Newsletter

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IN THIS VOLUME:

Demands on geotechnical design

by Julian Venter, SRG Limited, Australia

Throughout history, civilisations have relied on geotechnical structures such as foundations, embankments, trenches, tunnels and slopes to help provide protection against the elements, wild animals and eanemies and also to provide access to water and mineral resources. As civilisations have grown and become more complex, so have their geotechnical needs. Buildings are getting bigger, more and more tunnels are being constructed that interact with buildings and each other, mines are getting larger, deeper and closer to critical infrastructure, to name but a few examples.

As a result of this evolving complexity, the level of rigour demanded of designs and designers is constantly increasing. In response to the increases in demand, it is natural for bureaucratic processes to expand in an effort to prevent anything important from being left out. This in itself poses a risk as more complicated processes are more difficult to follow and may often result in important aspects being ignored while the focus shifts to box ticking. The challenge for the geotechnical community is to produce a design system or methodology that allows important aspects to be considered, is simple enough to use, flexible enough to change with changing technology, and still leaves scope for innovation.

One such system was proposed by Bieniawski (1991) who defined six design principles and ten design steps. This article presents a summary of Bieniawski's design principles and proposes a few amendments to fill potential gaps identified based on the author's experience.

Bieniawski's design principles

A common tool used by geotechnical engineers to improve design quality, and also as an audit tool, is the six design principles published by Bieniawski and the associated ten design steps (Bieniawski 1991). The six design principles are (Figure 1):

1. Clarity of design objectives and functional requirements.
2. Minimum uncertainty of geological conditions.
3. Simplicity of design components.
4. State-of-the-art practice.
5. Optimisation.
6. Constructability.

Continued page 2

Based on these principles, Bieniawski developed ten design steps (Figure 3):

1. Statement of the problem (performance objectives).
2. Functional requirements and constraints.
3. Collection of information.
4. Concept formulation.
5. Analysis of solution components.
6. Synthesis and specification of alternative solutions.
7. Evaluation.
8. Optimisation.
9. Recommendation.
10. Implementation.

These principles and design steps certainly represent a formidable system that may be improved by adding one item and amending a second.

The item to be added is risk identification. One could argue that risk identification is part of Principles 1 and 2 but it is not explicitly stated. Given the increasing complexity of geotechnical structures and their interaction with their environment, not identifying risks and associated controls could result in design failure.

The item to be amended is Principle 5: optimisation. Optimisation can be interpreted in two ways. The first is the removal of the unnecessary while still achieving the objective. The second is selection of a solution that maximises a particular metric based on the concept or model selected. Design Principle 5 therefore introduces risk into the design if the second interpretation of optimisation is selected.

Bieniawski's design principles represent a major step forward in improving design practice; however, two improvements can be made: identification of risks and opportunities should be explicitly stated, and Principle 5 and Step 8 should be amended so as not to introduce unnecessary risk.

Proposed solution

To apply the identified improvements it is proposed that Bieniawski's design principles be amended (Figure 4):

Figure 2 As civilisations have grown and become more complex, so have their geotechnical needs

1. Clarity of design objectives and functional requirements.
2. Identification and quantification of risk.
3. Targeted minimisation of geological uncertainty.
4. Simplicity of design components.
5. State-of-the-art practice.
6. Balance between optimisation and robustness.
7. Constructability.

The intent of Principle 1 remains unchanged. It is important that the objectives and requirements of a design are specified and listed. In civil engineering design this is often done through the concept of Limit States. Serviceability Limit States are those functional requirements pertaining to normal operating conditions and Ultimate Limit States are those functional requirements pertaining to severe events. A similar concept to Ultimate Limit States is often employed in project management where scenarios are considered. Each scenario being a set of conditions that a design is intended to meet. Some scenarios can be in place over the long term, such as a dam being 100% full for a long period of time, or short term where a dam needs to survive a flood event. Principle 1 is not limited to just listing objectives and criteria but also to challenge them. Often when criteria are being set it is done without realising the cost of adding constraints, but once the cost implication is assessed and communicated, these constraints are removed. Principle 1 is not to be confused with selection of acceptance criteria which is specified in Principle 3.

Principle 2 covers the search for and discovery of risk, i.e. things that can go wrong that will result in the objectives and functional requirements not being achieved. This includes activities such as fault-event trees, risk matrices and risk registers. It may seem strange to keep a risk register for a design but it is a very effective way of communicating to a designer, end user or reviewer, which items were considered and how important they are to the outcome.

Principle 3 was amended to 'targeted minimisation of geological uncertainty'. The reason for the inclusion of 'targeted' is to reflect the fact that resources will always be limited and there is substantial risk of resources being wasted on collecting

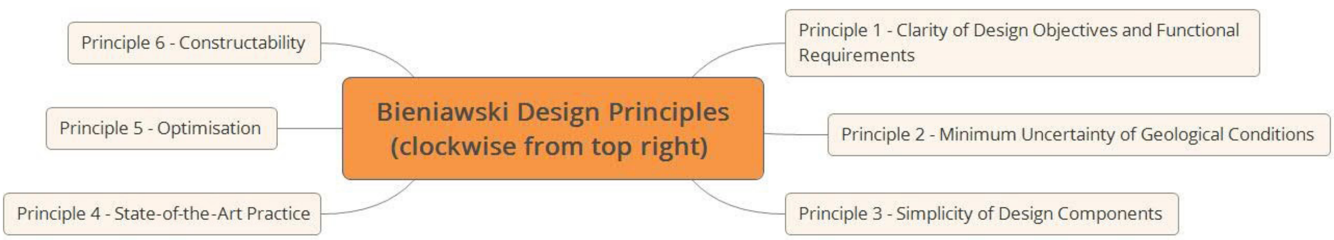

Figure 1 Bieniawski's design principles

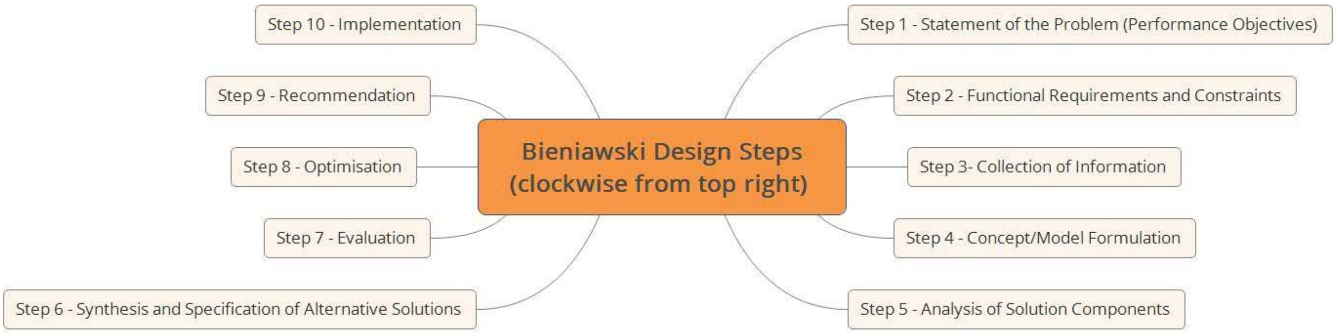

Figure 3 Bieniawski's design steps

Figure 4 Modified design principles

information that will not affect the outcome while truly important information is not collected. Professor Milton Harr once said that, "the most common and grievous engineering mistake is to assume that: that which is easy, is important" (Harr, personal communication, 2007). For this reason the collection of information needs to occur after the risk analysis. Naturally this becomes an iterative process with risk analysis identifying information required, which opens the door for additional risks or better understanding of risk, which in turn opens the door for targeting the collection of information. This process should continue until the acceptance criteria are achieved. It is therefore suggested that the design process be completed before going back to the beginning to start over again.

Principle 4 (Bieniawski Principle 3) remains unchanged. Simple design components are essential to successful design.

Principle 5 (Bieniawski Principle 4) is included as it is important that new techniques are incorporated into designs as they have the potential to add value. One must however guard against using untested and unvalidated techniques. It is also good practice to always use multiple calculation or design approaches for high-risk items to guard against software, end user or calculation errors. This last point is very important as software complexity has increased exponentially in recent years. It is also suggested to develop simple calculations to help validate numerical modelling results, as suggested by Starfield and Cundall (1988).

Principle 6 (Bieniawski Principle 5) is changed from optimisation to finding an appropriate balance between optimisation and robustness. Over-optimised designs are frequently not fit for purpose as they fail to survive all the design scenarios and result in a structure failing or having to be remediated. It is suggested that optimisation be carried out with the design functional criteria in mind.

Principle 7 (Bieniawski Principle 6) remains unchanged. It is worth noting that adhering to this principle goes beyond just thinking about how to construct a design, it includes selecting a construction strategy such as Terzaghi's Observational Method, New Austrian Tunnelling Method or Barton's Norwegian Tunnelling Method, and others. Often significant risks identified as part of Principle 2 can be controlled at this stage of a design. Hence the requirement to first go through all the design steps before starting a new iteration at Principle 1.

The design steps are to be amended as follows (Figure 6):

1. Statement of the problem (performance objectives).
2. Functional requirements and constraints.
3. Component definition.
4. Acceptance criteria.
5. Identification of failure mechanisms.
6. Risk identification and quantification.
7. Collection of information.
8. Concept/model formulation.
9. Sensitivity analysis of solution components.
10. Synthesis and specification of alternative solutions.
11. Evaluation.
12. Balancing of optimisation and robustness.
13. Recommendation.
14. Implementation.

Step 1 – Statement of the problem

Figure 5 Bieniawski's design principles represent a major step forward in improving design practice

or defining performance objectives is a way to determine what a design should be able to do, or not do. For example, a motor vehicle manufacturer might design a car that is capable of a top speed of 120 km/h, accelerate at 0 to 100 km/h in 15 seconds and uses only 1 L of fuel per 100 km. It should carry 4 passengers and have 500 L of luggage capacity. A geotechnical example might be to design a slope with the steepest angle at 200 m depth, given geology. For the purpose of the design, the toe position is to be fixed but the crest can move. Unfortunately many designs go wrong at this first crucial step as performance objectives are either not determined, not recorded and then forgotten, or changed regularly throughout the project. It is suggested that the performance objectives are determined through rigorous discussion to flesh out all the details and are recorded before embarking on a design.

Step 2 – Functional requirements and constraints represent the boundaries within which a design is to be carried out and can take many forms. There may be a limited budget and time to carry out a design or implement construction. There could be legal or social requirements that need to be adhered to. There could be specific requirements, such as proximity to infrastructure or cultural sites. Each one of these will have its own specifics that need to be defined. It is suggested that a functional requirements and constraints list or register be kept for a design to ensure all requirements are evaluated before accepting, and the compliance checked.

Step 3 – Component definition consists of breaking a design into functional units. In motor cars each component is separate but not independent from the others. The same is true of geotechnical engineering, although the components are not always unique and could be arbitrary. For open pit slopes one could view components as: the overall slope, inter ramp slope, batter faces and berm widths. Additionally, an open pit could be divided into several geotechnical domains comprising any combination of these components.

Step 4 – Acceptance criteria needs to be defined for each component based on the previously defined constraints and performance objectives. Admittedly in open pits there is often not much change in acceptance criteria from one design to the next as standard tables are used. This approach may result in a lot of waste and significant savings can be achieved through rigorous probabilistic design combined with site specific acceptance criteria. For underground mining and civil tunnelling, a wider range of acceptance criteria can be specified. It is important that proper thought be put into this activity or it will skew the design process.

Step 5 – Identification of failure mechanisms is the process of determining how components fail to meet the acceptance criteria. This includes the various kinematical and rock mass failure mechanisms but should also be expanded to include displacement mechanisms and whole system mechanisms such as determining crown pillar and panel sizes in coal mines to prevent catastrophic collapse.

Step 6 – Risk identification and quantification starts with the assembly of the list of components with associated mechanisms, as well as system mechanisms. Each mechanism is then assigned a potential consequence. The likelihoods cannot be assigned at this stage as the design analysis has not been completed. This list is then ranked according to severity of consequence. This early risk register is the basis for understanding what information is important to collect and determine the amount of rigour that will be applied to each calculation in Step 9.

Step 7 – Collection of information can now occur based on the relevant risks identified in Step 6 and within the constraints defined in Step 2. Often in geotechnical projects, the collection of information may be a protracted period lasting several months or years. In these cases, multiple design phases may be used such as conceptual, order of magnitude, pre-feasibility and feasibility. When such clearly defined phases are used, it is suggested that this full design process be repeated from Steps 1 to 14 for each phase, with a list of information to be collected before the next phase, as part of the outcome of each phase.

Step 8 – Concept/model formulation can occur globally for the whole design or separately for each component. There are often multiple models such a groundwater, structural geology, geology and geotechnical models. It is also common for models to be different for different components, i.e. overall scale slopes may assume isotropic continuum models while batter scale models consist of joint networks. Models need to be tailored to failure mechanisms, so there can be different models for the same component to cater for each failure mechanism. For example, an overall slope can be tested for rockfall potential using a rockfall model but tested for rock mass instability using a rock mass model. It is suggested that models not be seen as constants but are updated over time as new information is added and their limitations are understood. Ultimately, models are human constructions and not statements of fact. Realising how, and to what extent, a model could be wrong leads to better decision-making during design.

Step 9 – Sensitivity analysis of solution components is carried out by analysing the selected failure mechanisms for each component using the models and ranges of feasible parameters selected in Step 8. The reason for not just using the best estimate parameters as inputs is that one needs to know how sensitive the analysis results are to the input parameters to

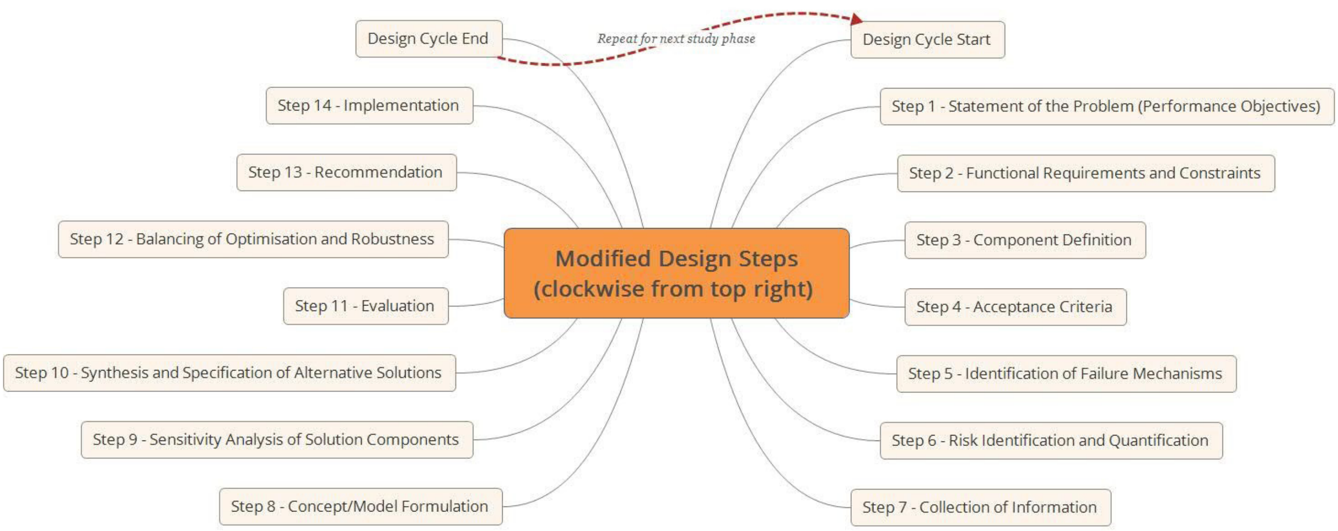

Figure 6 Modified design steps

determine which parameters are more important and also whether a design will survive if the assumptions are pessimistic. This is useful when selecting solutions, as well as when deciding what information to collect during the next phase.

Step 10 – Synthesis and specification of solution components is made using the results of the sensitivity analysis carried out in Step 9, and the outputs from all earlier steps. The reason for including sensitivity analysis is to ensure that the best solution is obtained with consideration of all model interpretations and ranges of inputs, not just the best estimate model with average inputs. This ensures robustness and realism in the design. Step 10 also includes the brainstorming of multiple solutions that meet the criteria. This is particularly important as many engineering problems have more than one workable solution and the practice of selecting the first solution that meets all criteria (satisficing) is not a good strategy.

Step 11 – Evaluation of the solutions determined in Step 10 against the objectives and constraints determined in Steps 1 and 2 forms the next step. Step 11 will often include further calculation to clarify attributes and often involves financial or cost evaluation. It is also possible that additional solutions may result from this process.

Step 12 – Balancing of optimisation and robustness is a process whereby the selected solution/s are evaluated to see how they can be optimised without affecting their ability to meet the design criteria or violating the constraints. When optimising though, it is important to consider that optimisation often results in fragile solutions. Solutions that are only workable if the best estimate models and average conditions occur. The results of the sensitivity analysis and the acceptance criteria should be considered to ensure a design solution is selected that will meet all the specified requirements.

Step 13 – Recommendation is the whole process of communicating the design. Several stakeholders often need to be considered during recommendation and may have individual and specific requirements. The implementer needs to be supplied with simple explanations and diagrams that are easy to read and understand and provide only sufficient information for implementation. The decision-maker requires sufficient information to become convinced that the solution meets the objectives and falls within the constraints and is the best solution among alternatives. The reviewer is interested in making sure that a design is sound, meets industry best practice and addresses risks appropriately.
A reviewer also needs to know that no major flaws are present. For this reason reviewers often require much more detail than other users of reports.

Step 14 – Implementation is the final step in design and covers not the actual implementation but rather a consideration of how a design is to be implemented. This includes a decision on which implementation strategy is to be followed, such as conventional design followed by implementation, Observational Method, New Austrian Tunnelling Method, Norwegian Tunnelling method etc. In addition, Step 14 implies the specification of a design verification system, and also triggers for re-evaluating a design, should conditions be different than assumed. The sensitivity analysis already carried out is useful for this step.

Discussion

The 14 design steps presented in this article are intended to be an iterative process, with a designer being able to move backwards and forwards as needed. In geotechnical engineering, site investigations often take several months to plan and execute. It is therefore not practical to follow iterative processes all the way through the steps. A practical solution has already been adopted by industry in the form of conceptual, order of magnitude, prefeasibility, feasibility studies and implementation studies. It is suggested that the full 14 steps be followed for each of these study phases based on information collected between phases, with the amount of calculation rigour determined by the study phase under consideration. The general strategy would be to use simple calculations to eliminate as many risks off the risk register as possible during the conceptual and order of magnitude stages and targeting the major risks with detailed data collection and higher level analysis in later stages. In this way, each successive stage considers fewer risks with more rigour. This implies that during conceptual studies there should be more risks in the risk register than during implementation studies but that implementation studies are based on more data and more rigorous analysis.

Conclusion

This article presented a short analysis of the Bieniawski's design principles and steps, and concluded that due to more complex structures being required and technological advances made since its last publication, an amendment is appropriate. An updated set of principles are presented increasing the total from 6 to 7 principles. The design steps originally presented by Bieniawski are expanded from 10 to 14. The additional design steps include, among others, a risk assessment and sensitivity analysis.

Please click here for article references.

Julian Venter,
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Australia

ACG Physical and Numerical Modelling of Caving Mechanics Workshop

12 May 2016 | Australian Technology Park | Sydney, New South Wales

The ACG will host the Physical and Numerical Modelling of Caving Mechanics Workshop alongside The AusIMM's Seventh International Conference and Exhibition on Mass Mining 2016. Our one-day workshop will bring together industry experts to discuss this topic.

The workshop facilitator is Professor Yves Potvin, ACG. The workshop will include sessions on field measurements in cave mining, numerical modelling of cave mining, calibration and validation from field measurements and physical modelling.

Workshop presenters include:
Dr David Beck, Beck Engineering Pty Ltd, Australia; Daniel Cumming-Potvin, The University of Western Australia (ACG); Dr Davide Elmo, University of British Columbia, Canada; Professor SW Jacobsz, University of Pretoria, South Africa; James Lett, Newcrest Mining Ltd, Australia; Dr Matthew Pierce, Dr Tryana Garza-Cruz, Itasca Consulting Group Inc., USA; Professor Yves Potvin; Associate Professor Bre-Anne Sainsbury, Monash University, Australia; and Dr Johan Wesseloo, ACG.

To register for this workshop, delegates are to contact The AusIMM directly. For more information, please visit www.massmin2016.com/workshops

International Seminar on Design Methods in Underground Mining Report

writes Maddie Adams, Australian Centre for Geomechanics, Australia

Professor Yves Potvin, Professor Emeritus Rimas Pakalnis, Geoff Senior and Don Grant

The Australian Centre for Geomechanics was delighted to welcome almost 100 delegates to Perth for the inaugural International Seminar on Design Methods in Underground Mining, held from 17–19 November 2015. The seminar focussed on both the numerical and empirical methods used for the design of underground metalliferous mines.

The seminar featured 36 high quality presentations on a range of topics. Over the course of the three-day technical programme, sessions were held on numerical modelling, designing for seismicity, optimisation of design, pillar design, design in narrow vein mining, input data for design, ground support, planning, design, production and financial input and geotechnical design, dilution control and orepass design.

This new seminar was initiated by seminar chair Professor Yves Potvin, ACG, inspired by his attendance at a specialised conference on Applied Empirical Design Methods held in Peru in 2014; organised by the International Society for Rock Mechanics. The interest generated from the conference's unique discussions on the intricacies of applying empirical design methods to a range of projects convinced Professor Potvin that this topic should be further explored.

Professor Potvin noted in his seminar opening address that he was pleased to see a strong international attendance, despite the downturn in industry. Delegates from countries around the world – including Australia, Canada, Finland, India, Indonesia, China, Saudi Arabia, South Africa, Sri Lanka, Sweden, UK and the USA – congregated at the international seminar.

The ACG appreciated the support of the seminar industry sponsor MMG Limited, as well as the trade exhibitors: Adam Technology, C.R. Kennedy & Company, DYWIDAG-Systems International Pty Limited, Geobrugg Australia Pty Ltd, GeoSight Pty Ltd, Haefeli-Lysnar Geospatial Solutions and Jennmar Australia. Their involvement in the seminar greatly contributed to its success.

Dr Will Bawden, Mine Design Engineering, Canada, was the first keynote speaker of the seminar and gave a fascinating presentation on the 'impact of technological change on mining geomechanics design and operations', where he discussed the history of mining geomechanics, both past and present limitations and challenges, and what the industry should aim to achieve in the future, including the role of technology in mining geomechanics.

Also on the first day of the seminar, Dr John Player, MineGeoTech, Australia, spoke on behalf of Paul Harris, MMG Limited, Australia, on his paper 'Dugald River case study – the importance of understanding your orebody and designing your mine for maximum value', where he presented on one of Australia's most interesting and challenging underground mining projects.

Professor Emeritus Rimas Pakalnis, Pakalnis & Associates and the University of British Columbia, Canada, is renowned for his involvement in the development of several empirical design techniques, his presentation was titled 'Empirical design methods in practice'. He summarised the applications and implementations of empirical design methods established over the past 30 years.

Day three's keynote speaker Emeritus Professor Dick Stacey discussed 'Rock engineering design – the importance of process, prediction of behaviour, choice of design criteria, review, and consideration of risk', outlining his views on the design process.

Prior to the seminar, a two-day course on Practical Application of Empirical Design Methods in Underground Mine Design was held. This course was facilitated by Yves Potvin and Rimas Pakalnis who conveyed their experience of over 300 underground mine operations that they have consulted and researched at.

Following the seminar was a course on Practical Application of Numerical Methods in Underground Mine Design. Facilitators Will Bawden and Dr Kathy Kalenchuk, Mine Design Engineering, Canada, discussed the role of numerical modelling in greenfield studies and projects involving mine operations, model collaboration and case studies.

The ACG team thanks the presenters, sponsors, exhibitors, delegates and all who contributed to the success of the International Seminar on Design Methods in Underground Mining. The seminar proceedings include 43 technical peer-reviewed papers and address a wide spectrum of themes that are central to the application of design methods in underground mines. It is intended that these proceedings will be a reference on this significant topic.

The peer-reviewed, hardbound seminar proceedings, which feature 39 technical papers, are available to purchase from acg.uwa.edu.au/shop

Instrumentation: the key to managing project performance

Attendees networking at FMGM 2015

Following in the big footsteps of the highly acclaimed FMGM symposia, the Australian Centre for Geomechanics, with collaborating organisation Pells Sullivan Meynink, were delighted to host the Ninth International Symposium on Field Measurements in Geomechanics, 9–11 September 2015, in Sydney — a first for Australia. More than two hundred mining, civil and tunnelling engineers and professionals assembled to explore the various topics related to field instrumentation, monitoring and associated project management. Delegates came from the four corners of the world with thirty-two countries represented.

As Mark Fowler, FMGM 2015 Symposium co-chair noted in his opening comments — it is hard to escape the reality that technology in everyday life is advancing so rapidly, and it is not just changing our lives, but in fact shaping it. The pervasiveness of smart phones and tablets, cloud computing, drones — data vacuums of the air — and the potential benefit and threat of big data may individually and/or collectively enrich and exploit our lives.

ACG Michele Salvoni, FMGM 2015 Best Young Engineer Paper winner (right) with Professor Phil Dight, FMGM 2015 Symposium co-chair (left)

Geotechnical monitoring is no exception. It is hard not to think we are in or approaching the golden age of monitoring and there is no question these advances have, and will, greatly further our profession.

The three day technical symposium programme featured 65 presentations. The scene was set with a riveting presentation from Dr Philip Pells, 'Monitoring – the good, the bad and the ugly'. This very appropriate paper highlights the pitfalls when the application of instrumentation is poorly understood; it is not there to 'tick a box'. The proceedings were supported by excellent keynote papers by: Dr Andrew Ridley on soil suction and its measurement; Dr W Allen Marr on instrumentation as a risk management tool with application to dam safety; Dr Ian Gray looking at understanding the in situ stress in real materials and the influence of fluid pressure; and Dr Martin Beth on how to manage the data obtained in a clear and easily accessible way.

Initiated at FMGM 2011, Berlin, and repeated in Sydney the Best Young Engineer Paper Award was well contested. ACG's Michele Salvoni won the prize with 'Improvement of pseudo-3D pit displacement mapping technique through geodetic prism data integration', and PSM's Michael Salcher was a close runner-up with 'Robust monitoring for high risk underground excavations'. Our gratitude to all who participated in the award.

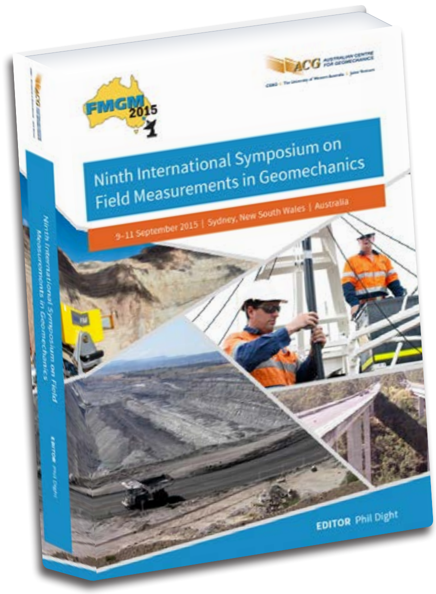
The symposium trade exhibition was sold out with 33 exhibiting companies showcasing their products and services which monitor performance. The support and encouragement received from our sponsors and exhibitors was much appreciated. We especially thank IDS Australasia Pty Ltd for being the Principal Sponsor – their involvement was integral to the success of the event and we acknowledge the wonderful contribution of their team: Garry Spencer, Henri Prevost and Susanna Botterill.

Two workshops preceded the symposium. The first, ACG InSAR and Emerging Technologies Workshop, attracted 40+ participants and focussed on various types of remote sensing together with emerging technologies for monitoring both above and below ground level. The second, ACG Radar and Monitoring Workshop, was attended by 35 delegates and explored some new developments relating to conventional terrestrial monitoring systems such as open pit radars, prisms, laser scanning, photogrammetry, as well as the integration of the different types of these monitoring systems and their interpretation.

The symposium dinner was a Sydney Harbour boat cruise which showcased, to the 130+ international and local attendees, the beautiful harbour and globally acclaimed landmarks.

Professor Phil Dight and his team were well supported by the International and Australian Symposium Organising Committees. In particular, we extend our appreciation to Dr Helmut Bock for his sage advice. We wish the organisers of FMGM 2018, Brazil, every success.

The ACG team was delighted to produce peer-reviewed, hardbound symposium proceedings, which feature 66 technical papers. To order your copy, visit acg.uwa.edu.au/shop



Critical short-term and strategic long-term slope monitoring radar – a holistic approach using SAR

by N. Coli, L. Leoni, G. Funaioli, F. Coppi, IDS Ingegneria Dei Sistemi SpA, Italy; and G. Spencer, H. Prevost, IDS Australasia Pty Ltd

Introduction

Slope monitoring radar is generally accepted as a powerful monitoring tool for monitoring movements in natural and engineered slopes. Radar technology offers the advantages of high accuracy measurements, long range capability and the limited impact of atmospheric effects on measurement performance. Radar has the ability to rapidly acquire data over an extremely large area in near real time.

Slope monitoring radars employ radar interferometry techniques. Originally developed for satellite borne earth deformation applications, synthetic aperture radar (SAR) technology is now configured on the ground for the simultaneous detection of rapid and slow moving deformations.

Ground-based radar interferometry has been used for slope monitoring of natural slopes (Antonello et al. 2004; Corsini et al. 2006; Bozzano et al. 2008), and open pit mines (Harries et al. 2006; Farina et al. 2009, 2013; Atzeni et al. 2015). Radar units are effectively used to gain a better understanding of the spatial distribution of slope movements, and for the provision of alerts in the event of progressive movements that can potentially lead to slope failure.

Following advances in radar technology and processing techniques, acquisition data is useful for the safety critical management of pit work areas using short-term datasets. In addition, radar also serves as a useful tool for the analysis of long-term slope behaviour. Powerful processing techniques have evolved to provide insightful information that enables data interpretation for use in geotechnical analysis in a variety of applications.

Ground-based SAR has evolved into a configurable tool to monitor the entire pit in almost real time. Rapid refreshment rates in the order of 2–3 minutes provide the user with instantaneous universal pit knowledge. Whether small or large, rapid or slow, displacement data now provides users with an all in one approach, capable of simultaneously combining the safety critical with long-term datasets across an extremely wide area in near real time.

SAR application to critical slope monitoring in open pit mining

Using SAR radar in open pit mines provides capability for the detection and management of potential large-scale instabilities in the overall slope, multiple inter-ramp slope segments, and localised bench scale monitoring detection, at the same time.

The principle reason for use of SAR is safety critical monitoring, namely the alarm generation for progressive movements based on the displacement/velocity measurement.

The radar becomes a tool to be combined with other sources of information that aids risk minimisation by identifying risk conditions and supporting the decision-making process.

Additionally, long-term monitoring of slope movements over very large portions of the pit can also be completed. This may allow the geotechnical staff to gain a better understanding of the mechanism of large-scale instabilities, and knowledge of the rock mass strength and deformation properties via calibration of the movement (Figure 2).

This use of the radar, mainly aimed at developing effective remedial plans, is also facilitated by the capability to integrate the geo-referenced displacement maps generated by the radar with other geological/geotechnical layers and import them into mine planning software and GIS. Basic geomorphological analysis can be carried out by displaying displacement or velocity maps draped over a digital terrain model (DTM) of the pit in a 3D view (Figure 1). In addition, detailed monitoring, from both spatial and temporal points of view, is a critical source of information for the calibration and validation of stability analysis models; to identify the mode of failure and the triggering mechanisms, and to assess the performances of the implemented slope design.

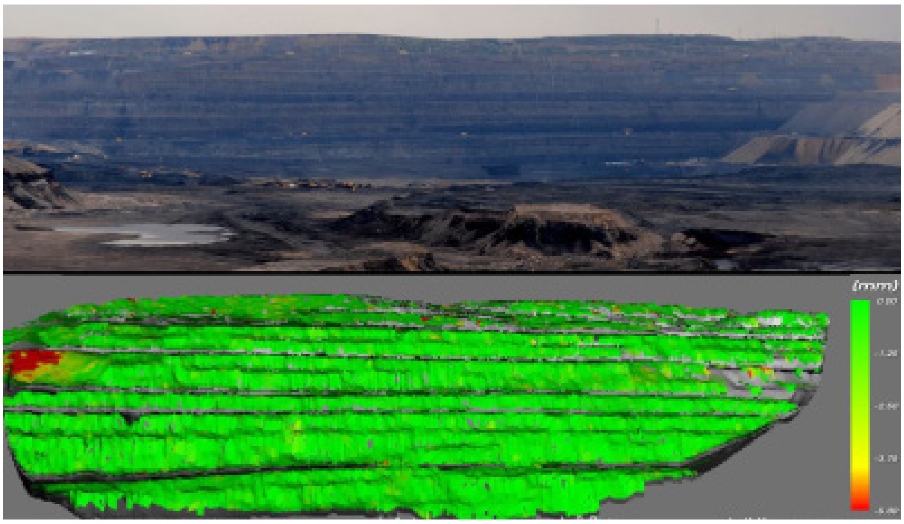


Figure 1 *Example of a coal mine SAR installation at a 2.4 km of maximum distance, and a displacement map draped on a DTM of the mine*

Full pit monitoring – 360°

Until recently, typical real aperture radar (RAR) usage was 1–4 systems which independently operated and displayed data from the subset of the open pit area. By taking advantage of SAR technology, newly developed software now extends the capability of critical safety monitoring and allows data from multiple SAR systems to be integrated and displayed into one display environment (Figure 3).

The early recognition of both large scale and bench scale instability over all the pit walls, without the need of a prior knowledge of the moving areas (as it may happen with short range radar), allows an increase in the knowledge of the slope behaviour.

The SAR high spatial resolution and wide capture area allows full pit monitoring using a minimal number of systems. Depending on the pit geometry and mine operational requirements, typically 2–4 systems may cover the full pit area.

Multi-scale processing

GBInSAR technology has the ability to measure fast movements from mm/day to few tens of cm/day, typical of the deformation rates expected (Figure 4). The system can also be configured to monitor very slow movements (from mm/month to mm/year). Slow movement monitoring is gained by using long-term installations/projects or by repositioning the radar unit. Through the combination of two specific processing approaches

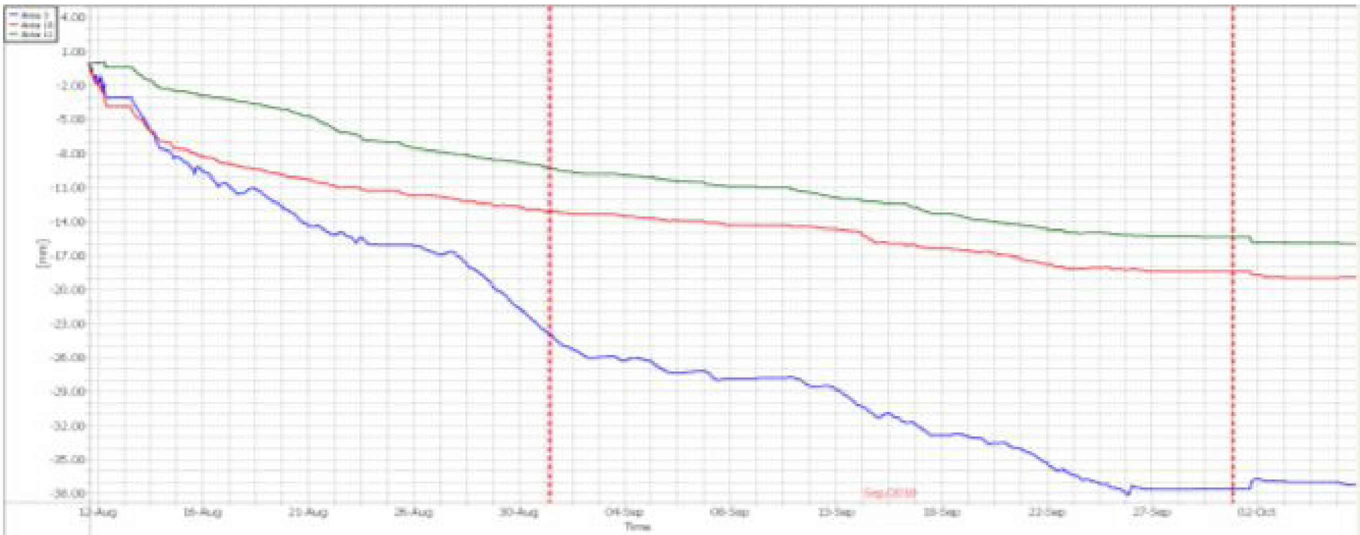


Figure 2 Time series of displacements (data courtesy of Minera Escondida Ltd)

undertaken on different time scales, it is possible to simultaneously track rapid and slow slope movements.

The use of longer term slow movement monitoring within large open pit mines can potentially remove the need for focussed mobile radar systems in certain situations.

The slow movement detection is unique part of the SAR radar processing engine (IBIS radar), which is able to cover, in real time, up to the fourth order of magnitude of movements (from tenths of mm/hour to few mm /month). The analysis of slope radar data using this processing method facilitates resolving a wide range of movements, enabling the user to simultaneously identify areas of rapid displacement, very slow moving areas of displacement and all rates of displacement in between, in real time.

The ability to detect unknown hazards begins with being able to resolve very slow moving areas while the widest possible portion of the slope is being monitored. Determining slow movement at very detailed spatial resolution is an approach that provides geotechnical engineers and planners with extra lead time to evaluate slope conditions and develop solutions before displacement begins to interfere with mining operations.

Multi-scale movement detection, coupled with full pit monitoring and long-term datasets, has recently (>1 year) become an important part of mine planning and geotechnical hazard mitigation.

Conclusion

Slope monitoring radar has evolved into standard practice for the near real-time monitoring of slope displacements in open pit mines. The development of slope monitoring radars based on the SAR technique recently marked a step forward in improving radar technology for monitoring capability. By covering all the scales of slope potential instabilities, from bench scale in open pit mines to overall slope instability, SAR can be effectively used for both the safety critical and long-term monitoring (Farina et al. 2012).

The advances of the SAR system with respect to the previous generation of RAR units are related to the improvement of spatial resolution, the working distance from the slope, acquisition time, atmospheric correction, less moving parts and lower power consumption. Improvement of these features enable users to better cover all typical scales of slope instabilities from bench-scale to overall slope failures, and to extend the range of monitored deformation rates to include slow movements (Farina et al. 2009). Further software development leverages off the SAR technology capability, which has now allowed full pit monitoring with integrated systems, providing the ability for 360° critical slope monitoring coverage of pit walls. As a result of the around the clock safety critical monitoring, the capability to handle long datasets for background monitoring and geotechnical back-analysis over the entire pit, the 360° SAR coverage is strongly influencing radar monitoring practice and standards in modern open pit mines.

Please click here for article references.

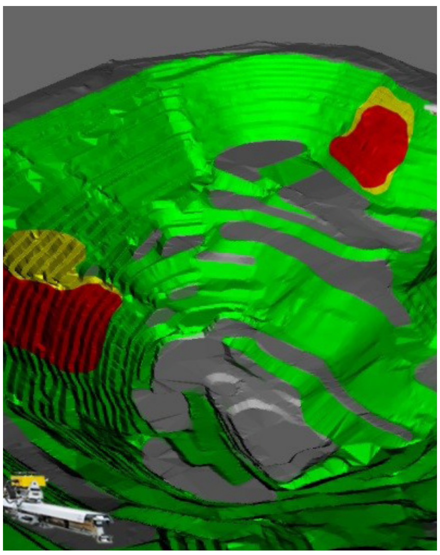


Figure 3 Conceptual example of the full pit monitoring setup

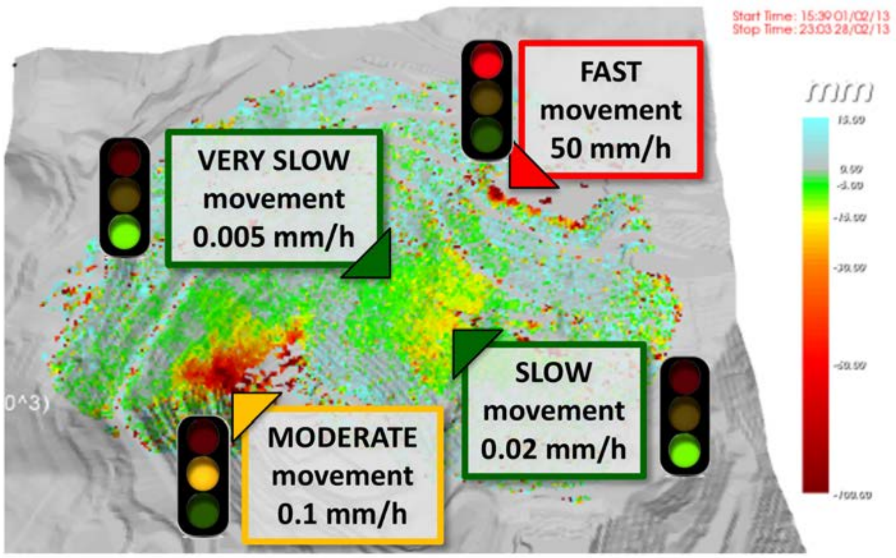


Figure 4 Conceptual visualisation example of the multi-scale processing technique

The mining industry got pasted

writes Daniel Bedell, Bedell Engineering, USA

Authors celebrating the launch of the "Paste and Thickened Tailings – A Guide (Third Edition)" at Paste 2015, Cairns

Getting pasted is a street term of when one gets punched in the face or beaten up. Such was the case for mining 25+ years ago, following a number of tailings dam failures and the terrible conditions of abandoned mining sites around the world. The public and environmental outcry was building and the mining industry had to step up and resolve these serious and real problems. I can still remember flying over a number of global sites and seeing ribbons of tailings winding their way to rivers and to the ocean. I must admit I am still haunted by those sights and of being glad when it became mandatory, in most countries, to impound the tailings. This did not solve the problem but only changed the dynamics of it.

This was a topic being discussed in many circles both inside and outside the industry. The criticality of the situation was reaching a boiling point from those who wanted to close all mining activity to the more rational that recognised that something had to be done urgently to address and, more importantly, solve these problems. As is often the case, great ideas and inspiration frequently arise out of casual discussion. Such was the case for Richard Jewell, Australian Centre for Geomechanics, and a number of mining and processing people who discussed the gravity of the challenges confronting the mining industry with its vast quantities of tailings. There had been several tailings dam failures that had caused much damage and mayhem in the surrounding communities and in the industry as a whole. The political and social impacts of these were real and increasing in intensity. These prompted additional investigations highlighting the need to reduce the amount of tailings through better or new ways of thickening. There is a definite need to properly close out a project with reclamation and not to just walk away as had been the case for a very long time. Taking a serious look at the overall problem from beginning to end seemed an almost unsurmountable task. The urgency of this setting became very apparent. The time was then fertile for real cooperation globally across industry, academia and suppliers. Not only was it right but it was critical for the mining industry. Dr Andy Robertson, InfoMine Inc., succinctly stated this continuing problem in his well-written treatise in the December 2012, Vol. 39, ACG Newsletter, entitled, 'Tailings: dammed, damned or damless'.

As a follow-up to this discussion, Jewell invited world experts in the fields of thickening, transportation and tailings management to explore the concept of producing a tailings product with as little water as possible. This meeting of experts took place in Canada at the University of Alberta and from that began the concerted effort to deal with this serious problem head-on. As everyone began to seriously examine the current technology, it became readily apparent that there would have to be major shifts in all aspects of the mining, processing, transportation, storage/containment and, finally, the closure of the mines and processing facilities. This turned out to be a monumental task in all areas, as changes in each area would impact others.

The tailings problem was broken down into categories. The following were some key areas to be dealt with:

- The increasing demand for metals and minerals by an ever-increasing world population.
- Diminishing ore grades requiring improved processing methods.
- Competition for water by mining with domestic users, farming etc.
- Increasing social and governmental pressures on the mining industry.
- Closing of several mining and technical institutions, such as the USA Bureau of Mines, leaving a need for new avenues of research.

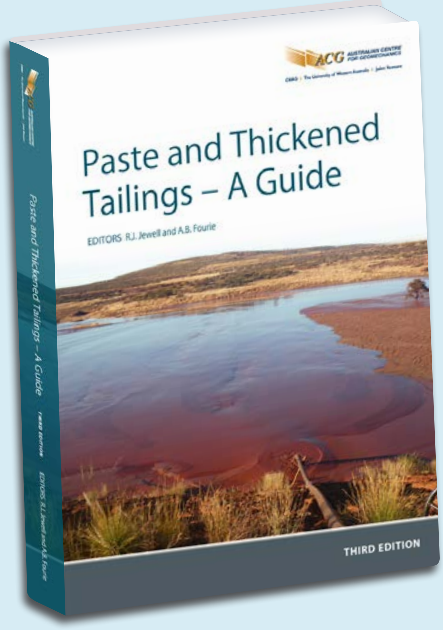
Following this initial meeting, we started holding international seminars under the guidance of Jewell, Professor Andy Fourie, and Ted Lord, with the support of the ACG. The ACG began to proactively address mining industry's needs (ACG Newsletter, vol. 38, July 2012). Initiated in 1999, the International Seminars on Paste and Thickened Tailings recognised a key need in the overall education and science of tailings generation, processing, transportation and disposal which resulted in workshops accompanying the annual seminars. Over the years, these workshops have been very successful in transferring the knowledge and hands-on experiences to help elevate the understanding and to promote increased awareness of the challenges and the needs in tailings. It became apparent to the management team of these seminars that there was a need to produce a paste and thickened tailings (P&TT) guide to capture as much of the technology in the various areas as possible, in a written and usable form. This became reality in 2002 when the first edition of the guide was published. In 2006 the second edition of the guide was published after the first edition had intially sold out. Nine years (2015) and many process and technological advancements later, the third edition of the guide was launched at Paste 2015, Cairns, Queensland to provide a concise helpful reference for readers to avoid potential pitfalls and obtain a quick understanding of the elements of generating and dealing with paste and thickened tailings.

The efforts over the past 25–30 years have wrought great changes in tailings management, disposal and water conservation. It may not be viewed as rocket science but the quiet, effectual impact on society around the world has been real. The lives of so many have been impacted in the form of health, jobs, safer communities, overall safety and environment having markedly improved. Are we there? No, but the progress is significant with continuing improvements, experience and with additional knowledge. The third edition of the guide should become another good tool in your battle and efforts to improve our industry.

It has been a signal honour to have been part of these changes and to associate with so many fine and talented men and women in this field. May we be forever young of heart and embrace these challenges and changes with inspiration and diligence, or as my wife has said, "You are just overgrown boys still playing in the mud!" Let us have fun and contribute positive changes that will show that we do care and can impact the world in a significant way.

Daniel Bedell,
Bedell Engineering,
USA

ACG Publication: Paste and Thickened Tailings – A Guide (Third Edition)



The third edition of the ACG 'Paste and Thickened Tailings – A Guide' is structured as a guidance and advice manual and aims to provide industry personnel with the information that will assist them in gauging the benefits of using the P&TT technique for their operations.

It includes new chapters on evolving technologies, such as filtering and post thickener polymer injection, as well as different thickening techniques. This is in addition to the fundamental chapters of the previous editions, which have been substantially revised and updated with new information and advancements in technology.

The aim of this guide is to outline the technologies available for thickening tailings to a higher concentration or density than that achieved as underflow from conventional plant thickeners, the advantages and disadvantages of doing so, and to provide a technical resource about the application of thickening technology prior to deposition for surface disposal. The ultimate objective has been to provide guidance and advice to those in the industry interested in finding out what is meant by thickened tailings and high-density slurry or paste tailings, and in determining whether the effort of thickening tailings to a density higher than that achieved in the underflow of normal plant thickeners can add value to their own operations.

The guidelines have a broad authorship and are laid out as a series of self-contained chapters that have been prepared by authors, including operators, consultants and regulators, with expertise in each specific area, and have a global representation of the mining industry. The chapter lead authors are Dan Bedell; Mark Coghill, Rio Tinto; Phillip Fawell, CSIRO Mineral Resources Flagship; Tim Fitton, Fitton Tailings Consultants; Andy Fourie, The University of Western Australia; Richard Jewell; the late Hugh Jones, independent consultant; Christian Kujawa, Paterson & Cooke; Ted Lord, tailings consultant; Gordon McPhail, SLR Consulting Australia Pty Ltd; Angus Paterson, Paterson & Cooke; Fiona Sofrà, Rheological Consulting Services Pty Ltd; Matthew Treinen, Paterson & Cooke; Andrew Vietti, Vietti Slurrytec (Pty) Ltd; and Patrick Sean Wells, Suncor Energy Inc.

Dr Andrew Robertson wrote in his foreword that, "The authors have succeeded in producing a comprehensive and authoritative documentation of the technology, provided the design basis relevant to these technologies, and infused a vast amount of valuable insight and guidance reflective of their diverse backgrounds in theory, design, field trials, construction and operation of tailings storage facilities." Dr Robertson further states that, "This is a 'must have' guide for this field of rapidly advancing Best Available Technology for tailings deposits design, construction, operation and closure."

This guide aims to raise awareness of emerging technology. Co-editor Professor Andy Fourie has outlined an issue facing the industry — when mines store their tailings in large mounds also holding water, occasionally the structure fails and discharges toxic slurries that can have a negative impact on local communities and the environment. An emerging solution involves thickening tailings, even to the extent of making them a semi-paste, a process that can decrease water loss resulting from evaporation and also reduce operating costs. Professor Fourie says that, "It also has the advantage of reducing the risks of these catastrophic failures. As communities become more concerned about mining impacts, this issue will become greater and greater."

The production of *Paste and Thickened Tailings – A Guide (Third Edition)* was generously supported by platinum sponsors BASF Australia Ltd and SNF Floerger; gold sponsors SLR Consulting Australia Pty Ltd and WesTech Engineering, Inc.; and silver sponsors FLSmidth and Paterson & Cooke.

To purchase *Paste and Thickened Tailings – A Guide (Third Edition)*, please visit www.acg.uwa.edu.au/shop.

19th International Seminar on Paste and Thickened Tailings, Santiago, Chile

Paste 2016 technical coordinator Sergio Barrera looks forward to welcoming tailing professionals to Chile later this year.

Paste 2016, Chile will explore technologies for efficient and safe tailings management

More than 14 years ago, during the Paste Seminar held in the Pilanesberg National Park, South Africa, the decision was taken to run the following seminar in South America. This seminar took place in Santiago, Chile, in 2002 and the attendance rate was significantly higher than previous events. The decision to award South America the rights to host this seminar showed confidence in the organisation's capabilities and the need to promote new technologies to the vast South American mining industry. Since 2002, four International Seminars on Paste and Thickened Tailings have taken place in South America: three in Chile and one in Brazil.

Looking back, the huge changes that these seminars have undergone are evident. Gone are the days when there were only presentations and photocopies distributed in a folder, attendees now receive a well edited proceedings (book and/or electronic proceedings). Also, back then, the majority of the articles were about the potentialities of thickening methods rather than real cases. Beach tailings slope predictions were largely based on experience rather than trials and more elaborate methodologies.

During those times there was also a great expectation that thickened tailings were the only solution for tailings management and that traditional solutions — not to say conventional — were destined to be replaced. However, the application of this new technology has faced obstacles and has been slightly more complex than expected, revealing that there is still a way to go in several areas such as the handling of large productions, difficulties in transporting thickened tailings, the accuracy of beach tailings slope estimate, the management of the variability of tailings (impact on the design) and the application of an integrated perspective of tailings management: balance between water recovery, costs and operational flexibility.

Notwithstanding the above, it has become increasingly evident that tailings management requires dewatering technology in order to meet economic, environmental and community demands. In many areas of the world, the scarcity of fresh water has severely limited the water resources available for the mining process, meaning that, in some cases, seawater is used. This clearly implies reducing the demand of fresh water, achieved via thickening or filtering technologies. In other areas, regulations penalise contact water discharge outside the mine area leading to the need to reduce the effluent flow which is also achieved using the technologies mentioned above.

The thickening and filtering technologies are welcomed by and have preferential attention from audit authorities and the community. This helps with the processing of permits which, due to the requirements and deadlines involved in mining projects, is very important. The key factor stems from a lower quantity of water when the tailings is discharged which results in a higher density layer and, in particular, a rheology which makes it more stable and different to conventional tailings behaviour. This is associated with water dams which, when emptied, produce significant damage to the area located downstream of the tailings' deposit.

The Paste 2016 Seminar faces several challenges which, in part, are a result of the success or rather the progress of the application of new technologies. Amongst these challenges is the need to:

- Identify areas that require further research or improve their development.
- Demonstrate actual experiences of application, including successes and failures.
- Present the developments in design methodologies and thickened tailings management.

With regards to the first point, we believe that stability of thickening process in light of the inevitable variability of tailings is an area that requires research. This is particularly important for high-density thickened tailings or almost paste. Another area of research is the transportation of thickened tailings over

It is increasingly evident that tailings management requires dewatering technology in order to meet economic, environmental and community demands

large distances and the most appropriate type of flow. Even though there has been considerable improvement in the last eight years in the area of beach tailings slope predictions (including the Prediction of Beach Slopes Workshop held in Perth in 2011), there are still knowledge gaps, in particular, with regards to high-density thickened tailings.

All new technology, including that which has better conceptual support, presents difficulties in its application. Sharing research, alternative designs, operational experiences and findings are always a source of progress. The problems that arise during the implementation phase are an inevitable part of the risk that is taken when proposing something new and should not be the subject of fear or shame. The mining sector should appreciate the effort of mining companies who dare to innovate as they are facilitating the way forward for the whole sector.

As a result we encourage all professionals linked to tailings management to participate in Paste 2016 which, after several years abroad, will once again be hosted in Chile and take place from 5–8 July 2016 in Santiago. The economic challenges that the mining industry is currently faced with should provide an impetus for increased collaboration during these events. It is usually during difficult times that processes need to be improved and optimised which, in the case of tailings management, has a significant impact on production costs.

Visit www.paste2016.com for more details.

Vale-Hugh Jones

In July 2015, Richard Jewell and the ACG team were very saddened to hear of the passing of our much respected and loved friend and esteemed peer, Hugh Jones. Hugh was with the WA Department of Minerals and Energy (DME) which was one of the joint venture partners when the ACG was founded in 1992. He contributed significantly to the activities of the Centre from inception right through to his final months.

Retiring from the DME where he was the general manager environment, Hugh joined Golder Associates in Perth in 1999 as a senior consultant. Hugh moved his family to Victoria in 2008 and continued his consulting part-time from Golder Associate's Melbourne office, where he collaborated with the design and environment teams.

Hugh consulted in mining environmental matters, including development, operational and closure planning. He delivered environmental management audits of major overseas mining operations to IFC requirements; conceptual mine closure plans for a range of WA mines; closure designs for tailings facilities; and government closure designs. Hugh also represented the United Nations Environment Program on the ICOLD Tailings Committee and was a key contributor to many ACG tailings and mine closure training and further education events, as well as being a lead author of the Closure Considerations chapter featured in all three editions of the ACG "Paste and Thickened Tailings – A Guide".

Hugh Jones

RISKGATE-hard rock – an opportunity to develop a risk management body of knowledge for hard rock mining

by Associate Professor Philipp Kirsch, Sustainable Minerals Institute (SMI), The University of Queensland (UQ); Chris Carr, consultant; Dr Gideon Chitombo, SMI, UQ; and Darren Sprott, Design Solutions, Australia

In 2010 the Australian coal industry embarked on a national programme to capture and share broad industry knowledge about the management of key operational risks. Resulting from four years of design and knowledge collection, the online system, riskgate.org, is a comprehensive, control-based risk management body of knowledge that comprehensively provides prompts about causal, control and consequence information around a very broad range of potential events and incidents (Figure 1). These prompts can be used by mining professionals to conduct risk management practices and guide risk assessment formulation; audit risk management practices and update major hazard management plans or protocols; provide focus for incident investigations; provide prompts for building site-level risk management systems; and give guidance for developing training and induction materials. RISKGATE-coal does not present a tick and flick document but instead is an invaluable reference tool to help formulate risk management processes that are unique to each site.

RISKGATE-coal utilises bow-tie modelling to present the data in a logical and easy-to-understand form. Even without prior familiarity with bow-ties, the information is presented in a form that is digestible and control-focussed.

Figure 1 The RISKGATE-coal system delivers knowledge for eighteen key hazards in coal mining operations

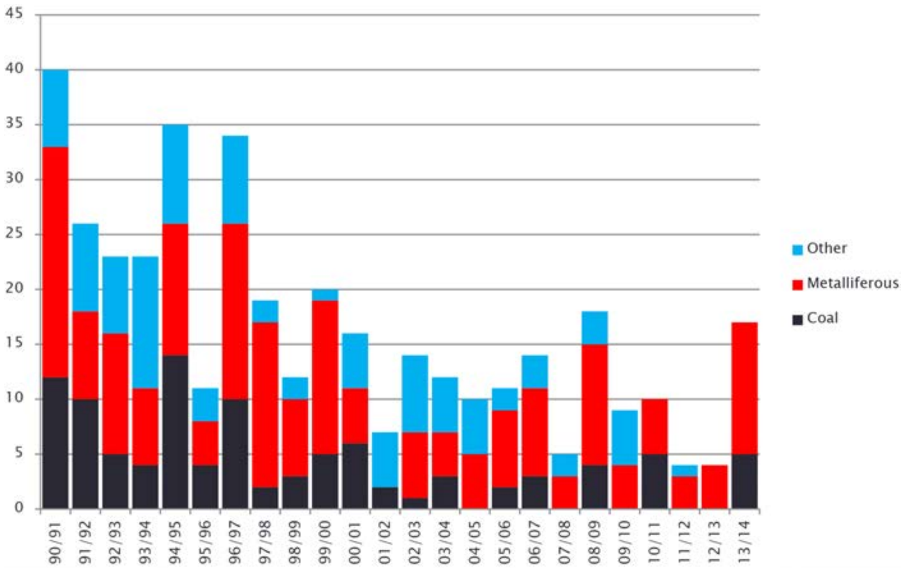


Figure 2 Australian mining deaths per fiscal year, by commodity, 1990-2014 (Kirsch et al. 2014)

In Australia the annual number of fatalities in both hard rock and coal mining has fallen steadily over the past three decades (Figure 2). However, it has been observed that the lagging safety statistics are plateauing and feature apparently random spikes. The surge in Australian fatalities in the last 18 months is cause for considerable concern to both hard rock and coal operators given the workforce is not experiencing a significant influx of inexperienced personnel. How can the Australian mining industry break the plateau effect and eliminate the poor spiking safety periods?

There are multiple possible reasons for any spike in incidents and maintenance of plateauing safety performances. Loss of corporate memory due to mergers, downsizing, retirement or a rostered commuting workforce is one possible factor, as are the dilution of knowledge and corporate culture during periods of rapid expansion, or new mine start-ups without corporate history where safety and health systems must be constructed from scratch. In a study of the mining industry in Ontario, Canada, deMeulles (2002, p. 65) noted, "*it is rare to find that [a] hazard was new or unknown. Far more often, the knowledge of hazards and their controls resides somewhere in the organization or the industry, but for some reason has not filtered through to the people who need it, or has not been applied at the right time.*" Establishment of a broad industry platform for knowledge sharing is a possible solution. In an analysis of the dramatic decrease in lost time injury frequency rates over fifty years (11, 1951; 2.5-4.5, 1981; 0.35, 1999; 0.072, 2012) in the global geophysical industry, Threadgold (2014) believes that "*the key driver for this change has been the willingness of companies and key individuals to share accident information across the industry sector. This enables the entire sector, not just the companies involved, to learn from an accident and also utilize the shared information to develop industry guidance documents.*"

The mining industry is embracing risk management methods, and bow-tie analysis specifically, at a global level. The International Council of Mining and Metallurgy (ICMM) published 'Leadership Matters: Managing Fatal Risk Guidance' (ICMM, non-dated), as well as the 'Health and safety critical control management: good practice guide' (ICMM 2015), a user guide on implementation of risk management and bow-tie methods. It is widely recognised that the most difficult step in developing risk management applications, such as assessments and investigations, is not so much identifying the hazards or potential consequences, but in identifying, developing and maintaining the focus on a meaningful list of controls (critical controls, control effectiveness, and control monitoring procedures) to prevent incidents or mitigate consequences.

RISKGATE functions as an online warehouse of control focussed knowledge that is up-to-date and accessible. This database was developed from the coal industry and for the industry through collaborative knowledge sharing of Australia's leading coal mining companies.

RISKGATE-coal is recognised within the coal mining industry as a holistic approach to site-specific risk management. While there are few examples of sharing risk management wisdom across different companies in any industry, RISKGATE-coal is the first example of this approach in the mining industry. The RISKGATE team estimated that over a quarter of the risks inherent to coal mining bear close similarity to key risks in hard rock; another third have some similarity to hard rock.

The Australian RISKGATE-coal project has delivered:

- A comprehensive set of control-based prompts; with a database of over 20,000 controls tailored to specific hazards.
- A complete visual snapshot of risk environments through bow-tie modelling.
- An interactive tool that generates reports and exportable data at any time.

The system comprises three discrete. components which can all be implemented in development and delivery of new bodies of knowledge:

- The Australian coal industry knowledge base (81 individual bow-ties for 18 different hazards).
- The semi-structured action research workshop process that has been fine-tuned for comprehensive knowledge building.
- The online framework that holds and delivers the knowledge that has been developed.

Adapting RISKGATE-coal to RISKGATE hard rock

The knowledge for risk management in coal mining encompasses different mining methods for both surface and underground operations. This knowledge has been acquired over four years of workshops with >140 industry experts from 9 Australian coal mining companies and >20 suppliers and regulatory agencies. While most knowledge is transferable to hard rock domains, due to the critical importance of this knowledge, we believe in the need to verify the information with expert panels of hard rock industry personnel prior to launching an online portal. Further, in adaptation for hard rock, it is likely that some topic areas will need to be completely restructured and some may need to be deleted and replaced with hard rock specific hazard information that has no application in coal.

The main driver of work in the adaptation of RISKGATE- coal to hard rock is the technology: differing equipment, mining methods and scales of mining. Open pit coal uses mainly truck and shovel, ripping and dozing, drag lines and bucket-wheel excavators. Equipment used in hard rock open pits does not include drag lines but

The RISKGATE project team

may have bucket-wheel excavators in stockpile management and may include scrapers and surface miners. Hard rock mining methods can create deeper pits with more significant high walls, highly selective mining with back-hoe excavators, dredging with mineral sands and, perhaps more significantly, tailings storage and waste dump management.

Underground coal essentially uses longwall techniques and room-and-pillar mining with intrinsically safe and specialist low profile mobile equipment. The key difference with hard rock is the third dimension (verticality) which introduces other hazards with people working on top of each other. Underground hard rock mining equipment is virtually all different to coal and mining methods and may include handheld and mechanised equipment, narrow open stoping, cut-and-fill, large open stoping, room-and-pillar, sublevel caving, block caving and, in South Africa, reef mining. Mines use various backfilling methodologies (longwall may be closer to caving than other methods) which are unique to the hard rock environment.

While there are various cultural and organisational differences between coal and hard rock mining, in the Australian context these are seen as relatively minor and the material developed represents no barriers to adaptation to hard rock. The existing RISKGATE-coal knowledge has a range of utility for hard rock mining, depending on the similarity of risks and operations between the two domains.

This range of utility can be divided into four areas:

- the knowledge is almost 100% portable between mining domains, e.g. explosives: open pit/surface and fitness for work.
- the knowledge is applicable with editing for domain content, e.g. vehicle interactions, fires etc.
- considerable domain specific content needs to be created, e.g. hazards specific to hard rock geological conditions or mining methods.
- completely new content will need to be developed for hazards unique to hard rock mining, e.g. mine seismicity, backfill or vertical openings).

The overall objective is to develop a RISKGATE-hard rock body of knowledge with utility for all mining methods and mining environments in Australia. It is anticipated that the project team will be a joint undertaking of the Minerals Industry Safety and Health Centre and the WH Bryan Mining & Geology Research Centre, both within The University of Queensland's Sustainable Minerals Institute. The material developed in this Australian project will also be available to other geographic regions that express an interest in developing similar approaches to the management of this type of knowledge.

Conclusion and invitation

The project leaders believe that a RISKGATE approach will generate an invaluable tool for the ongoing continuous improvement of health and safety outcomes in Australian hard rock mining. Please contact us via p.kirsch@uq.edu.au if you would like to participate at any level: from being a knowledge expert on workshop panels targeting specific hazards, to being part of the industry management committee, to being a supporting company that provides cooperative research funding to underwrite this new research project.

Please click here for article references.

Associate Professor Philipp Kirsch,
The University of Queensland,
Australia

DEEP MINING 2017

ACG Eighth International Conference on Deep and High Stress Mining

28–30 March 2017 | Perth, Western Australia

Underground mining continues to progress at deeper levels and industry is now extracting mineral reserves at depth that previously would have been considered unmineable. Deep mining is a very technical and challenging environment. A high level of understanding and technically sound approaches are essential to satisfactorily deal with the significant geotechnical (from squeezing ground to rockbursts) and logistical (transportation, ventilation) issues of deep and high stress mining, and best practice and innovation need to be implemented.

The ACG looks forward to hosting the Eighth International Conference on Deep and High Stress Mining in Perth in March 2017. This follows the previous conferences held in Sudbury, 2014; Perth, 2012; Santiago, 2010; Perth, 2007; Quebec City, 2006; Johannesburg, 2004; and Perth, 2002.

Conference themes

- Geotechnical and financial risk assessment and management.
- Numerical and empirical design and analysis.
- Case histories (success stories as well as failures).
- Rock mass response to mining (rockbursts and seismicity, squeezing ground).
- Occupational health and safety.
- Ground support.
- Blasting.
- Ventilation.

ABSTRACTS DUE 4 JULY 2016

Intending authors are requested to prepare and submit their abstracts before 4 July 2016. Deep Mining 2017 abstracts can be submitted online at www.deepmining2017.com/authors or via email to publications-acg@uwa.edu.au.

12th International Conference on Mine Closure

Host organisation

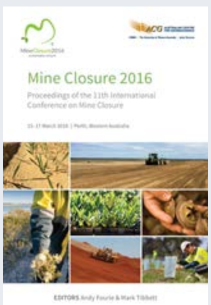
InfoMine
Mining Intelligence & Technology

October 2017 | JW Marriott Hotel Lima, Peru

The Mine Closure 2017 Conference will be held in the Peruvian capital city of Lima, a city full of rich flavours, unique cultural experiences and a magical union of past and present, as evidenced by a harmonious co-existence of ultra-modern high-rise condos and pre-Columbian temples. Lima is an easy-to-get-to destination, with its international airport servicing over 30 national and international airlines.

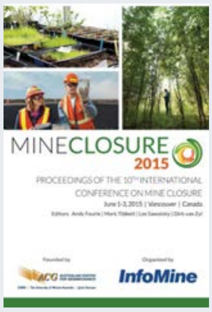
InfoMine's Dr Andy Robertson, Professor Dirk Van Zyl, Olga Cherepanova and Ursula Alvarado look forward to welcoming many mine closure practitioners to Lima next year!

Contact InfoMine via ocherepanova@infomine.com for conference details.



Mine Closure 2016

11th International Conference on Mine Closure Proceedings



Mine Closure 2015

10th International Conference on Mine Closure Proceedings

To purchase these, and other publications, please visit www.acg.uwa.edu/shop

mXrap geotechnical data analysis and monitoring platform

Research undertaken by the ACG attracts both national and global support and the outcomes of our projects are utilised to promote safer mining practices and operating efficiencies.

The mXrap software is a geotechnical data analysis and monitoring platform within which data analysis tools have been developed. mXrap and its predecessor, MSRAP, were developed as part of the ACG's Mine Seismicity and Rockburst Risk Management Project which was completed in early 2015. As part of this project, the software was a transfer tool to bring the project outcomes to the sponsors' sites. The software design and capabilities, however, created the opportunity to extend its use outside the field of mining-induced seismicity, from which it originated.

The mXrap software provides the environment within which Apps dedicated at specific tasks are being developed. The ACG research team, comprising Dr Johan Wesseloo, Gerhard Morkel and Paul Harris, has developed several tools for the monitoring, analysis and management of mining-induced seismicity. Examples are shown in Figures 1 and 2. Apps are also being developed for wider applications, and users may build and share their own Apps. Visit www.mxrap.com/mxrap-apps/ to view some typical mining-related Apps.

mXrap Consortium

Since February 2015, further development of mXrap is being performed under the umbrella of the mXrap Consortium, separate from any mine seismicity research projects undertaken at the ACG. The consortium members are companies that use the mXrap software. The mXrap Consortium financially supports the maintenance of mXrap and guides the development of the software. Software licences are only available to mXrap Consortium members. Membership fees are directly related to the number of licences required by the consortium member. For more information or to become a member of the mXrap Consortium, please contact info@mxrap.com or visit the mXrap website www.mxrap.com. A list of current mXrap Consortium members can be found on www.mxrap.com/consortium/

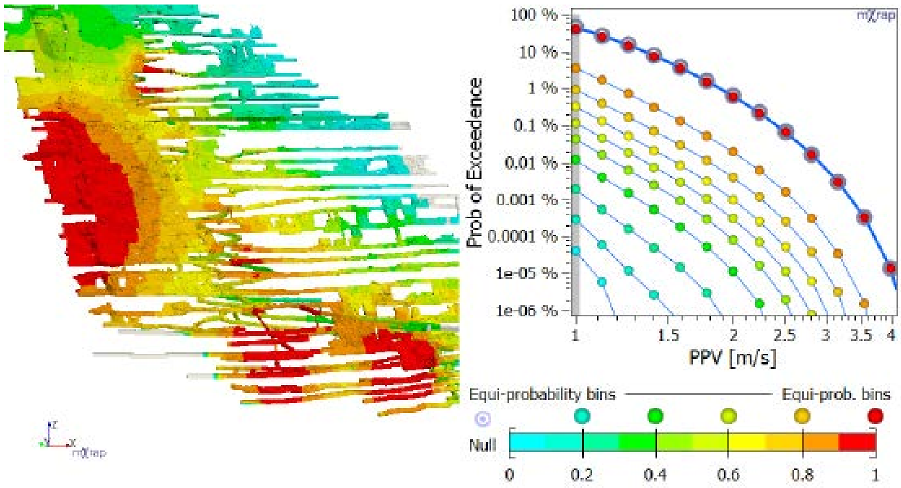


Figure 1 Seismic hazard assessment results showing the equi-probability zones on the hazard map and the associated probabilistic strong ground motion curves in the chart

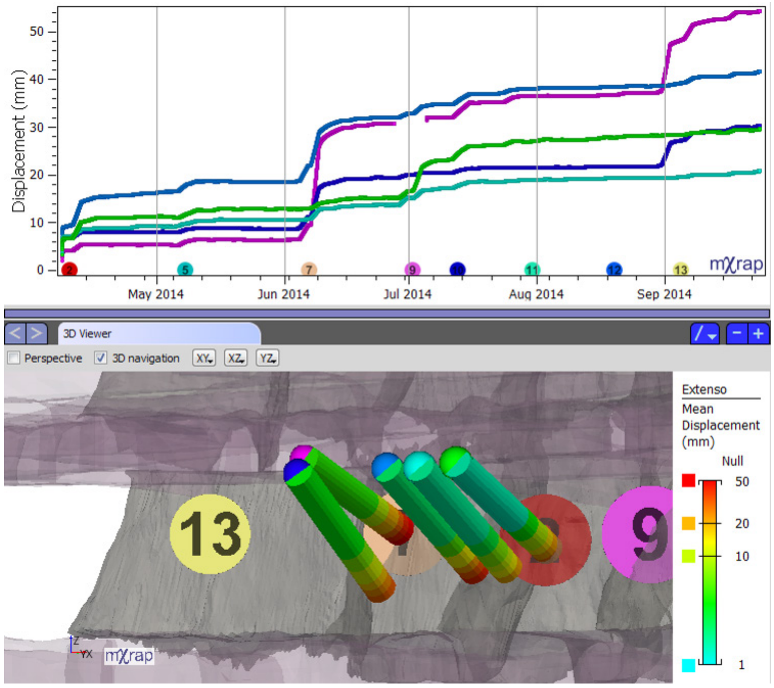


Figure 2 Extensometer data in the hanging wall of a stope in an Australian mine

The ACG acknowledges the support and commitment of the mXrap Consortium members to advancing mine safety.

Dr Johan Wesseloo,
Australian Centre for Geomechanics

Gerhard Morkel,
Australian Centre for Geomechanics

Paul Harris,
Australian Centre for Geomechanics

ACG Board of Management farewells long-serving member Mark Adams

The ACG paid tribute to its long serving board member, former MMG Limited general manager Queensland Operations, Mark Adams, who retired from the ACG board of management in July 2015.

ACG director, Yves Potvin described Mark's contribution to the success of the ACG as outstanding. "For many years Mark provided invaluable guidance to ACG activities to improve mine workers safety globally through our geomechanics training and research programmes. MMG is a highly valued sponsor and contributor to many of our research projects, including the Ground Support Systems Optimisation Project and the Open Pit Microseismic Monitoring at Century Mine Project. MMG is also an active member of the mXrap Consortium."

Ian Suckling, ACG board chair, thanked Mark for his fourteen-year membership and for his efforts in aiding the Centre to establish a strong credibility throughout industry, as well as an influential network of international collaboration. Ian referred to the value Mark brought to the board through his breadth and depth of industry experience; his respected technical acumen; and his innovative mindset. These allowed Mark to contribute sound advice to strategy and decision-making within the Centre based on a balanced appreciation of operational, academic and commercial considerations. Mark's reliably energetic contributions could be relied upon to be directed towards advancing the interests of the mining industry, solving its problems and improving the safety of those who work in it.

The board assists the ACG to focus on activities that provide focussed expert support to the mining industry by way of a unique combination of services, comprised of applied research projects that have a direct, practical application to operations; relevant training and education required to optimise their application; renowned international conferences and seminars; and technical publications of the highest quality.

Mark Adams

In his three and a half years at MMG, Mark has successfully worked with his leadership and site teams to deliver an era of significant changes. Of his many achievements, most notable are the sustained improvement to workforce safety at both Century and Dugald River, improved asset utilisation, significant year-on-year operating cost reductions, world-class planning for the closure of Century and completion of the trial stoping programme for Dugald River. Mark joined MMG with the clear aim of delivering these outcomes and his achievements are a direct reflection of his significant mining industry experience.

Mark has a long association with North-West Queensland, which included thirteen years in Mount Isa working for Mount Isa Mines in a number of mine operations and technical specialist positions. In 1994, Mark was appointed mining manager and then general manager of BHP's World Minerals' Cannington Project. Mark was responsible for the construction, organisational development and commissioning of Cannington Mine and led the operation during its first three years of operation.

Relocating to Western Australia in 2000, Mark spent eleven years leading multi-site mining and processing operations with Sons of Gwalia, WMCR Nickel and Iluka Resources. Prior to joining MMG, Mark was chief operating officer for Barminco; Australia's largest underground mining contractor.

Mark is presently chief operating officer, Konkola Copper Mines PLC, Zambia.

ACG Corporate Affiliate Memberships

Tangible support for the ACG by industry is demonstrated by our Corporate Affiliate Memberships. The ACG currently has 12 highly valued affiliate members that receive exclusive benefits such as discounted event registration fees and reduced costs for the Centre's onsite training courses and products. These memberships are fundamental in assisting the Centre to play a crucial role in identifying and developing research initiatives and professional education in Australia, particularly as industry moves towards increasing the number of larger open pits and deeper underground mining operations.
Keen to get onboard? Please call the ACG for further information.

2016 Corporate Affiliate Members

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coffey SPECIALIST KNOWLEDGE EXTRAORDINARY OUTCOMES
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SOUTH32
srk

Introducing a new rock doctor!

The ACG heartily congratulates Dr Kyle Woodward on his well-deserved achievement. Kyle invested many long hours and much dedication to be awarded his PhD and our entire team wishes Kyle the very best in his future aspirations.

Kyle's PhD thesis is entitled, 'Identification and Delineation of Mining Induced Responses'. As Kyle notes, "the phenomenon of seismicity is observed in many hard rock underground mines around the world. Seismic events pose a significant geotechnical challenge due to their potential to damage underground excavations". His thesis sought to develop a comprehensive method that is capable of identifying and delineating mining induced seismic responses in space and time while taking into account the unique characteristics of seismicity that arise due to a range of rock mass failure processes caused by routine mining activities. Kyle's supervisors were Professor Yves Potvin and Dr Johan Wesseloo.

Dr Kyle Woodward

Welcome onboard

Professor Martin Grenon, Mining Engineering, Laval University, Canada is spending his one year sabbatical with the ACG. In October 2015 we were delighted to welcome him to the team.

Dr Grenon has more than 15 years' experience in mining and civil engineering geomechanics. He started his career as a ground control engineer at Brunswick Mine, Canada. In 2001 Martin was appointed Professor at Laval University. He was also a visiting Professor at École des Mines de Paris in 2008. Martin has extensive experience in discrete fracture modelling, rock mass characterisation and probabilistic geomechanics mine design. He is the current chair of the Rock Engineering Society, Canadian Institute of Mining and Canadian Association of Rock Mechanics. While in Perth, Martin will contribute to the ACG's Ground Support Systems Optimisation Research Project as well as our mXrap Consortium project.

Professor Martin Grenon

Farewell

Teo da Costa

Despedida do Teo, desejamos boa sorte na continuidade do seu PhD!

The ACG farewelled Teófilo da Costa in October 2015 after spending 18 months with the ACG. Teo is currently a technical coordinator for Vale's Ferrous South Division hydrogeology and geotechnical open pit operations where he manages slope stability, slope design and databases. Teo joined the ACG in 2014 to undertake his PhD in 'Banded Iron Formations (BIF) in the Western Side of the Iron Quadrangle, Brazil. Geotechnical Properties of Fresh to Completely Weathered Rocks and their Importance for Slope Stability in Open Pit Mines'.

Vale's Iron Quadrangle mines generally exhibit weathering profiles that can reach over 400 m in depth. This means that for shallow mines less than 400 m in depth, slopes will predominantly be composed of partially to completely weathered rocks. However, in deeper mines (more than 400 m in depth), slopes will comprise a range of completely weathered to fresh rocks. The objective of this research is to evaluate and describe the physical and chemical properties of the BIF and their correlation with the main geotechnical characteristics for different weathering profiles. A better understanding of the geotechnical behaviour variation from the hard and fresh rock to the weak and completely weathered would optimise the final pit slope design and promote a better understanding of potential failure mechanisms, leading to a reduced risk of slope failure and, hence, an improvement of operational productivity and safety of the iron ore mines. Teo will continue to undertake his PhD studies as an external, industry-based student.

Adjunct Associate Professor Ken Mercer

Adjunct Associate Professor Ken Mercer

Ken left the ACG in July 2015 after three years as Professor of Environmental and Mining Geomechanics. Ken led our environmental geomechanics programme and contributed to our slope stability research during this period. Ken's longstanding interest in mentoring and capacity development for the mining industry, especially in developing countries, resulted in a fruitful partnership with the IM4DC. Ken has returned to industry but retains close ties with UWA and the ACG as an Adjunct Associate Professor.

Irene Neskudla

It was with a heavy heart that we farewelled Irene Neskudla in 2015. Irene joined the team in 2008 as an administrative officer and has been a guiding light in ensuring that our office hums along smoothly and professionally. Irene developed many excellent internal and external working relationships over the years and her helpfulness and patience will be sorely missed. We've much cherished our time with Irene and wish her all the very best in her future endeavours.

Shereen Braack

Shereen Braack

We were also saddened to lose Shereen, our events and administration officer, in January 2016. Shereen's positive disposition and dedication were highly valued by our cohesive team and we wish her every success in the next phase of her professional career.

ACG event schedule*

Australian Centre for Geomechanics | Volume No. 44 | March 2016

ACG AUSTRALIAN CENTRE FOR GEOMECHANICS
CSIRO | The University of Western Australia | Joint Venture

2016

Geotechnical Systems that Evolve with Ecological Processes Course	13 March 2016 | Perth, Australia
Mine Closure Implementation Workshop	14 March 2016 | Perth, Australia
11th International Conference on Mine Closure	15–17 March 2016 | Perth, Australia
Seeking Shared Value Through Stakeholder Engagement and Partnerships for Mine Closure Workshop	18 March 2016 | Perth, Australia
Physical and Numerical Modelling of Caving Mechanics Workshop	12 May 2016 | Sydney, Australia
Blasting for Stable Slopes Short Course	2–4 September 2016 | Brisbane, Australia
Instrumentation and Slope Monitoring Workshop	5 September 2016 | Brisbane, Australia
First Asia Pacific Slope Stability in Mining Conference www.apssim2016.com	6–8 September 2016 | Brisbane, Australia
Management of Moving and Unstable Slopes Workshop	9 September 2016 | Brisbane, Australia

2017

Eighth International Conference on Deep and High Stress Mining www.deepmining2017.com	28–30 March 2017 | Perth, Australia

www.acg.uwa.edu.au/events/current

*The ACG event schedule is subject to change.

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by N. Coli, L. Leoni, G. Funaioli, F. Coppi, IDS Ingegneria Dei Sistemi SpA, Italy; and G. Spencer, H. Prevost, IDS Australasia Pty Ltd

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by Associate Professor Philipp Kirsch, Sustainable Minerals Institute (SMI), The University of Queensland (UQ); Chris Carr, consultant; Dr Gideon Chitombo, SMI, UQ; and Darren Sprott, Design Solutions, Australia

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