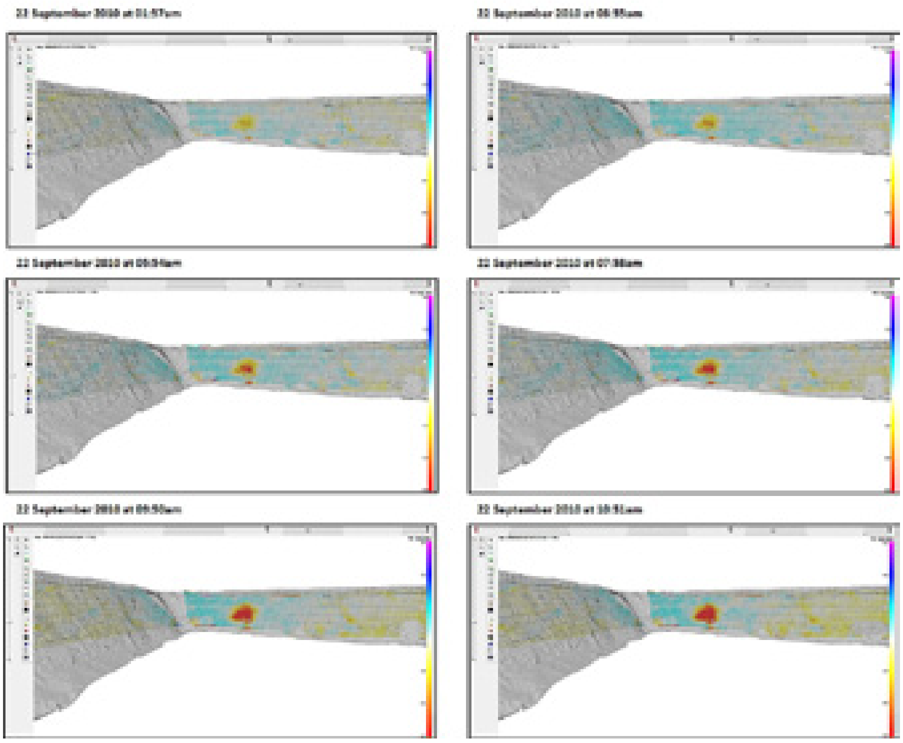


Figure 4 MSR screenshots on a displacement versus time basis, depicting the identification and tracking of a failure

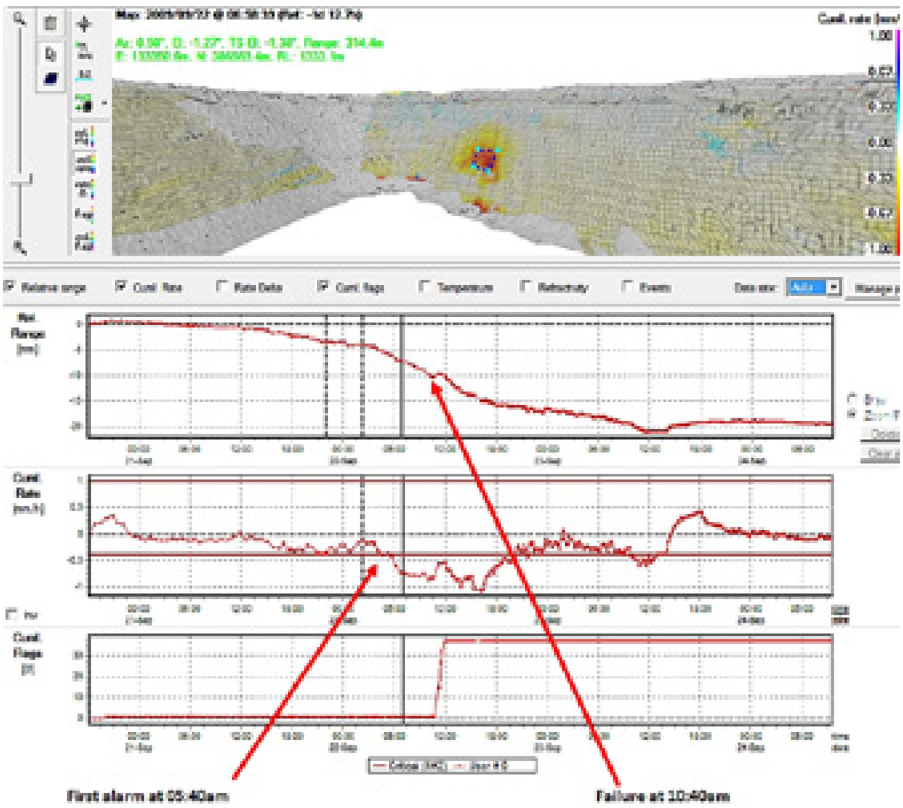


Figure 5 MSR trend plots showing movement trends of the entire area of failure. The cumulative rate (average velocity) alarm was triggered five hours before the actual failure

Case study 1 – United States

A MSR300 unit had to be deployed at the edge of the pit in a coal mine in the United States so as to ensure that there was no interference from blasting activities. The particular seam configuration at the area of interest meant that it was not possible to use crack meters or prisms. The MSR identified and tracked an imminent failure over a period of approximately nine hours (Figure 4). The first alarm was triggered five hours prior to the failure and provided ample time for evacuation (Figure 5) of the mine using established procedures.

Case study 2 – South America

A slope failure at a large open pit copper mine in South America resulted in a 20,000 tonne collapse directly on to a haul road. The failure developed over a period of 21 hours (Figure 6) and was detected six hours before it occurred by a MSR system operating at a range of 800 m. The warning provided sufficient time for the evacuation of personnel and equipment from the area. There were no resultant injuries or damage to equipment.

‘Advances in slope stability monitoring technology have improved significantly in recent years even though the basic functional requirements from the user in the field have largely remained unchanged’

Case study 3 – Africa

A MSR300 unit was deployed at a mine site in Africa to monitor the settling of previous failures as well as the development of new potential failures. Geotechnical engineers created high threat scan regions (red areas in Figure 7) where it was thought that movement could and should occur.

Movement unexpectedly developed outside the relevant areas of interest over a period of approximately 12 hours. It was however successfully identified (yellow area in Figure 7) and monitored due to the non-localised, large coverage area of the MSR system.

Conclusion

Advances in slope stability monitoring technology have improved significantly in recent years even though the basic functional requirements from the user in the field have largely remained unchanged. Current technological research and development is still being driven by the need for an integrated, highly accurate, real-time, all-weather monitoring system.

With MSR systems operating on mine sites in over 17 countries worldwide the high safety and productivity benefits associated with using this technology are growing ever more apparent. It is safe to say that this cost-effective mine safety and productivity management tool has become an industry standard on major open pit mines throughout the world.

Alex Pienaar,
Reutech Mining, South Africa

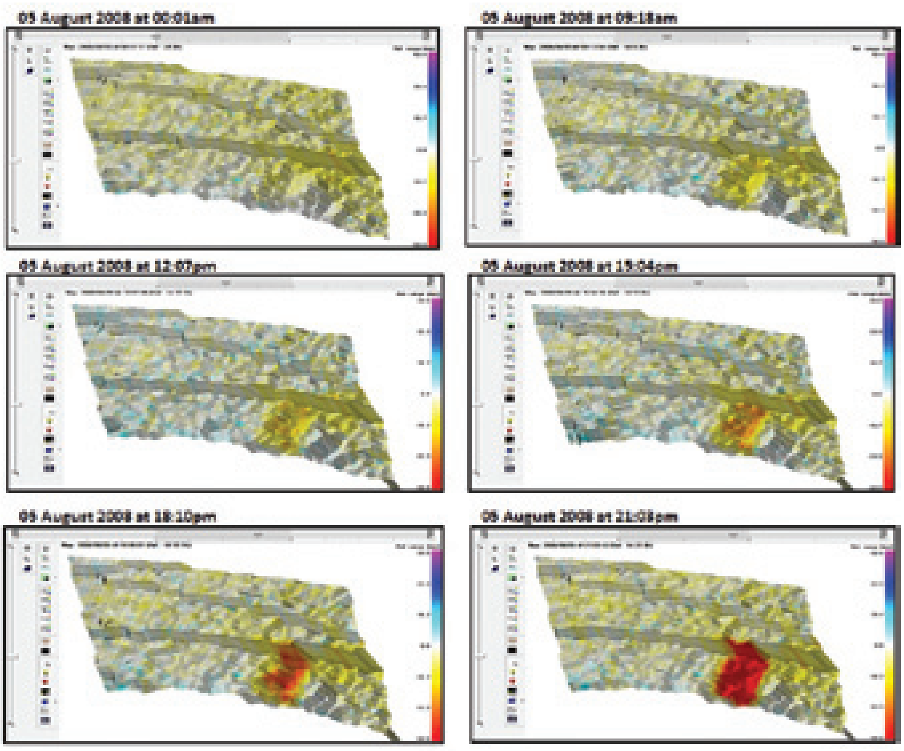


Figure 6 MSR screenshots on a displacement versus time basis showing the distinct development of a failure

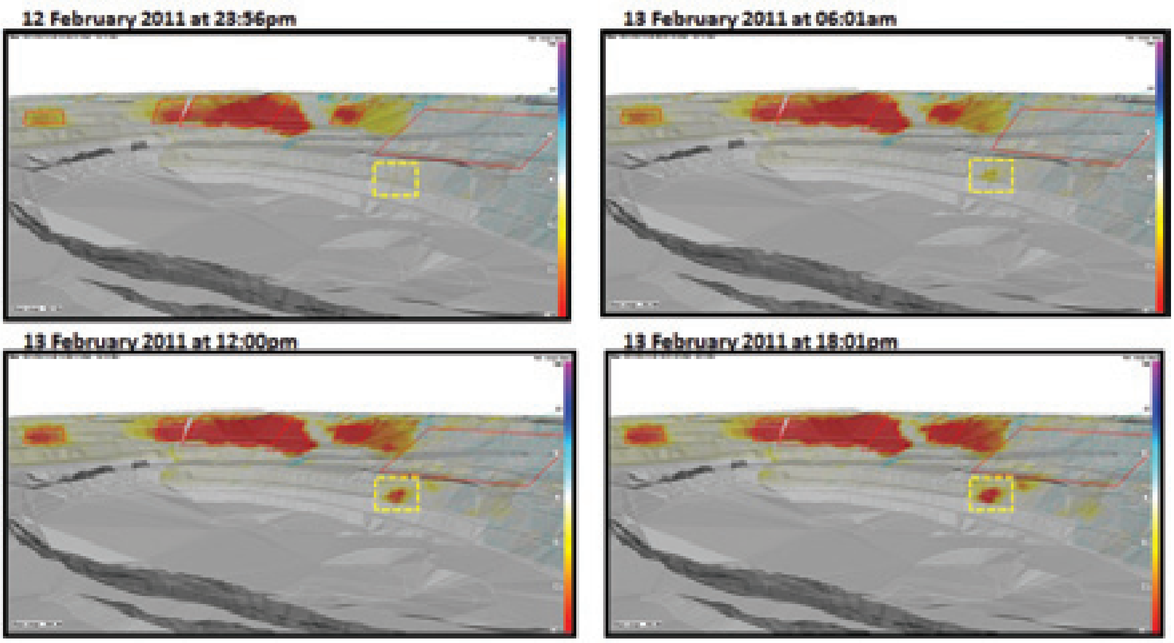


Figure 7 MSR monitoring unexpected movement (yellow area) developing over a period of 12 hours

Mine closure through the 21st century looking glass

Edited from ACG's Seventh International Conference on Mine Closure proceedings keynote paper as written by Caroline Digby.

Reinventing Cornwall

'Cornish lads are fishermen, and Cornish lads are miners too, but when the fish and tin are gone, what are the Cornish boys to do?' – graffiti on the wall of South Crofty tin mine.

When South Crofty, the last tin mine in Cornwall, closed in 1997, something akin to grief took hold of its surrounding communities. By that stage there were few employees, less than 400, so we were not primarily mourning the loss of jobs. The grief focused on loss of identity, on the end of 3,000 years of Cornish hard-rock mining, on our diminishing influence in the world and powerlessness to do anything about it. Mining was part of our culture, our sense of who we were. Now we were part of a homogenous global service economy, where, 'visitors will make the noise and order drinks from Cornish boys'. Proposals for structural regeneration of the area, including a mining history visitor attraction, have been greeted with weary cynicism.

The Eden Project was conceived in this climate. Its scale and ambition were greeted with incredulity, but this visionary project has brought more than £1 billion in economic benefit to Cornwall in the last 10 years and has laid the foundation for the entire county to reinvent itself as the green peninsula. The clay mining industry is spread over some 85 km^2 around St Austell, has a huge legacy of post-industrial land to address, and is facing major challenges of global competition, ageing infrastructure and rising costs. As an ex-china clay quarry, the Eden site is a symbolic and practical demonstration of regeneration. As well as demonstrating a *tour de force* of derelict land restoration and re-use of post-industrial land, it sent a message out across mid-Cornwall that it was time to start thinking about the future rather than regretting the loss of the past.

So much of the effort involved in closure projects focuses on physical, structural outputs; re-landscaping waste tips, restoring habitat, turning post-industrial buildings to good use. However, without reference to the community, these initiatives may actually be counter-productive. The re-landscaping of Cornish clay tips, for example, is perceived by some communities as an attempt to airbrush out their industrial history and pride, and the emphasis on 'heritage' uses for post-industrial sites is often seen as a poor substitute for the real thing.

At Eden, we have been exploring new methodologies for regeneration that might support communities through times of rapid change, placing value on the creation of convivial spaces, on the importance of listening, bearing witness to people's opinions and feelings about change. The parts of the brain responsible for memory are the same as those involved in imagination and planning. Therefore, a creative project reflecting on the past can provide a good springboard for imagining the future. This kind of work can allow a community to develop a new story about itself: 'this is who we were, this is who we are now.' It is, however, notoriously difficult to evaluate 'soft' outputs, not easily captured in quantitative questionnaires. We are in the process of developing other ways to evaluate projects, using narrative forms, film and imagery.

The background

Rising populations and rising consumption across the globe are putting unprecedented pressures on natural resources. While we have a clearer scientific understanding of the threats we face if we cross thresholds of climate change, water use and land degradation, rising energy prices and faltering economic systems are putting enormous strains on society. Business as usual is no longer an option.

The mining industry has been gradually repositioning itself over the last decade or so to adapt to this new reality. There has been considerable progress in understanding and implementing good practice in environmental stewardship, and even where it is not being implemented effectively there are rules and guidance on what should be done. However, there has been far less progress in delivering successful social outcomes, particularly in preparing communities for life after mining.

Mines frequently constitute a larger proportion of the local economy than other kinds of industry. In the classic remote mining town, closing the mine often means closing the town as well. Planning for mine closure has tended to focus on the environmental mitigation aspects and costs as the most obvious and manageable aspects of rehabilitation. However, the social and economic dimensions are increasingly recognised as critical. These issues are challenging to address as they deal with human perceptions, hopes and expectations, as well as the fundamental matters of skills, jobs, local beneficiation and sustained quality of life. The closure or wind-down of mining activities impacts on the local economy (unemployment, low wages, lack of inward investment); on demographics (emigration of the young and skilled, aging population); on public health (poor housing, unhealthy lifestyles); on education (lack of transferable skills, poor education performance); and the lack of leadership (crime and anti-social behaviour).

Many mineral-rich countries are skills-poor, and have large, vulnerable populations. If mine closures do not translate into further opportunities, the consequent socio-economic problems can affect the entire country.

Integrated closure planning

The mining industry has always been pioneering. Figuring out how more successful models of mine closure will work presents a huge opportunity for the industry to be on the front foot in developing how a new economy can emerge from the legacy of the mine life.

It is 10 years since the Mining, Minerals and Sustainable Development report 'Breaking New Ground' recommended integrated mine closure planning as a necessary element of responsible mining performance. This term refers to a coherent planning approach that addresses socio-economic aspects at the same level of detail as environmental impacts, and which is integrated into corporate and engineering planning processes. A cursory scan of the table of contents of the proceedings of International Conferences on Mine Closure over the last seven years indicates how little attention has been given to the people side of mine closure. Perhaps the community experts are meeting in a different forum to discuss these issues? Or do we interpret this as an indication that we are still struggling to work effectively with local communities to plan for what happens after mining?

Apologists will argue that every closure is site specific and that local circumstances will determine local post-mining outcomes, so there is little to be learnt from generalisations. There are of course issues that will play out differently from one location to another, relevant in one culture but not another. However, there are also some universal elements of good practice that could be agreed on.

Increased societal expectations are making it much more difficult to close a mine and walk away. A social licence to operate is becoming an increasingly important consideration for mining companies operating across many countries. Non-government organisations (NGOs) are mobilising much more effectively across country boundaries to interrogate the reputations of multi-nationals. The International Finance Corporation's latest 'Performance Standards on Environmental and Social Sustainability' include the requirement of free, prior and informed consent from indigenous communities where a project is proposed. National legislative requirements for financial provisioning for mine closure have been strengthened and made more extensive. Stock exchange requirements are demanding a much more risk-based approach and greater transparency in reporting.

From an environmental stewardship perspective, good mine closure practice today is unrecognisable from 20 years ago and responsible companies increasingly comply with legislation that requires effective technical solutions to

The Bodelva pit, soon to be the Eden Project site, in 1999 decommission the mine, undertake site rehabilitation and revegetation and establish a post-closure environmental monitoring programme. The local community and the statutory bodies are kept advised of plans and progress and, in many instances, efforts are made to create local employment in the landscape restoration and monitoring activities.

Problems still arise because many mines are transferred to smaller, less-skilled operators as they reach end of life, or there is poor enforcement of legislation because the implementing authority lacks capacity, or the long-term environmental legacy costs have been underestimated, or the closure decision is revoked as rising commodity prices and/or exchange rates move mines along the cost curve. However, by and large, mining companies understand what is required of them, and how much it will cost to close a mine in an environmentally appropriate way.

It's a people thing, really...

The outstanding challenge is how to work with the community to ensure that they are equipped for life after mining. Community ownership of what happens when the mine closes is critical because the mining company will no longer be present to make things happen, to drive the local economy, to create additional jobs through its sourcing and procurement practices or to shape the make-up and culture of the place.

When a mine closes and the surrounding landscape changes, human, emotional narratives are often disrupted. This rarely claims a consideration in the decision-making process; consultation is frequently an exercise in marketing a *fait accompli*, rather than a genuine attempt to listen. Instrumental consequences of the mine closure, loss of employment and loss of facilities, will need to be addressed. However, the impacts in the affective domain are harder to quantify and are harder to heal. This is the great challenge: how do we help communities and individuals confront change, honour the past and embrace the future?

We are made by the places we live in. By creating the framework for our memories and providing the landscape of our emotions, they shape us and define our identity. Recent research tells us that the neural pathways of our brain are literally built by our early experiences; the more stimulating our early lives, the more complex and flexible the architecture of our brain is in later life. Our relationship to these places is often intensely emotional, built on a layered web of narratives: childhood adventures, community celebrations, first kisses, families at play, and shared moments when world events arrive on our doorsteps.

The Mine Closure 2013 Conference will take place at the Eden Project, Cornwall, UK – set in the heart of a UNESCO World Heritage Site

In thinking about mine closure, we need to understand how the change in landscape will have an impact on the culture of the local community. Our community relationships are tightly bound into the nature of the landscape they inhabit. Routines of work, travel and play are built on the foundations of spaces, routes and resources. What can give us some clues as to how we might start to acknowledge the significance of human connection to landscape and place and use it to help build new narratives with communities facing closure?

This entire topic rests on reaching a shared understanding of what effective community consultation looks like and agreeing on a more collaborative approach to planning, not only for mine closure but from the very outset of mine exploration through the life-of-mine. It requires a better understanding of partnership approaches to development and a long-term post-mining view into decision-making.

Through the operation of the mine, the company has a huge influence on the local economy, its development trajectory and the economic legacy it will leave behind. From the design and location of roads, buildings and other infrastructure in such a way that they can be easily re-purposed, through the development of the mine supply chain to develop local businesses, to the enterprise and business training skills for locals that will be useful in post-mining employment – these decisions about local economic spend during the life-of-mine are infinitely more significant and sizeable than any corporate social responsibility (CSR) or community development spending.

'In thinking about mine closure, we need to understand how the change in landscape will have an impact on the culture of the local community'

The author thinks there are three critical elements which could help to set us up for successful closure planning.

The first element requires a change of mind-set from the earliest design stages to focus on 'design for closure'. To recognise that mining is only a temporary use means that all aspects of the mine operation (design, location, training, capacity-building, mitigation measures) are developed in a way which maximises its flexibility to be re-purposed for new uses. How this principle manifests itself at the site level will vary enormously depending on remoteness of the location, the culture and aspirations of the local community, the other economic sectors nearby and so on. While it is likely to be most effective for new mine planning, this principle can be applied retrospectively to guide operations and planning for existing mines.

The second critical element is to establish and nurture a constant two-way dialogue with the local community. The stronger this relationship is, the more likely a smooth transition from operating a mine to post-closure and new economic activities will be. Historically, the author thinks we have underestimated the business case for effective company/community relationship-building and dialogue and, therefore, not enough resources have been dedicated to putting the right people and management processes in place to make it work effectively. There remains a tangible nervousness among many corporates about disclosure and transparency, but this landscape is changing fairly rapidly as site level reporting becomes more commonplace.

Companies are increasingly looking for community and social experts who can liaise with a wide number of members of the local community and can facilitate inputs into the planning process. It is important to distinguish between this kind of dialogue or consultation, where the company attends to community concerns and aspirations, and its communications role, where information is broadcast to the community and other stakeholders.

Regular dialogue allows both company and community to exchange views and news locally, nationally and internationally, table emerging concerns or revised plans in good time, discuss changes in politics and governance, ground truth assumptions and debate input for planning processes. It all sounds like common sense but it requires considerable trust-building on both sides and its success is largely predicated on the facilitation and leadership skills of the individuals involved. The location and timing of these conversations, along with the manner of presentation and language of the information being discussed, all require careful prior consideration. As mine closure approaches and tensions rise, community engagement becomes more difficult, so the earlier trust-building becomes essential to support the community through the transition.

The third element of the closure planning process is the need to consider looking outside the mining sector for solutions. There is a huge wealth of knowledge in the brownfield regeneration literature about communities transitioning from one economy to another. It would be a rewarding piece of research to assess how some of these case studies might be adapted to mines facing closure.

Finally, a brief journey back to Cornwall. The Eden Project's work has international relevance, but it has its roots in Cornwall. The county has seen great wealth come and go, intimately related to natural resources; it encompasses extremes of natural beauty and dereliction; it is rich in creativity and with a strong sense of identity; it has a strong history of invention and enterprise; it has seen the collapse of industries that helped define that identity and that grew out of the enterprise, leaving behind fractured communities and a devastated economic base. The Cornwall experience therefore has much to say about the challenges of radical transformation and change, of sustainable use of resources, and of how communities find the strength and inspiration to move forwards.

Our lives will change in the years ahead in ways that may not totally be within our control, but in ways that we can influence. The 21st century is going to demand the best of us, our innovation and imagination, our sense of justice, our creativity, our resilience, our humanity. We will need flexible, innovative, inspired and strong individuals and communities, ready to respond to the challenges ahead and are fully aware of the need to support each other. We need to be open to ideas, voices, and inspiration from people across the globe who have been working to meet the challenges and finding real solutions that deserve to be shared.

The message must be a call to arms to all mine closure practitioners to develop a new vision of community and social action. It is in our gift to leave places better than we found them. The mining industry could then be confident that it truly is contributing to sustainable development for future generations.

Please click here for the full, unedited paper.

Caroline Digby,
Post-Mining Alliance, Eden Project, UK

Mine Closure 2012 conference report

A mine closure conference is held annually throughout the world and is readily recognised as the premier event on the calendar of mining professionals working in the field of mine closure. A key feature of this conference series is the diversity of disciplines and expertise that come together to focus on the pressing issues facing the mine closure community internationally.

The range of topics presented at the ACG's Seventh International Mine Closure Conference, held in Brisbane in September 2012, was once again very wide. Reflecting the truly international nature of the delegates to this conference, case studies were presented from many countries including: Germany, China, Canada, Indonesia, the United States, Chile and Australia. Aside from case studies, specialist sessions included those dealing with long-term stability, cover systems, community engagement, ecosystem reconstruction and post-closure monitoring.

Prior to the conference, the ACG hosted a number of workshops. Dr Gord McKenna presented a highly interactive Sustainable Mining and Landform Design Workshop. Cranfield University's Professor Jane Rickson and Dr Rob Simmons presented the Prevention is Better than Cure; the Causes, Consequences and Control of Soil Erosion in Mine Rehabilitation Workshop that was attended by more than 20 delegates. Attendees thoroughly enjoyed the Interpretation of Geochemical Data for Environmental Applications Workshop presented by Associate Professor Ron Watkins, Environmental Inorganic Geochemistry Group, Curtin University. This one day workshop explored the application of geochemical data in the assessment of the mining environment. Given its success, the ACG looks forward to working with Dr Watkins to host this workshop in Perth next year.

The ACG team was delighted to have the wonderful support of the conference sponsors and exhibitors. Photo courtesy of KK Consultancy Ltd

Cranfield University Professors Mark Tibbett and Jim Harris, accompanied by Jeff Battigelli, presented the Delivering Effective Rehabilitation: Monitoring and Manipulating the Soil Biota for Success Workshop. This workshop was attended by environmental managers, regulators and consultants keen to understand more about how the biology of the soil functions and how it can be used in the monitoring and management of mine site rehabilitation.

More than 35 delegates attended the Designing for Closure: Appropriate Design Criteria and Methods of Analysis Workshop facilitated by UWA Winthrop Professor Andy Fourie.

Professor Bernd Lottermoser, Research Professor in Environmental Geochemistry at the University of Tasmania opened the Mine Closure 2012 conference with a keynote presentation on 'Environmental indicators for acid mine drainage: advances in knowledge and challenges ahead'. Dr Lottermoser explored how environmental indicators are measures to track changes in the quality of air, water, land and ecological systems. He reviewed the predictive indicators used for acid mine drainage (AMD) and noted that more than ever scientists have important contributions to make as they design and validate environmental indicators and provide the

The mining method used at West Moreton is a multi-thin-seam operation

data necessary for rational decision-making, including mine closure and the formulation of closure plans.
Dr Lottermoser stated that some of the most urgent problems facing scientists working on AMD indicators are validating existing AMD indicator tests and their applicability for forecasting environmental mine sites. As well as designing better AMD indicator tests that accurately predict environmental processing in the long-term.

Keynote speaker Professor Jim Harris presented a thought provoking paper, 'Ecosystem concepts: can we use them to guide management decision-making in mine closure programmes'. 'The minerals extraction industry inevitably brings with it intense disruption to the ecosystems within which the minerals of interest are found, due to the large-scale civil engineering operations required.' Dr Harris noted that except where hard infrastructure is to be put in place post-mining, a return to some degree of ecosystem function is a goal of reclamation and restoration programmes. Dr Harris' presentation explored ecological concepts which may be employed to guide the way in which mine rehabilitation during closure may be carried out to provide effective and sustainable ecosystem function.

Conference co-chairs Professors Andy Fourie and Mark Tibbett were delighted to commission a keynote presentation from Rory Haymont on 'Critical analysis and mine closure: why do things still go wrong in a swirl of feasibility and planning?'. Haymont noted that 'mine closure planning is attended by more comprehensive regulatory, technical, corporate and financial planning requirements. However, in some parts of the mining sector in Australia, there are very significant areas of mining disturbance that clearly cannot be relinquished. Further proposals in the process of approval do not suggest that many of the new developments in these areas will be significantly better.' Haymont believes that 'there is a large and increasing inventory of mining properties which are now closed, but which have significant ongoing post-closure liabilities. For these properties, an environmental risk financing structure could enable a mine owner to transfer the liabilities and to contract all closure and post-closure obligations to a qualified third party'. Moreover, Haymont noted that 'a properly designed and fully-funded environmental risk financing programme will meet or exceed the guidelines for corporate social responsibility, by providing a financial mechanism that will ensure there are adequate funds available for a responsible party to manage the closure and post-closure obligations of a mine and offers an effective response to community and NGO concerns about environmental legacies from mining operations'.

The Mine Closure 2012 conference concluded with a site tour to New Hope Group's West Moreton Operations. West Moreton operates two open cut coal mines, Jeebropilly and New Oakleigh,

Progressive rehabilitation is undertaken and systems are in place to ensure a high standard of environmental management at all New Hope operations

More than 250 mine closure practitioners attended Mine Closure 2012 – the environmental, social and long-term stability considerations of mine closure activities place this conference at the centre of this 'top ten' issue of concern to the mining industry

near the town of Rosewood, 92 km from the Port of Brisbane. The mining method used at West Moreton is a multi-thin-seam operation utilising trucks, excavators and front-end loaders. Overburden is blasted or ripped by bulldozers prior to extraction. Progressive rehabilitation is undertaken and systems are in place to ensure a high standard of environmental management at all New Hope operations.

The ACG expresses our gratitude to the West Moreton team for generously providing their time and resources for this site visit.

During the three day conference, delegates had the opportunity to forge new friendships and catch up with peers and friends alike. Attendees were also able to keep up with the latest products and services by visiting the trade exhibition booths. The ACG was proud to have the support of, namely, Iluka Resources Limited, MMG Century and Sinclair Knight Merz.

Welcome onboard

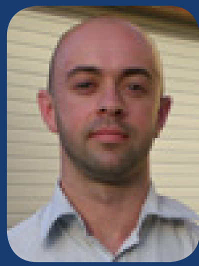
Maddie Adams

Marketing and Communications Assistant

Maddie joined the team in July 2012 as our marketing and communications assistant. Maddie assists with coordinating our industry events and seminars. Maddie also assists with developing our promotional material as well as updating the various ACG websites. Prior to commencing with the ACG, Maddie studied public relations and graphic design at Edith Cowan University.

Garth Doig

Publications Officer



Garth joined us in August 2012 as our publications officer. Garth is responsible for developing and managing the ACG's suite of symposium, seminar and course proceedings. Garth designs material to support the ACG's various training and education events, and maintains and develops our websites. Before joining the ACG team, Garth was a desktop publisher in the oil and gas exploration field.

ACG 20 year anniversary

More than 50 industry peers and friends joined us to celebrate 20 years of the ACG delivering geomechanics research, training and education excellence to the mining industry. Guests enjoyed the scenic views of The University of Western Australia campus and the Swan River while listening to celebratory speeches presented by ACG director Yves Potvin; past director Richard Jewell; our current Board of Management chairman, Ian Suckling; and past chairman Andrew Grubb.

Since 1992 the ACG team has grown to become a leading international organisation that delivers worldclass coordinated research, technology transfer and improved education and training in the geomechanics discipline

Events of interest – 2013

Coal Operators' Conference – www.coalconference.net.au	14–15 February 2013 | Wollongong | Australia
International Conference for Effective and Sustainable Hydraulic Fracturing – hfconference2013.hydrofrac.wikispaces.net	20–22 May 2013 | Brisbane | Australia
16th International Seminar on Paste and Thickened Tailings – www.paste2013.com	17–19 June 2013 | Belo Horizonte | Brazil
6th International Symposium on In Situ Rock Stress – www2.kankyo.tohoku.ac.jp/RS2013	20–22 August 2013 | Sendai | Japan
8th International Symposium on Rockburst and Seismicity in Mines – pts.mi-perm.ru/rasim	1–6 September 2013 | Moscow and St Petersburg | Russia
8th International Conference on Mine Closure – www.mineclosure2013.com	14–22 September 2013 | Cornwall | UK
5th International Seminar on Strategic versus Tactical – www.saimm.co.za	1–3 October 2013 | Muldersdrift | South Africa

Celebrating 20 Years

ACG AUSTRALIAN CENTRE FOR GEOMECHANICS

CSIRO | Curtin University | The University of Western Australia Joint Venture

ACG event schedule*

2013

Environmental Geochemistry of Mine Site Pollution – An Introduction, Short Course	18–19 March 2013 | The University Club, The University of Western Australia, Perth, WA
Total Tailings Management Seminar	20–21 March 2013 | The University Club, The University of Western Australia, Perth, WA
Advanced Tailings Management Seminar and Workshops	22 March 2013 | The University Club, The University of Western Australia, Perth, WA
Interpretation of Geomechanical Data for Environmental Applications Workshop	29 April 2013 | Novotel Perth Langley, Perth, WA
A Framework for Managing Risk After Mining Workshop	30 April 2013 | Novotel Perth Langley, Perth, WA
Mine Rehabilitation and Closure Seminar Series and Workshops	1–3 May 2013 | Novotel Perth Langley, Perth, WA
Advanced Application of Seismology in Mines Short Course	7–10 May 2013 | The University Club, The University of Western Australia, Perth, WA
Shotcrete Design and Performance Workshop	12 May 2013 | Pan Pacific Hotel, Perth, WA
Seventh International Symposium on Ground Support in Mining and Underground Construction – www.groundsupport2013.com	13–15 May 2013 | Pan Pacific Hotel, Perth, WA
Ground Support Technology – a WASM/CRC Mining Workshop	16–17 May 2013 | Pan Pacific Hotel, Perth, WA
Instrumentation and Slope Monitoring Workshop	23 September 2013 | Sofitel Brisbane Central Hotel, Brisbane, QLD
Slope Analysis and Design in Anisotropic Materials Workshop	24 September 2013 | Sofitel Brisbane Central Hotel, Brisbane, QLD
International Symposium on Slope Stability in Open Pit Mining and Civil Engineering – www.slopestability2013.com	25–27 September 2013 | Sofitel Brisbane Central Hotel, Brisbane, QLD
The Business Case for Risk-based Slope Stability Design Workshop	28 September 2013 | Sofitel Brisbane Central Hotel, Brisbane, QLD
Blasting for Stable Slopes Short Course	4–6 November 2013 | Novotel Perth Langley, Perth, WA
Unsaturated Soil Mechanics for Mining Seminar	9–13 December 2013 | Perth, WA

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

2014

11th International Symposium on Mining with Backfill – www.minefill2014.com

2015

Ninth International Symposium on Field Measurements in Geomechanics – www.fmgm2015.com

Season's Greetings

The ACG team wishes you and your family a safe and happy Christmas and New Year. We thank you for your support over the past year and look forward to 2013.

Our office will be closed from Monday, 24th December 2012, reopening on Monday, 7th January 2013.

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An economic risk-based methodology for pit slope design

Luis-Fernando Contreras and Dr Oskar Steffen *SRK Consulting, South Africa*

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