Newsletter

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DEEP MINING 2017

Eighth International Conference on Deep and High Stress Mining

28–30 March 2017
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Deep and High Stress Mining 2017 will provide a forum for discussion and sharing of the significant geotechnical and logistical issues of deep and high stress mining, as well as best practice, new technologies and innovation.

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Ground support recommendations for mining drives

by Professor Yves Potvin, Australian Centre for Geomechanics, Australia and Professor John Hadjigeorgiou, University of Toronto, Canada

Commencing in November 2013, the Australian Centre for Geomechanics (ACG) Ground Support System Optimisation (GSSO) research project investigated: explicit ground support numerical modelling, the use of probabilistic methods for ground support design, and a benchmarking exercise to capture actual ground support practices at mine sites. This article reports on selected findings from this benchmarking initiative, which initially involved questionnaires, phone interviews and mine site visits. Ultimately, most of the information was derived from a comprehensive review of Ground Control Management Plans (GCMPs). Ninety-two GCMPs from five countries were studied, with the vast majority being from Australia and Canada.

A popular design approach is the analytical limit equilibrium method based on the Rocscience software Unwedge, which was mentioned in 56% of the GCMPs. However, the most popular method used in mines is the empirical graph originally published by Grimstad and Barton (1993) (Figure 1), which was cited in 75% of the GCMPs as the main approach to justify the selection of ground support systems used at mine sites. It is believed that the method's simplicity and ease of use and the fact that it relies on rock mass classification data, which is often the main type of data available at the pre-feasibility and feasibility stages, contribute to the popularity of this method.

Consequently, in mining operations, the ground support design process generally involves a preliminary design performed at the feasibility study stage based on the Grimstad–Barton graph. The design is subsequently modified as mine development commences, more data becomes available and experience is gained. These changes dictate modifications to the preliminary design. This can be qualified as an experience based approach and the final design could be quite different from original recommendations. Once mining is underway it is common that

ground support evolves from two or three ground support standard patterns during feasibility, to 6 to 10 variations for specific ground conditions and types of drives.

Notwithstanding its popularity, the relevance of the Grimstad–Barton graph in mining applications deserves further scrutiny. The predictive capability and accuracy of any empirical method is significantly more reliable when the application is within the same environment as the database used to develop the method. In this case, the entire database behind the Grimstad–Barton graph contains civil tunnelling cases. The limited relevance of this graph to modern underground mining becomes obvious when looking at the ground support recommendations from the method.

works well in compression, which occurs as a result of the deformation of a full ring of shotcrete applied to a circular opening.

The poor compatibility of ground support recommendations with mining practices is further evidenced by the fact that mesh, which is the most widespread surface support in mines, does not appear in any of the support recommendations. Furthermore, cast concrete lining (category 9) is very rarely used in mines.

Potvin and Hadjigeorgiou (2015, 2016) identified that the Grimstad–Barton graph, as employed by the majority of mining practitioners, does not comply with the requirements of the method. In particular, the original stress reduction factor (SRF_{74}) (Barton et al. 1974), in the calculation of the rock mass quality index Q, is used by

Another source of confusion, identified during the benchmarking study in the mining application of the Grimstad–Barton graph, is the use of the Excavation Surface Ratio (ESR), which acted as a de facto safety factor on the support design. The method requires the use of an ESR value of 1.6 to 2 for permanent mine openings and 3 to 5 for temporary mine openings. Given the same ground conditions, this implies that a reduction in ground support requirements (a lower safety factor) is recommended for temporary mine openings. This does not reflect modern mining practices. Permanent mine openings will often use ground support products that are corrosion resistant compared to temporary openings, but would generally not reduce the safety factor as mine workers are exposed for periods ranging from several months to several years. This disconnect between the method and the mining practices has translated into noticeable confusion in the selection of ESR values in the GCMPs.

Given the many deficiencies of the current practices involving the use of the Grimstad–Barton graph for preliminary or first pass ground support design in mining, there is an obvious need to develop a similar user-friendly method, based on rock mass classification and mining case studies. This information was available to the GSSO researchers through the GCMPs collected and was utilised to develop new ground support guidelines for development mining drives. A conscious decision was made to continue using the Q system, Barton et al. (1974), as a rock mass classification tool to capture the rock mass structural regime.

At the feasibility stage, mine designers need to provide a preliminary ground support design as a starting point to develop the mine and to enable cost estimations and development mining cycle times. The key design parameters to be defined by ground support guidelines include:

1. Bolting pattern, expressed in terms of bolt density (bolt/m^2)
2. Bolt length
3. Selection of surface support: mesh or reinforced shotcrete
4. The thickness of reinforced shotcrete if selected as surface support
5. The coverage of the ground support on the wall; down to the floor, mid-drive or shoulder

It was established from the comprehensive review of GCMPs that the bolt length used for mining drives is generally a function of regional practices rather than ground conditions. The standard

Reinforcement categories:
1. Unsupported
2. Spot bolting, sb
3. Systematic bolting, B
4. Systematic bolting (and unreinforced shotcrete, 4-10cm), B(+S)
5. Fibre reinforced shotcrete and bolting, 5-9cm, Sfr+B
6. Fibre reinforced shotcrete and bolting, 9-12cm, Sfr+B
7. Fibre reinforced shotcrete and bolting, 12-15cm, Sfr+B
8. Fibre reinforced shotcrete > 15cm, reinforced ribs of shotcrete and bolting, Sfr, RRS+B
9. Cast concrete lining, CCA

Figure 1   Rock mass classification — permanent support recommendation based on Q and NMT. Note the extensive use of S(fr) as permanent support (after Grimstad and Barton 1993)

The first two recommended support categories, unsupported and spot bolting, are ground support options no longer available to operating mines, because they are seen as unsafe practices. Mine workers in Canada and Australia are not to be exposed to unsupported ground. Given the typical excavation shapes in mines, which are square or with a slightly arched roof, shotcrete is mostly solicited in bending or tension and, in such conditions, unreinforced shotcrete (recommendation category 4) is not advisable. Plain shotcrete

most mining practitioners to determine the value on the X axis of the graph (Figure 1). This is despite the fact that SRF was modified in 1993 (SRF_{93}) specifically to address the perceived limitations of the original SRF_{74} in high stress conditions that resulted in inadequate ground support recommendations. The significant modifications to the ratings of SRF_{93} included a maximum value of 400 compared to 20 in SRF_{74}. This has a significant impact on the calculation of the Q value for mining at depth.

practice is to use 2.4 m long bolts in Australia, whilst in Canada the length varies from 1.8 to 2.4 m. Three metre long bolts are also used to reinforce larger excavations and specific ground conditions.

Further study of ground support strategies for different ground conditions established that, generally, as the rock mass quality decreases:

- The bolt density increases
- The wall coverage increases and is extended further down the wall
- The selection of reinforced shotcrete over mesh increases, as well as the thickness of the shotcrete

When shotcrete is used, the bolt density tends to be reduced by about 0.2 bolts/m², as the bolting pattern is no longer dictated by the size of the weld-mesh sheet.

These trends were quantified based on GCMPs and new empirical guidelines for selecting ground support for mining drives (Figure 2) that have recently been published (Potvin and Hadjigeorgiou, 2016).

These guidelines are specific to 4-6 m wide mining drives and are meant to be used as a first pass preliminary design at the feasibility study stage. The guidelines do not provide indications of the specific reinforcement products to use. It is realised that different products have different load bearing and displacement capacity. However, rockbolts act primarily as a rock reinforcement, preventing displacement and keeping the rock mass tight and confined. Following the principle that rock reinforcement is designed to help the rock mass to support itself, as promoted by Hoek and Brown (1980), the vast majority of rockbolts, independent of the product used, are rarely loaded to full capacity.

The guidelines should provide a conservative preliminary design as the database is from proven successful ground support standards documented in the GCMPs. It also represents many kilometres of drives from a large number of mainly Australian and Canadian mines. It is recognised that these guidelines are not suitable for extreme ground conditions such as squeezing or rockbursting prone areas.

For more detail on this work, the readers are referred to Potvin and Hadjigeorgiou (2015, 2016).

GSSO sponsors

This work was performed as part of the ACG's Ground Support Systems Optimisation project that is sponsored by the following companies. Major sponsors: Glencore Mount Isa Mines, Independence Group NL, Codelco Chile, MMG Limited, Minerals Research Institute of Western Australia, and the Australian Centre for Geomechanics. Minor sponsors: Jennmar Australia, Dywidag-Systems International Pty Ltd, Fero Strata Australia, Golder Associates Pty Ltd, Geobrugg Australia Pty Ltd, and Atlas Copco Australia Pty Limited.

The sponsors not only offer significant financial contributions, but also a large pool of expertise that provides extremely valuable input into the research projects and development of the GSSO guide. The project will culminate with the publication of a new ground support design guide in mid-2017.

For the latest project information, visit http://gsso.com.au/

Article references are available at http://acg.uwa.edu.au/newsletters-annual-reports/

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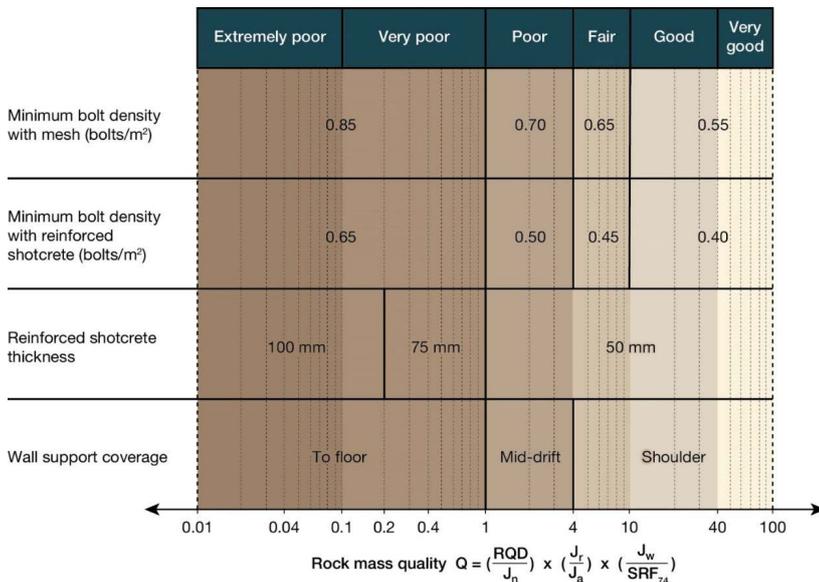
Figure 2   Ground support guidelines for mine drives of 4 to 6 m span

ACG Ground Support in Open Pit and Underground Mining Course

23—25 August 2017 | ibis Hotel Perth | Perth, Western Australia

This basic course has been developed to cover both the technical and practical aspects of ground support for open pit and underground metalliferous and coal mines. The course is designed to assist mining personnel involved with the design and implementation of mine ground support.

www.acg.uwa.edu.au/events
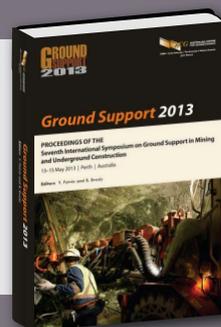
Ground Support 2013

Seventh International Symposium on Ground Support in Mining and Underground Construction Proceedings available for purchase at the ACG online shop.

www.acg.uwa.edu.au/shop

Analysis of wedge stability using the Cell Method

by William Gibson, SRK Consulting Argentina, Argentina

The stability of multiple wedges in open pit benches or underground excavations can be analysed using a novel method based on a discretisation of the rock mass with cells that are connected to form wedges. The advantage of this method is that it is possible to work with complex geometries and a Discrete Fracture Network (DFN) in a straightforward manner, without the need for meshing and there is no limitation on the shapes of wedges.

The method is utilised in the Frac_Rock software and involves the use of a regular cell mesh whereby each cell is connected to its neighbour so as to form a large block. The cells inside excavations or above topography are deleted in order to generate the geometry to be analysed. A DFN is added, which modifies the contacts, thus changing their orientation, elastic properties and strength parameters. Each contact modified by a fracture in the DFN has an assigned Mohr–Coulomb strength envelope. In future development, a Barton–Bandis strength envelope (Barton, 2013) will be included as an alternative.

SRK has incorporated these ideas into the Frac_Rock program, which has recently been released internally as a beta version for testing and validation.

Formulation

Block generation

Meshing can be a time-consuming and costly exercise, especially when software programs cannot mesh complex models and a large amount of time is spent fixing the geometry in order to obtain a mesh for the analysis.

The formulation used by Frac_Rock does not require meshing; it is based on a regular 3D grid connecting nodes with rigid contacts. Joints (fractures) can be added to the model, either as individual features or as a generated DFN using the standard information available for joint sets (i.e. spacing, persistence, joint dimension, dip and dip direction).

The rigid contacts are modified when a joint intersects them; the orientation and the strength parameters for the new contacts are based on the orientation and properties of the joint. The contacts possess Mohr–Coulomb strength criteria based on friction and cohesion properties attributed to the joints. Figure 1 illustrates the concept for the 2D case.

The joints cutting the rigid contacts automatically generate the blocks (wedges) in the model. Two blocks do not share a rigid contact but are surrounded by contacts modified by joints. This process of block generation is simple. Figure 2
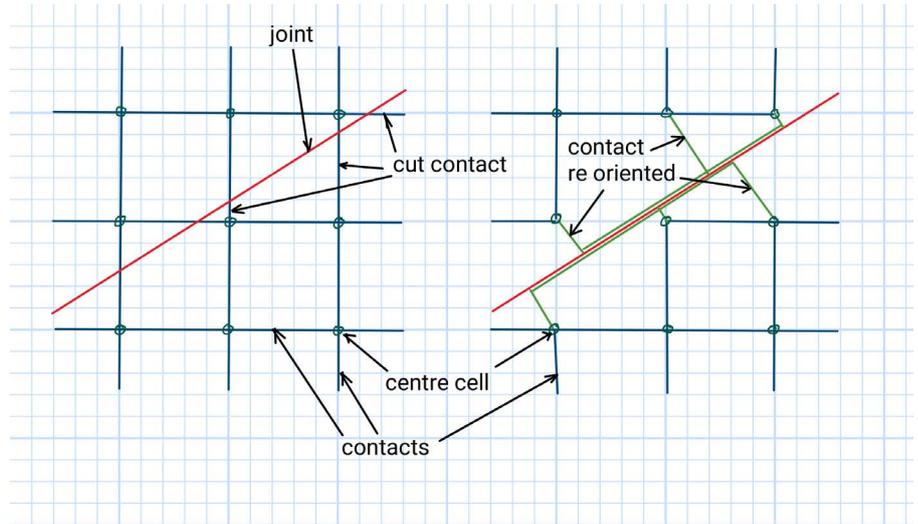
Figure 1   Cell Method formulation

illustrates a case of two wedges with an overlap. Note that even though the representation of the wedges is with step boundaries (Figure 2, left), the actual mathematical model is a plane following the joint orientations that create the wedge (Figure 2, right).

Figure 2   Isometric view of wedge contacts

Contact forces and joint strength

For each contact, an area equal to the projection of the grid face onto the joint is assigned; this area is used to calculate the contact stresses and adjust the stiffness of the contact such that at equal deformation, the stress is the same.

The joint strength is defined by Mohr–Coulomb, including tension cut, and the strength is characterised by friction and cohesion. Later improvements will include a non-linear envelope (Barton, 2013).

Equilibrium calculation

The interaction between blocks is through contacts: the forces acting on each block are both gravity and forces from other blocks transmitted through the

contacts. The equations of equilibrium are solved in an iterative fashion to take into consideration the non-linear behaviour of joints. They can behave elastically, be open, or reach peak strength during the calculation. Figure 3 shows the calculation sequence.
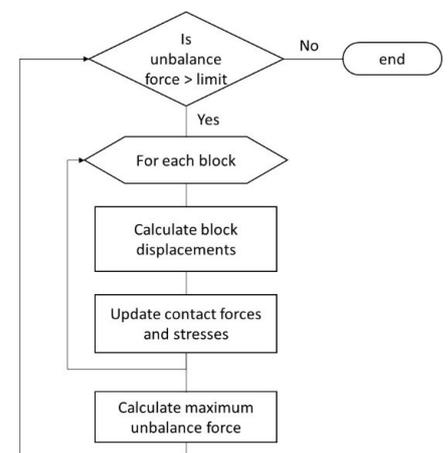
Figure 3   Calculation sequence

Verification

Wedges in open slopes

For verification purposes, several wedges of different shapes in a slope (Figure 4) were analysed with Frac_Rock and the alternative software programs, Swedge (Rocscience, 2013) and MWedge (Gibson, 2016). The properties for all joints are friction 30° and cohesion 10 kPa. In Frac_Rock, a different grid size was used: the 0.25-0.75 m range.
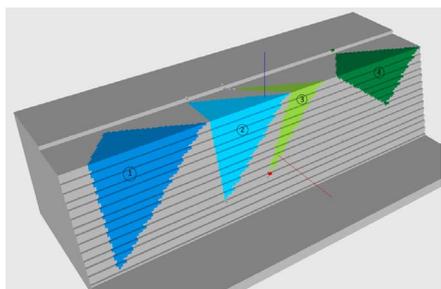

Figure 4   Isometric view of wedges in a slope

The comparison shows the results are not very sensitive to grid size.

The results are shown in Table 1. There is a good correlation between the Factors of Safety (FoS) for each wedge failure calculated using the Limit Equilibrium Methods (LEMs) (SWedge and MWedge), and Frac_Rock. The exception is wedge 3, which may be due to the assumption for LEM of constant stresses on the joints. The analysis carried out in Frac_Rock indicates this is not true for wedge stability analysis (Figure 5).

Wedges in tunnels

A similar comparison with Frac_Rock was completed for underground excavations using the program Unwedge (Rocscience, 2014). Figure 6 shows the model used for the comparison and Table 2 shows the agreement in FoS calculation between the two programs.

Applications

Frac_Rock was applied to analyse the stability of wedges in a portal and the effect of cable bolts on the wall stability. Figure 7 shows the geometry of the portal. The analysis was carried out for alternative cases, with and without cable bolts. This example is used to demonstrate another capability of the Frac_Rock method of assessing material movement. The program calculates the resting position of the material from unstable blocks/wedges. It does not calculate the dynamics of the falling rock, but instead assumes the material will flow from its original position to a resting place. Swelling is taken into account during the calculation.

The results can be compared in Figure 8, where the unstable blocks are

Table 1   Comparison Factor of Safety calculated for various software programs

Wedge	Joints	Volume (m³)	FoS MWedge SWedge (*)	FoS Frac_Rock for different cell size a (m) (*)		
				a = 0.25	a = 0.50	a = 0.75
4	1-4	615	1.084 (0.789)	0.967 (0.791)	0.976 (0.791)	0.955 (0.791)
3	1-3	300	2.640 (1.940)	1.822 (1.049)	1.881(1.072)	1.646 (1.025)
2	1-2	708	0.895 (0.640)	0.885 (0.615)	0.873 (0.615)	0.873 (0.615)
1	1-5	1032	0.548 (0.404)	0.545 (0.416)	0.545 (0.404)	0.545 (0.416)

(*) values in brackets are FoS for cohesion = 0.
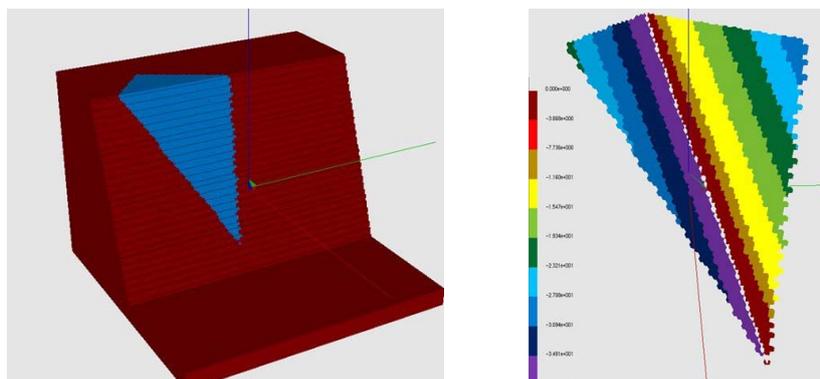
Figure 5   Isometric view of normal stress calculated for wedge using Frac_Rock
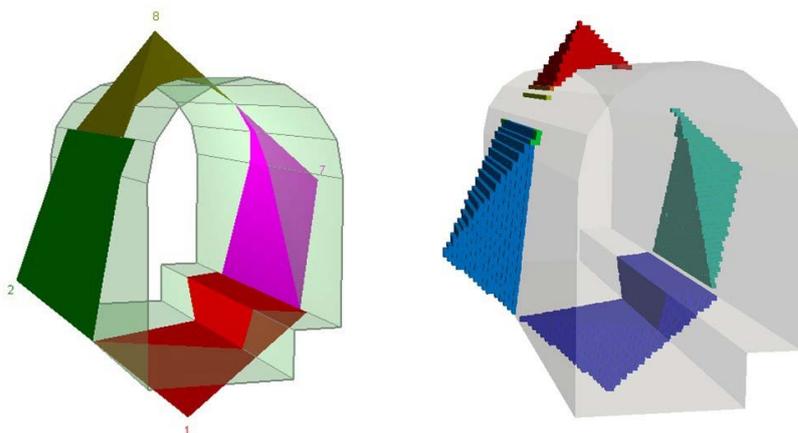
Figure 6   Unwedge and Frac_Rock models

Table 2   Comparison Factor of Safety calculation for each program

	Unwedge			Frac_Rock		
Wedge	Weight (kN)	FoS Fric = 30° coh = 0	FoS Fric = 30° coh = 12 kPa	Weight (kN)	FoS Fric = 30° coh = 0	FoS Fric = 30° coh = 12 kPa
1	206	Stable	Stable	210	Stable	Stable
2	214	1.008	1.911	216	1.014	1.857
7	136	0.333	1.131	137	0.334	1.049
8	37	0.000	0.000	32	0.006	0.006
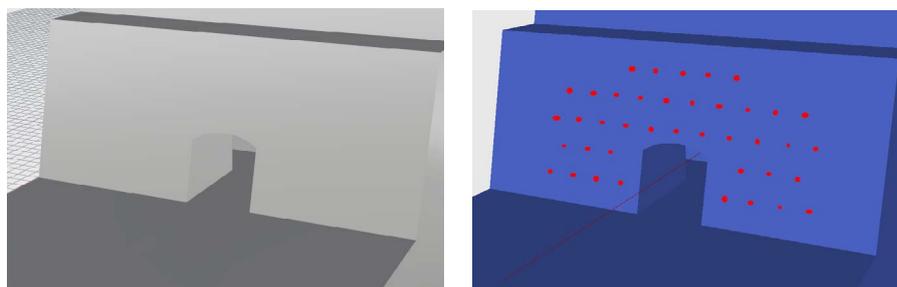
Figure 7   Isometric view of portal and cable bolt locations

shown in red and the stable blocks in green. The final location of the material from unstable blocks is shown in yellow. For the case without cable bolts, the failed material blocks the portal completely.

Figure 9 shows another example of benches in a pit, with stable wedges shown in green and material from failed wedges shown in orange.

Conclusion

The Cell Method presented provides a more efficient alternative for stability analysis of wedges. The method used in Frac_Rock software currently allows the inclusion of cable support in the analyses and assesses material movement, with other kinds of support to be added in the future. The results of wedge failure analysis produced by Frac_Rock compare favourably with alternative well-known methods and programs.

Future developments for Frac_Rock will enable the inclusion of alternative means of ground support, pore water pressure in joints, alternative joint shear strength models, and in situ stresses in the analyses.

Acknowledgement

The author thanks SRK Consulting (Australasia) Pty Ltd for sponsoring the development of the Cell Method.

Article references are available at http://acg.uwa.edu.au/newsletters-annual-reports/

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No cable. Wedge in red = unstable, green = stable

No cable. Final location unstable material

Cables. Wedge in red = unstable, green = stable

Cables. Final location unstable material
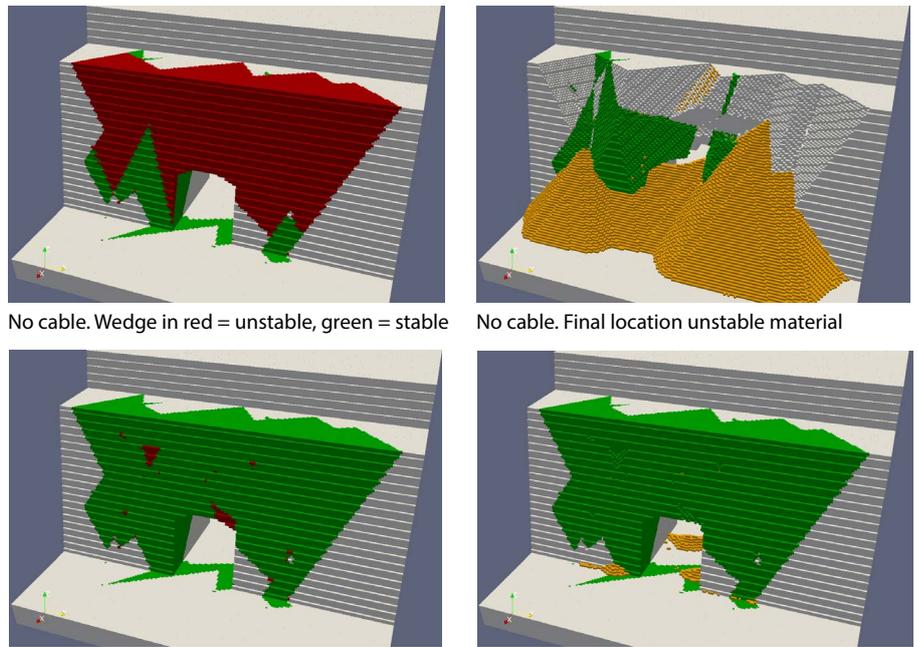
Figure 8   Isometric views showing results from stability calculations of a portal with and without cable bolt support
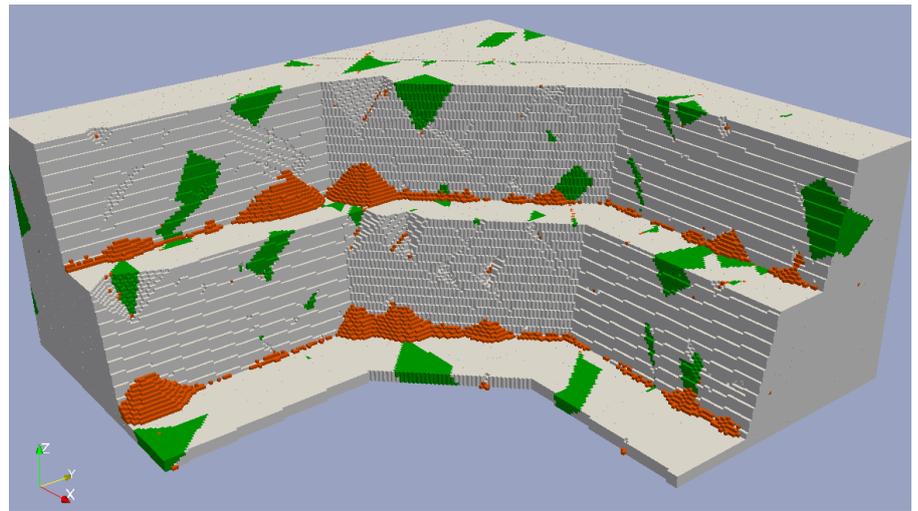
Figure 9   Isometric view of a pit slope, showing stable wedges (green) and the final location for material from failed wedges (orange)

First Asia Pacific Slope Stability in Mining 2016 Conference report

Maximising value through geomechanics

The Australian Centre for Geomechanics was delighted to host almost 150 delegates, speakers, sponsors and exhibitors at the First Asia Pacific Slope Stability in Mining Conference, held at the Sofitel Brisbane Central, 6-8 September 2016.

The conference provided a forum for best practice and state-of-the-art technologies that are targetted to the unique challenges and environs of the Asia Pacific region, with respect to pit slope investigations, design, implementation and performance monitoring.

The conference featured 55 quality presentations on a variety of topics. The three-day technical programme consisted of sessions covering monitoring slopes and rockfalls, modelling and analysis, practical analysis, design considerations, risk management, slope performance, geotechnical data considerations and design, data and visualisation technologies, and new methods for analysis and control.

The ACG was proud to have IDS Australasia Pty Ltd as the principal sponsor of the conference. Thanks go to IDS for their fantastic support, as well as our exhibitors: 3D Laser Mapping Ltd, 3v Geomatics Inc., ADAM Technology, Geobrugg Australia

Pty Ltd, Geofabrics Maccaferri, Huesker Asia Pacific Pte Ltd, itmsoil Australia and Worldsensing, MetaSensing BV and Geosystems Australia, Softrock Solutions Pty Ltd, Soldata, TRE ALTAMIRA, as well as our special sponsors Infra Tech Pty Ltd who supplied the pens and Pells Sullivan

Meynink (PSM) who sponsored a University of Queensland student to attend the conference and conference dinner. The support of all of our sponsors and exhibitors is greatly appreciated.

Chaired by the ACG's Professor Phil Dight, the conference featured an opening address by Mark Adams of KAAMA Consulting. The first keynote speaker of the conference was Adjunct Professor Tim Sullivan of PSM and the University of New South Wales who spoke on 'Design, performance and monitoring – strategies for success' followed by Professor Andy Fourie, The University of Western Australia, whose presentation focussed on 'Relying on suction to maintain slope stability'.

Day two's keynote speakers were Julian Venter from AngloGold Ashanti presenting on 'Designing with risk' and Dr Jeff Price, SRK Consulting with his presentation 'Implications of groundwater behaviour on the geomechanics of rock slope stability'.

The third and final day of the conference brought with it Mark Eggers, PSM, and his presentation 'Engineering geological modelling for pit slope design in the porphyry copper-gold deposits of Southeast Asia'. The final keynote address was given by Dr Cameron McKenzie from Blastechnology who spoke on 'Blasting near open pit walls'.

Prior to the conference, over 35 delegates attended the Instrumentation and Slope Monitoring Workshop, facilitated by Professor Phil Dight. This workshop featured numerous presentations from a wide range of local and international experts.

The Management of Moving and Unstable Slopes Workshop followed the conference with almost 35 attendees. This workshop was facilitated by Mark Fowler from PSM.

Both workshops allowed for indepth questions and discussions on the respective targetted topics around slope monitoring and management.

The conference proceedings include 55 technical peer-reviewed papers representing 19 countries. These papers address a wide spectrum of topics in relation to slope stability in open pit mining. An important subject in terms of optimising both safety and return on investment.

The hardbound conference proceedings include a colour figure CD, and are available for purchase at acg.uwa.edu.au/shop

Spatial analysis of seismicity – a case study

by Ruth Stephenson, AMC Consultants Pty Ltd, Australia

Over the last 15 years there have been significant advances in microseismic data processing and interpretation through the increased functionality of tools such as Vantage, and post-processing tools such mXrap. Unfortunately, the reality at many mines is that due to under-resourcing, detailed post-processing and interpretation is often not done. This article presents a case history which highlights how improved management of mine seismicity can be achieved through the simple spatial analysis of seismic data.

Spatial (and temporal) analysis of microseismicity can be a useful method of analysis to locate large-scale structures that could slip and cause damaging events, if a good dataset is available. Microseismicity can concentrate around pre-existing structures, including those that might appear well-healed in the drill core or underground exposures.

One of the key areas of interest is how closely the seismicity is associated with

blasting, both in space and time. Ideally, all the damaging seismic events would be closely associated with blasting, both spatially and temporally. This makes it easier to manage because personnel can be excluded from the perceived elevated risk areas and periods. Where the events are more widely distributed, relative to the active mining areas, and/or they occur outside a practical exclusion period (e.g. more than 24 or 48 hrs), the reliability of the various controls diminishes, and the costs and impact on safety and production may become untenable.

In order to conduct a meaningful spatial analysis, the following information is required:

- An accurate date and time history of stope and development firing and backfilling that can be related to 3D mining shapes
- A 3D model of the known large-scale structures and geological contacts
- A seismic database, cleaned of

spurious data, particularly blasts, and large events that locate well outside the system sensor array

The case study presented is from a mine with a well-maintained seismic system, and a well-designed array that allows for good location accuracy. A seismic spatial analysis using the seismic data is presented using a standard 3D mining software package. A set of 3D files was constructed from mining as-built and stope cavity monitoring system (CMS) surveys on a quarter by quarter basis, and then monthly for the last year analysed. At this mine, the levels of seismicity had increased significantly during that last year and so the analysis was conducted in more detail for that period.

The seismic database information was split into time periods, imported into the software and compared with the 3D as-built mining shapes for the corresponding periods. The results viewed on screen are the seismicity that relates
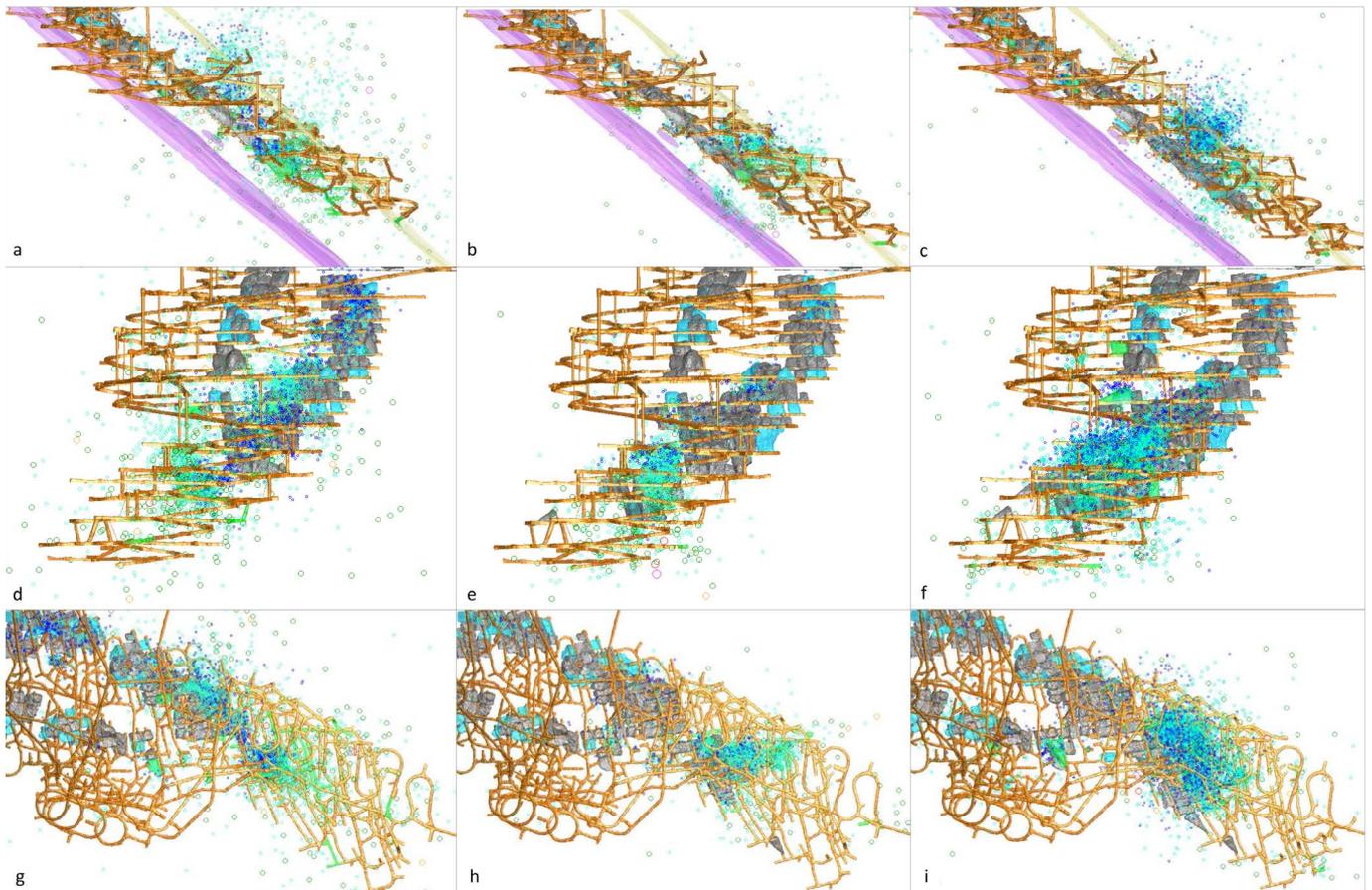
Figure 1
a. Time step 1 – January to March, 2014 (cross-section) b. Time step 2 – April, 2015 (cross-section)
c. Time step 3 – November, 2015 (cross-section) d. Time step 1 – January to March, 2014 (long-section)
e. Time step 2 – April, 2015 (long-section) f. Time step 3 – November, 2015 (long-section)
g. Time step 1 – January to March, 2014 (plan view) h. Time step 2 – April, 2015 (plan view)
i. Time step 3 – November, 2015 (plan view)

Key - Wireframes	Key - Seismic events (local magnitude)
Existing development	-3 to -2
Existing backfilled stopes	-2 to -1
Existing stopes, no backfill	-1 to 0
Development and stopes extracted that period	0 to 0.5
Ultramafic	0.5 to 1
Metasedimentary unit	>1

Figure 1   An example of spatial seismic analysis

to those areas mined during that period, and areas previously mined, which could be important, particularly if they were not backfilled.

At the case study mine, the spatial analysis identified a concentration of seismicity which was found to coincide with an ultramafic geological contact, which was little known at the time. This concentration of seismicity included approximately half of the largest events in the database. The other half of these events occurred in the hangingwall and are probably related to relaxation of the hangingwall after stoping.

The hangingwall of the mine consists of a 'very strong' and 'good' quality basalt, intersected by a thin meta-sedimentary unit approximately 2 m thick. The ore zone is contained within a large regional shear zone, a mafic schist which is highly foliated but 'very strong'. An ultramafic unit lies at the footwall contact of the shear zone. The mine infrastructure was placed in the hangingwall instead of the footwall because the rock mass conditions were known to be better in the hangingwall. As such, the importance of understanding the causes of seismicity and damage are paramount to reducing the related hazards in the hangingwall development.

Figure 1 presents an example of the spatial seismic analysis. The figure shows a cross-section, long-section and plan view for each time period. Three time steps are shown: the second step relates to the mining sequence three months after the first, and the third step relates to the mining sequence eight months after the second. The selected time steps presented the clearest indication of the relationship between seismicity, structure and stoping. Each view reveals different information of the relationship between seismicity, stoping and large-scale structures.

The cross-sections in Figure 1 show that large events are occurring approximately 70 m into the footwall of the stopes. The analysis prompted an investigation into the footwall geology which was previously poorly understood. An extensive talc-chlorite ultramafic unit was identified and modelled. The recorded seismicity is interpreted to be a result of shearing at the contact of this unit.

From the figure, it is also evident that seismicity is not clustered near the meta-sedimentary unit within the hangingwall. However, this structure is important because development is more damaged proximal to the structure, despite levels of seismicity similar to the surrounding rock mass. The damage was observed as undercutting of the unsupported lower walls, cracking of fibrecrete and shearing of bolts. It was observed that the rock mass in this area is strongly sheared and can be more blocky or fractured in character than in other areas, making it inherently weaker and more prone to stress damage, but without significant seismic response. The ground support was upgraded in the areas surrounding this structure from a relatively stiff system comprising fibrecrete and fully-encapsulated solid bar bolts, to a system with greater dynamic capability and yield capacity. The new support included mesh over the fibrecrete and dynamic bolts.

The long-section and plan views in Figure 1 indicate that the majority of the intense clusters of seismicity are associated with active stopes. There are, however, clusters of activity present after the stopes are backfilled. This is particularly apparent in time (step three) and less easy to explain. Further investigation into mining rates and sequence revealed that the mine had reached a point at which careful attention to mining rate and sequence was required to limit seismicity and associated damage. Smaller clusters can also be observed

associated with stopes that have not been backfilled which are further away from active stoping.

A relatively simple spatial analysis of mine seismicity can provide improved understanding of the controls on mine seismicity, the sources of potential large damaging events, and highlight opportunities to reduce seismic hazard through improved ground support in targetted areas and mining sequencing. Specifically, at the case study mine the analysis provided the following insights:

- An ultramafic unit exists in the footwall which is shearing and causing large seismic events
- Seismicity is not necessarily closely associated with the hangingwall meta-sedimentary unit, despite higher levels of damage observed surrounding the unit
- Careful mine sequencing and scheduling have become key to limiting deformation and rehabilitation
- Stopes should only be left open (unfilled) in areas that will no longer be accessed, and where there is no long term infrastructure

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AMC Consultants Pty Ltd, Australia

ACG mXrap software – advancing mine safety by delivering research outcomes as useful software

Since 1999 the ACG has researched and pursued the mitigation of economic and safety risks associated with seismic activity in hard rock mines. mXrap formed an important part of the ACG's Mine Seismicity and Rockburst Risk Management Project as a technology transfer tool.

Since 2015, ongoing mXrap software development and maintenance is under the auspice of the mXrap Consortium; separate to mine seismicity research. The Consortium currently comprises more than 20 mining

houses that receive benefits from the different apps developed in mXrap.

mXrap is a geotechnical data analysis and monitoring platform which provides generic tools which can be used by engineers to script specific task-focussed apps that can be shared between different users. Several standard apps have been developed over the years for the analysis and management of mining-induced seismicity. The mining-induced seismicity suit includes, amongst others:

- General analysis tools with powerful range temporal, property and spatial filters
- Seismic hazard assessment
- Grid-based evaluation of seismic source parameters
- Data quality analysis tools

Other apps are being developed to translate the ACG and other institutional research outcomes into useable software. More at http://mxrap.com/

The mXrap Consortium is a proud *Student Registration Sponsor* of the Eighth International Conference on Deep and High Stress Mining

mXrap

Paste and thickened tailings operations and research in China

by Professor Aixiang Wu, University of Science and Technology Beijing, China

Background

From prehistoric times to the present, mining has played an important part in human existence. The history of mining parallels the history of civilisation. Many cultural eras were identified by minerals, such as the Stone Age, Bronze Age and Iron Age. Mineral resources are essential for human development and civilisation.

World mineral consumption has increased sharply in modern times. China has developed one of the world's largest mining and minerals industries that underpins the continual development of bulk commodities, aerospace infrastructure, military supplies, building materials, and transportation infrastructure. There are 171 varieties of mineral resources in China, and its proven reserves of mineral resources constitute 12% of the global reserves. China is one of the largest global producers and consumers of mineral resources.

With rapid economic development in the past 30 years, numerous non-ferrous metal mines have been intensively exploited throughout China. Mining activities bring about substantial solid wastes and severe surface or groundwater pollution. Mining alone has left behind about 1,500,000 ha of waste land in China; increasing at a rate of 46,700 ha per year. Environmental disasters caused by heavy metal pollution have been aggravating. Far worse, tailings dam failure, underground voids collapse and land subsidence occur occasionally, directly causing injury or death. On 8 September 2008, a tailings dam located in Shanxi Province collapsed and 277 people were killed.

During the early stages of the industrialisation in China, one of the major concerns was to utilise natural resources to support economic development. Presently, public perception of mine pollution and disaster has driven the industry to search for green mining technology that can prevent or minimise the effect of mining activities. China's central government recently enforced several regulations, pushing hard on the practice of mine backfill. The State Administration of Work Safety has specified that the cut-and-fill method shall be the preferred method for newly built mines. The Ministry of Finance declared a 50% resource tax exemption for mining companies using mine backfill technology.

Evolution of cemented paste backfill in China

Traditionally, hydraulic fill with diluted slurry and high density hydraulic fill has been widely used in China. Due to high water content, diluted hydraulic fill has to deal with cement loss, low backfill strength, underground pollution, and the high costs for water and mud pumping in the dewatering process. Meanwhile, the thickening of tailings for surface disposal and underground backfill has been extensively practiced in the mining industry worldwide, outside China, because it could prevent or minimise environmental and safety impacts.

China started to carry out research and application of paste backfill in the 1980s. A number of research institutes, manufacturers, and universities have been devoted to research, equipment development and system design of paste technology. Paste technology could well expect a tremendous market amongst China's 153,000 mines. The first paste backfill system in China was built in 1996 at the Jinchuan Nickel Mine (JNM), and

cement is fed directly to an above-ground mixer to produce paste. Finally, gravity flow is adopted to deliver the paste. Such simplification significantly reduces operational difficulties in the paste filling process. The solid concentration of paste at HLZM is 78-80%; the filling capacity is up to 1,264 m³ per day. The filled paste shortens the time required for stope alternation, improves the stress state of surrounding rocks, and enhances the underground working environment.

With increasing mining depth, problems such as broken surrounding rock, crustal stress increases, and high water content occur at higher frequency. All these problems are experienced at JTCM, where the current mining method is shrinkage stoping. The surrounding rock at this mine site is highly water sensitive, and five subsidence areas have already appeared on surface. Fortunately, cemented paste backfill was adopted and built at

Figure 1   The paste backfill station at Jiashi Tonghui Copper Mine

the first paste backfill system based on deep cone thickening technology in China was built in 2006 at the Huize Lead-Zinc Mine (HLZM), which is the deepest mine (1,562 m) in China. Later, at Jiashi Tonghui Copper Mine (JTCM), the first cemented paste backfill system using pumping agents in China was designed and established.

HLZM, Yunnan, owned by Yunnan Chihong Co., China, is one of the largest poly-metallic mines in the world. Its success in paste filling application is owed to the greatly simplified process. Deep cone thickener is employed for one-stage thickening and dewatering, and dry

JTCM in 2014. The cemented paste backfill, providing higher filling strength, less water bleeding, and lower cost, effectively solves many problems at JTCM.

The ultra-fine unclassified tailings of high viscosity in JTCM also brought about the challenge to improve paste strength and transportability. Coarse aggregate and pumping agents are added to produce more versatile paste that addresses this challenge. The transport capacity in JTCM is 70-90 m³/h. The solid concentration is increased to 75-81%, thus the water bleeding into the voids is substantially decreased and argillisation is effectively

avoided. The fill strength reached 2-5 MPa after 28 days, which is sufficient to ensure the stability of the underground voids.

The cemented paste backfill system design at JTCM provides significant guidance for other mines facing similar situations and also promotes the application of cemented paste backfill technology in China.

Although the cemented paste backfilling technology has been used in China, it is still in the initial stage, and many key problems need to be explored. It is crucial for cemented paste backfilling technology to improve fundamental theories, actively promote the application of new materials and new technology, and accelerate the development of equipment with independent intellectual property rights.

Application of paste disposal technology in China

Technical experiments of dry-stacking were firstly conducted in gold mines. As an adaptation of dry-stacking, paste disposal technology is being rapidly developed. It is considered an energy-saving tailings management method among mining enterprises. Compared with the cemented paste backfill technology, paste disposal is relatively new in China. Wushan Copper Mine (WCM) was the first to employ the paste disposal technology to manage its ultra-fine unclassified tailings in China; it was commissioned in 2007.

WCM, owned by Gold Group Corporation, China, is the fourth largest poly-metal deposit in China, promising a total metal reserve of 2.67 million t. The ore-processing capacity is 30,000 t per day, and the tailings is discharged at high-concentration. A set of two 40 m deep cone paste thickeners are used to thicken the tailings, whose underflow contains 70-72% solid by weight.

The paste is of good mobility and flows by gravity in the open channel between the discharge point and the tailings fan, after which the paste is able to spread smoothly into a delta-type flow profile to the border, increasing the exposed area, promoting water evaporation and accelerating the consolidation process. The paste disposal technology enables WCM to reduce water consumption notably and increases the solid handling capacity of its tailings dam. This successful practice at WCM proves that paste disposal is especially feasible in alpine regions, and serves as an important reference for similar mines.

Aside from WCM, more and more mines in China are implementing paste disposal technology to manage tailings. However, many problems still exist when dealing with ultra-fine unclassified tailings. There is still a long way to go to solve these problems and it requires a breakthrough of basic theories

Figure 2   Paste flow in the Wushan Copper Mine tailings pond

and specific equipment development.

Paste seminars in China

In order to provide a platform for the exchange and cooperation among research institutes, mining companies and equipment providers, Professor Aixiang Wu, vice president of the University of Science and Technology Beijing, initiated the International Seminar on Paste Backfill in China. This seminar commenced in 2013 and is held every two years.

In November 2013, 300 delegates from five countries attended the first seminar in Beijing and shared the achievements and improvements of paste technology in China and other countries. A total of 20 speeches were made covering six themes: paste backfill, chemical material, equipment, thickening, pumping, and case studies. The second seminar took place during 6-9 November 2015, and attracted more than 400 attendees. A total of 33 presentations focussed on five themes: mechanical properties, preparation, transportation, design and optimisation of paste backfill systems, paste backfill in coal and metal mining.

Paste 2017

In 1999, the Australian Centre for Geomechanics initiated the series of international seminars on paste and thickened tailings. The objective of the seminar series is to disseminate the latest advancements in the field of paste and thickened tailings technology. Each year a paste seminar takes place worldwide; past countries include: Australia, Canada, South Africa, South America and Ireland. For the first time, a seminar will be held in China. Paste 2017 will be hosted and organised by the University of Science and Technology Beijing which is renowned for its research and education on metal mining engineering, ranking third in Chinese universities.

As the capital of China, Beijing hosts a large number of mining company headquarters, consulting companies and colleges. The mining professionals in China will show our enthusiasm towards international delegates worldwide. Paste 2017 will consist of three sections: seminar, exhibition and technical visit. The Beijing Conference Center is the seminar venue and technical visit is to the WCM.

We look forward to welcoming you to Beijing in June 2017!

Professor Aixiang Wu
University of Science and Technology Beijing, China

PASTE·2017
20th International Seminar on Paste and Thickened Tailings
15-18 June 2017
Beijing Conference Center, China
www.paste2017.com

Rock properties to predict rockburst vulnerability in three dimensions

This new ACG research project aims to equip the mining industry with support systems knowledge to mitigate strainburst/rockburst risk

As mines continue to be mined deeper and open pits expand, strainbursts and rockbursts are increasing the cost of mining safely, i.e. ground support requirements, microseismic monitoring, restrictions to production and sequencing, as well as delays in re-entry, sometimes lead to the premature closure of a mine. These problems are a major threat to the future exploitation of deep mining resources.

Several strainburst/rockburst risk management approaches are available and are currently used by many mines. However, once the mining method and sequence are determined, the hazard state is more or less locked in, leaving implementation of dynamically resistant support as one of the only short-term controls of excavation damage potential. Consequently, the selection of an appropriate dynamic support system is of paramount importance in managing burst risks in mines.

To aid industry to design more appropriate support systems to mitigate the potential problem in July 2016, the ACG commenced an industry and Minerals Research Institute of Western Australia (MRIWA) funded research project into 'Rock properties to predict rockburst vulnerability in three dimensions' (MRIWA Project M464).

Project objectives

This new ACG research project will examine the properties of rocks in 3D covering the pre-peak and post-peak behaviour in order to identify where rockburst could occur. Pre-peak behaviour is dominated by rock brittleness and fracture generation. Post-peak behaviour is likely to be dominated by rocks which release energy following failure (called Type 2 or self-sustaining behaviour). The aim is to identify early indicators of fracture toughness and Type 2 behaviour and to examine whether this is directional or not. Once the rockburst potential nature can be identified, Dight et al. (2013) has shown that the energy from the self-sustaining behaviour can be related to the ejection velocity, which means that the demand on and parameters for ground support may be determined for dynamic situations.

The ultimate benefit of the project to the mining industry will lead to fewer mines closing due to rockburst and help identify approaches for reducing the consequences of rockbursts, in particular, by designing more appropriate support systems. This will contribute to making deep mines safer and more sustainable in the future.

The problem

Ortlepp and Stacey (1994) defined rockburst as 'damages that occurred in a tunnel as the result of a seismic event, or which is directly associated with a seismic event.'

The implications of rockbursts from a mining operational perspective can vary depending on the circumstances. The consequences could range from being minor (no immediate action required), some rehabilitation of the support system, or limited production delay, up to as severe as damage to equipment and mine infrastructure, injuries to personnel, write-off of reserve, permanent mine closure and even fatalities.

The pervasiveness of the rockburst issue in many mining operations suggests that it is still one of the major ground control issues waiting to be resolved and one which could affect all operations. Despite decades of research, factors affecting the occurrence of rockburst damage are still not yet well understood (Heal, 2010). Hence, there is a demand for an alternative approach to understanding their occurrence and how to better manage the risks associated with this problem.

A more recent classification for rockbursts has been proposed by Hudyma (2008), based on the Es/Ep energy ratio and the event magnitude. Notwithstanding these (or other) rockburst classifications.

A review of seismic monitoring in Australian mines (Heal, 2010) and Canadian mines (Hadjigeorgiou, 2014, pers. comm.) shows that about 80% of all measured burst damage occurs within the source radius – this is commonly termed 'strainburst'. Hence, 20% of damage can be attributed to seismic events remote to the opening (rockburst).

Kaiser and Cai (2013) concur with the assertion that most rockbursts are in fact a form of strainburst, and suggest that even when a large seismic event occurs far away from the damage location, the damage is often controlled by the local rock properties/stress conditions (and geometry).

This has profound implications for the way industry designs its ground support systems.

Implications for open pits

Until recently strainburst was considered a phenomenon solely in the underground space, however, anecdotal evidence suggests a recent fatality in an open pit mine could be attributed to a strainburst in a mine less than 200 m deep (Costa, pers. comm., 2015). Indeed there is ample evidence of spalling following blasting in both open pit and underground mines which can be attributed to strainburst behaviour.

Stress measurement is not a standard procedure in open pit mine evaluation and is largely ignored (Read and Stacey, 2010), but if stress concentration at the toe of a slope, blasting problems at the toe of a slope and development of extensional cracking (Stacey 1981; Dight, 2006; Dight et al., 2009) behind the face are known unknowns, then the mechanisms need to be understood and taken into account as part of the hazard management.

Photo courtesy of Peter Hills

This research project will examine the properties of rocks in 3D covering the pre-peak and post-peak behaviour in order to identify where rockburst could occur

Potential industry benefits

Other project deliverables may be derived from a new way of looking at rock properties, i.e. anisotropy, brittleness and super-brittleness, etc. These include:

- Are rock properties directional or omni-directional? Is preconditioning or de-stress blasting appropriate and in which location are they effective, based on the stress field?
- The proposed testing may revolutionise the way in which numerical modelling is undertaken for mining because the results of the testing may provide three-dimensional rock properties versus the commonly assumed isotropic properties, potentially leading to a sounder engineering approach to design
- The research work may have important implications in better understanding some stress related open pit slope failures
- The project may also aid a better understanding of the link between blast damage and self-sustaining brittle behaviour evidenced both in open pit and underground mining. This could provide an observational approach to understanding where the rock may be more susceptible to strainburst and guide engineering solutions to reduce risk
- Finally, since stress measurement from core based on the concept of 'stress memory' will be an integral part of the project research work, the potential, the reliability and the limitations of this technique is expected to be more advanced
The research project team will explore:
- In situ stress recovery
- Pre-peak intact properties
- Post-peak properties (energy demand from Type 2 behaviour)
- Demand for the design of dynamic support

Introducing the research project team

The project team is led by the ACG's Professor Phil Dight and comprises the following researchers:

- Professor Arcady Dyskin, chair, Computational Mechanics Discipline Group, The University of Western Australia
- Dr Ariel Hsieh, research associate in mining, ACG, The University of Western Australia
- Adjunct research associate Max Lee, geotechnical specialist, Monash University
- Associate Professor Bre-Anne Sainsbury, director, Resources Engineering, Monash University

Research project team

Professor Phil Dight *Professor Arcady Dyskin* *Dr Ariel Hsieh*

Adjunct Research Associate Max Lee

Associate Professor Bre-Anne Sainsbury

This team is supported by the following PhD candidates:
- Mark Burdett, Monash University
- Broadus Jeffcoat-Sacco, ACG, The University of Western Australia
- Ali Keneti, Monash University
- Dale Luke, ACG, The University of Western Australia
- Hongyu Wang, ACG, The University of Western Australia

Collaborating universities

The majority of the research work will be conducted at The University of Western Australia. Research undertaken by Monash University includes the consideration of pre-peak and dynamic studies through the application of geological investigations and numerical modelling in three dimensions.

Project sponsors

- Minerals Research Institute of Western Australia
- Aeris Resources, Tritton Resources Limited

- Agnico Eagle Mines Limited, LaRonde Mine
- AngloGold Ashanti Australia, Sunrise Dam Gold Mine
- Ernest Henry Mining Pty Ltd (a Glencore Company)
- Gold Fields Australia Pty Ltd, Granny Smith Mine
- Gold Fields Australia Pty Ltd, Agnew and St Ives Gold Mines
- Luossavaara-Kiirunavaara AB, Kiruna and Malmberget Mines
- Newcrest Mining Limited, Cadia Valley Operations
- Northern Star Resources Limited, Kalgoorlie Operations
- Sudbury Integrated Nickel Operations (a Glencore Company), Nickel Rim South Mine
For more information or for project sponsor opportunities, please contact the ACG. Article references are available on request. www.acg.uwa.edu.au/newsletters-annual-reports/

ACG Strainburst in Mining Seminar – How to Mitigate the Consequences

Tuesday 10 October 2017 | Radisson Hotel Sudbury | Sudbury, Canada

This ACG seminar seeks to explore the latest technologies and methodologies used at mining operations to mitigate and manage strainburst risk. It is hoped that by learning more about these phenomena, successful methodologies to reduce the likelihood and consequences of strainbursting can be idientified and shared. This will contribute to making deep mines safer and more sustainable in the future. More at www.umt2017.com

11th International Conference on Mine Closure report

The ACG mine closure conferences are held throughout the world and are readily recognised as the premier events on the calendars 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.

Much has changed since inception of the conference series in Perth in 2006, with transformations to the financial climate, regulatory controls, technological instruments and, most notably, the appreciation of community engagement.

The range of topics presented at the ACG's 11th International Mine Closure Conference, held in Perth in March 2016, was once again very wide. MC 2016 provided a forum for more than 250 mine closure professionals to expand their current thinking, challenge existing doctrine and explore new paradigms in all aspects of mine closure.

The peer-reviewed conference proceedings include 52 papers that challenge miners to think of post-mining futures and that (at last) acknowledge (typically) unreported failures; often the greatest lessons on the path to success.

Given the current downturn in the global resource sector, mine closure is a fact of life and this conference series continues to be highly relevant and pertinent.

Prior to the conference, the ACG hosted a number of workshops. Mine Closure 2016 Conference co-chairs, Professors Andy Fourie and Mark Tibbett presented a "Geotechnical Systems that Evolve with Ecological Processes Course". This course explored the importance of geotechnical systems, such as landfills, mine tailings storage facilities (TSFs), slopes and levees, which are required to perform safely throughout their service life, which can span from decades for levees to in perpetuity for TSFs.

Mine Earth Pty Ltd's Shannon Mackenzie facilitated a new "Mine Closure Implementation Workshop" that was attended by more than 30 delegates. This practical workshop addressed what was needed to implement an effective mine closure project and included a site visit to Alcoa of Australia's Huntly Mine. The ACG and workshop attendees are grateful to the Huntly team for generously providing their time and resources for this site visit.

Attendees thoroughly enjoyed the "Seeking Shared Value through Stakeholder Engagement and Partnerships for Mine Closure Workshop", facilitated by Sonia Finucane, Bioscope Environmental Consulting Pty Ltd. This one day workshop recognised that building better relationships with stakeholders not only assists the development and operation of mining projects, it facilitates mine closure and custodial transfer.

Mr Doug Warden, chief financial officer, Iluka Resources, opened the Mine Closure 2016 Conference with a unique message for the attendees that highlighted the importance of mine closure to the global mining sector, "your work is not in any way separate or supplementary to the resources industry; it is a vital part of the resources industry, as indispensable as that of our colleagues working in operations, engineering, finance and elsewhere".

Warden stated that quality rehabilitation and closure is an expectation in industry, and is of considerable significance to Iluka Resources.

"Iluka's rehabilitation budget for 2016 is A$54 million; and the company's total rehabilitation spend over the past five years is A$204 million. To put that into context, in the same five-year period Iluka spent A$130 million on exploration activities – so, at a time when the company is actively looking to invest counter-cyclically, it has outlaid almost double the amount on rehabilitation as it has on one of its key internal growth options."

The achievement of quality, value-for-money rehabilitation is important to Iluka Resources. It enables this mineral sands company to create and deliver value to its shareholders. Warden described how "Iluka has grounded its rehabilitation practices in the concept of 'proactivity' – meaning the relentless pursuit of internally-set standards that extend beyond compliance with environmental regulation". He reported that Iluka had completed 2,592 ha of rehabilitation since 2011; exceeding new land disturbance; and reducing the total area opened by the company by 339 ha.

Doug Warden, Chief Financial Officer and Head of Strategy and Planning, Iluka Resources, Australia

The opening address set the scene for an interactive and thought-provoking conference. Six keynote addresses followed, including: "Ecological research needed to manage risk and meet rising standards in mining rehabilitation", presented by Dr Ben Miller, Botanic Gardens and Parks Authority, Kings Park; and "The eye of the beholder – utility and beauty in mine closure", presented by Adjunct Professor Bruce Harvey, The University of Queensland.

A big thank you to those that attended and supported the MC 2016 Conference.

A special thanks for our sponsors…

During the three day event, 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 and encouragement of the Conference Principal Sponsor, Iluka Resources.

The achievement of quality, value-for-money rehabilitation is important to Iluka Resources. Photographs courtesy of Iluka Resources
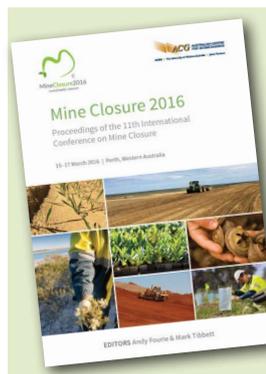
The Proceedings of the 11th International Conference on Mine Closure are available at acg.uwa.edu.au/shop

The 12th International Conference on Mine Closure will be held in Leipzig, Germany in September 2018.

The assessment of seismic responses to mining

by Dr Kyle Woodward, Australian Centre for Geomechanics, Australia

Introduction

The phenomenon of seismicity is observed in many hard rock underground mines around the world. The potential for seismic events to damage underground excavations can create a significant hazard to mining personnel, equipment and infrastructure. The management of seismic hazard is an essential component in minimising the political, social and economic risks associated with mining. The effective management of seismic hazard is underpinned by a sufficient understanding of the magnitude, spatial and temporal characteristics of seismicity. These characteristics of seismicity are controlled by causative seismic source mechanisms within a mine and are related to stress conditions, rock mass strength, excavations, geology and geological features.

This article focusses on the assessment of seismic responses which are spatially clustered events generated by time dependent rock mass failure processes, e.g. following blasting or large seismic events. The study of seismic response characteristics has significant implications for mining operations where seismicity is a source of hazard for the workforce and infrastructure. The potential for seismic risk to adversely affect mining operations and the requirement for the mining industry to continually improve the management of seismic hazard is illustrated by the 2006 Anzac Day event at Beaconsfield Gold Mine, Tasmania. In addition to significant economic loss, this event resulted in the loss of one life and a 14 day operation to rescue two trapped miners. The extensive review following this tragedy highlighted the importance of improving methods of managing seismic response hazard (Melick, 2007).

There are numerous interrelated factors that can influence the characteristics of seismic responses and this makes it difficult to establish meaningful correlations with causative processes. Furthermore, the management of seismic response hazard has the tendency to rely on the site specific experience which has inherent limitations. These challenges can be partly addressed by the quantification of seismic responses, which allows for the development of an objective understanding of seismic responses. This article presents a brief outline of a recently published methodology for the assessment of seismic responses. While this article provides a limited overview of the implemented methodology, further details can be found in Woodward (2015). Two case studies illustrate the typical implementation, results and benefits of quantifying seismic responses. Firstly, a case study of individual seismic responses and, secondly, results from the assessment of seismic data for an entire mining environment.

Delineation of seismic responses in space and time

The process for delineating seismic responses is an iterative process with three distinct steps:

1. Identification
2. Spatial delineation
3. Temporal delineation

An example of the method's practical application is provided in Figure 1.

Firstly, a seismic response is identified in space and time by increased event occurrence (grey sphere in the 1st frame). Secondly, the information provided by response identification is used to spatially delineate events associated with the response using density based clustering techniques (grey cross in the 1st frame).

Thirdly, temporal modelling using the Modified Omori Law (MOL) delineates a period of consistent time dependent behaviour for the spatially delineated events (grey cross in the 2nd frame). Note that the modelling period (and response events) has been refined due to inconsistencies late in the response. The delineated response is removed from the dataset (orange spheres in the 3rd frame). The procedure is iteratively re-applied to the remaining events and an additional response is identified, delineated and removed (purple spheres in the 4th frame).

Case study 1: assessment of an individual seismic response

The following case example presents analysis results from the delineation of an individual seismic response within an open stope mine over a short time period. This seismic response of 192 events was well-modelled by the MOL (AD = 0.55), with a nominal decay rate (p = 1.04), productivity (K = 22.24), and a small time offset (c = 0.008). Figure 2 shows a summary of modelling results (top), time series of cumulative occurrence of all events, modelled events (green) and events not modelled (red) (left). Additionally, this figure provides a sectional view of modelled events (green) with respect to stopes (right). Note that the algorithm did not include seismic response event portions as they are not spatially clustered and are outside the sectional view.

The modelling results only consider a dataset of 30 hrs after this response, although this seismic response continues well beyond this formative period. In this somewhat exceptional case, due to the time between subsequent blasting, this response can be modelled for an additional 31 days with only minor changes to temporal modelling results and a slight degradation to suitability of fit (p = 1.00, K = 23.8, c = 0.006, and AD = 1.12). These parameters are remarkably close to the decay rate and productivity found by modelling of the 30 hr dataset.

The quantification of this response, in terms of the consistency of spatial and temporal occurrence, provides an anecdotal basis for considering these events to be part of a consistent and continuous rock mass failure process. Furthermore, these results imply consistent seismic responses without the influence of additional stress changes (e.g. blasting or large events), and that modelling of an early period may provide a forecast of future seismic activity rates. The ability to forecast seismic activity rates
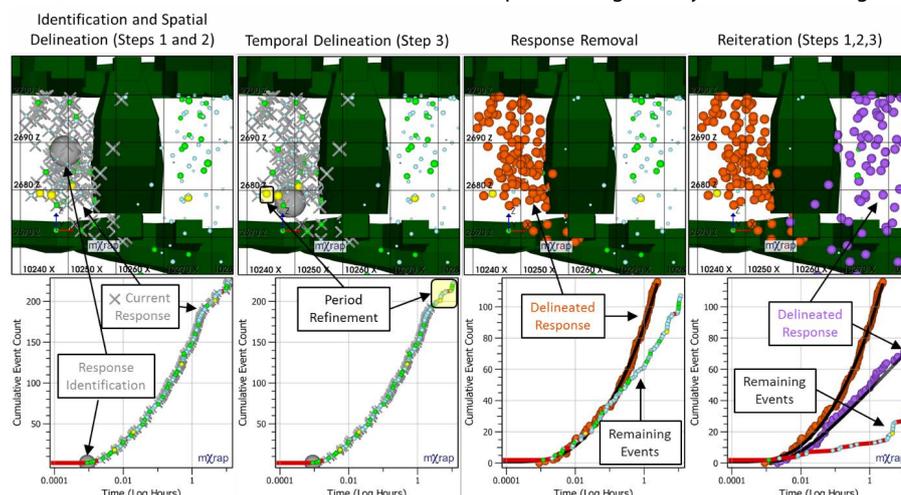

Figure 1   Application of the method to identify and delineate a seismic response

| ID	D$_S$	S$_T$	p(±)	K(±)	c(±)	AD	#Events
1	30	50	1.04(0.04)	22.24(1.90)	0.008(0.004)	0.55	192
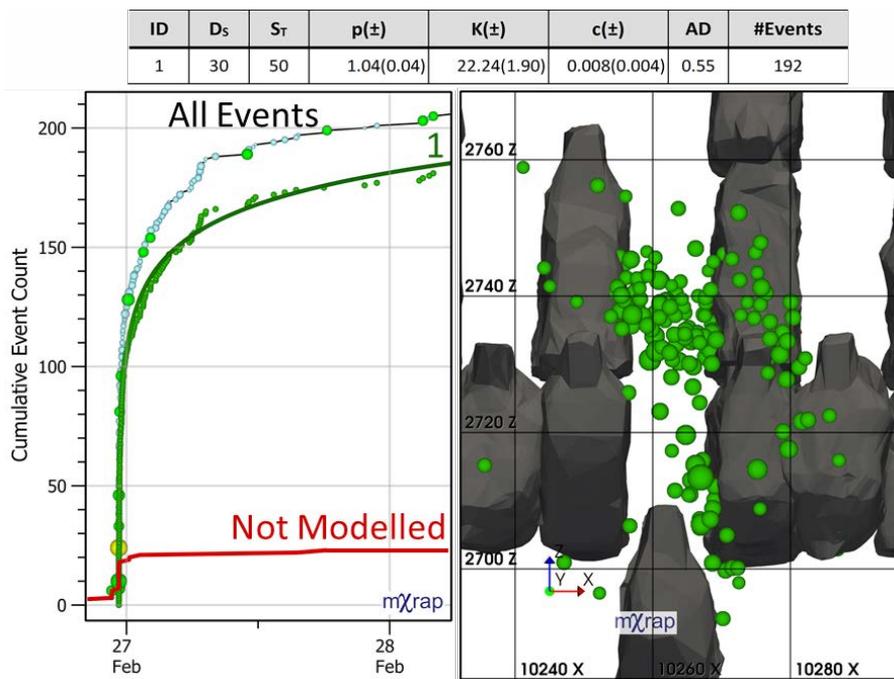
Figure 2   Top: A summary of modelling results. Left: Time series of cumulative occurrence of all events, modelled events (green) and events not modelled (red). Right: a sectional view of modelled events (green) with respect to stope surveys

is beneficial when attempting to assess at what time in the future re-entry restrictions could expect to be lifted. A consistent approach to quantification allows for a history of seismic responses that build confidence in nominal parameters, given similar mining conditions, and ultimately allows for the transparent formulation of protocols with respect to reliability and operational considerations.

Case study 2: retrospective mine wide response assessment

This retrospective response assessment aims to establish characteristic parameters for different conditions within a sublevel caving mine. This assessment evaluates the components that represent a measure of seismic hazard, specifically K parameters, p parameters, c parameter, b values and modelling intervals. The identification and delineation of seismic responses was applied to a dataset containing 360,000 events. The assessment identified and delineated 1,559 responses containing 96,000 events (≈ 25% of all events). Only responses with reasonable parameters were considered in subsequent analysis by removing responses that were unsuitably modelled by the MOL, unreasonably short, exhibited high uncertainty in parameters, or required a high c parameter. This filtering removed 8,500 events associated with 190 responses from further consideration.

Seismic responses are spatially allocated to unique geotechnical domains, primarily with respect to the nature of mining (e.g. direction of mining, and development versus established production). These domains also represent different geological and geotechnical considerations which account for the nature of mining. Each domain is described with respect to qualitative mining characteristics and given an arbitrary ID in Table 1 that corresponds to the associated figures. This table provides quantification of mean parameters from temporal modelling. Each spatial geotechnical domain has distinctly coloured markers in Figure 3 and is annotated by the corresponding numerical ID (left: plan view, right: Y section). Each sphere in this figure represents a single seismic response. The same marker colours correspond to the cumulative density functions of K parameters (left) and p parameters (right) for each geotechnical domain (Figure 4).

Considering the distribution of response quantification with respect to specific geotechnical domains allows the following qualitative observations. Geotechnical domains that only contain development blasting result in higher p parameters and lower K parameters (light blue, blue and dark blue). Geotechnical domains with high stress conditions, i.e. deeper in the mine (light blue), or cross-cutting principal stress directions (green), have relatively higher b values. Domains with lower b values are likely influenced by geological features (Legge and Spottiswoode, 1987), and also have lower p parameters and higher K parameters (dark blue versus light blue). Domains that likely contain a mixture of influences (stress concentration, geology, production and development blasting) have lower p parameters and higher K parameters (green, yellow and orange).

Quantifying seismic responses through the mining environment is essential to optimising the management of seismic response hazard. The identification and delineation of seismic responses provides historical characterisations of geotechnical domains and provides guidance for future responses in these regions. Retrospective quantification also provides a reference to assess when seismic responses are uncharacteristic of a geotechnical domain. For example, when geology begins to influence seismic responses to deeper development (and production), it can be expected that the productivity of responses will increase, the temporal decay of event occurrence will decrease, and there will be more large events relative to small events.

Concluding remarks

The identification and delineation of seismic responses allows the consistent quantification of spatially clustered, time dependent seismicity which contributes to improved management of seismic hazard. The ability to statistically assess if an individual seismic response is consistent in space and time provides a basis for assessing if events are due to a continuous rock mass failure process and may prove

Table 1   The geotechnical domain, number of responses in each domain (count), characteristics, and relevant mean parameters for temporal and magnitude quantification

| Domain description	ID	Count	T$_S$	T$_E$	p(±)	K(±)	c(±)	b(±)
Raise bore development under high stress conditions	1	136	0.032	12.7	0.65(0.38)	11.1(11.8)	0.00(0.01)	1.40(0.02)
Development blasting, faulting, and contrasting rock properties	2	315	0.019	11.6	0.86(0.29)	7.3(5.8)	0.01(0.02)	0.99(0.02)
Development and production blasting, and geologically controlled stress conditions	3	205	0.020	19.0	0.74(0.27)	8.4(4.2)	0.01(0.02)	1.00(0.01)
Development and production blasting, geological features, and cross-cuts principal stress	4	420	0.023	20.0	0.64(0.29)	11.6(10.0)	0.01(0.02)	1.21(0.01)
Development blasting under high stress conditions due to increased depth	5	297	0.015	9.2	0.99(0.28)	5.6(4.1)	0.01(0.02)	1.42(0.03)
Development and production blasting, geological features, and varied stress conditions	6	91	0.013	13.7	0.86(0.26)	9.0(7.0)	0.01(0.03)	0.99(0.02)
Isolated responses to development blasting	7	95	0.027	9.7	0.95(0.32)	5.4(3.8)	0.00(0.01)	1.35(0.05)

valuable when attributing seismicity to seismic source mechanisms. Assessment of historical seismic responses builds confidence in nominal parameters for various geotechnical domains and provides guidance for future responses in regions experiencing similar mining conditions. The quantification of nominal response parameters is an important aspect for the objective formulation of re-entry protocols and assessing when re-entry protocols are not applicable to uncharacteristic responses.

Article references are available at http://acg.uwa.edu.au/newsletters-annual-reports/

Dr Kyle Woodward

Australian Centre for Geomechanics, Australia
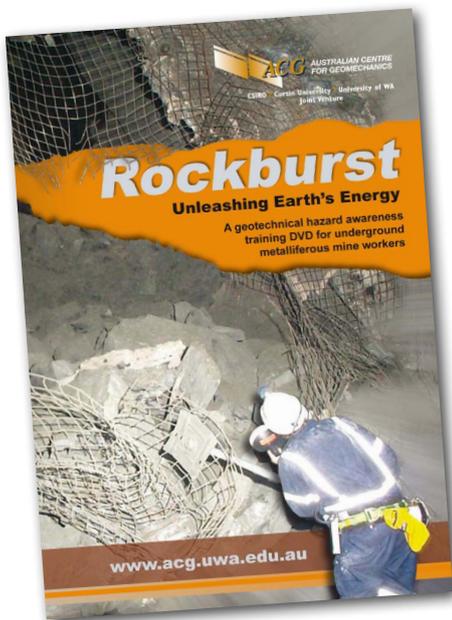
ACG Rockburst – Unleashing Earth's Energy Training DVD

Unleashing Earth's Energy: A geotechnical hazard awareness training DVD for underground metalliferous mine workers.

Available for purchase at www.acg.uwa.edu.au/shop
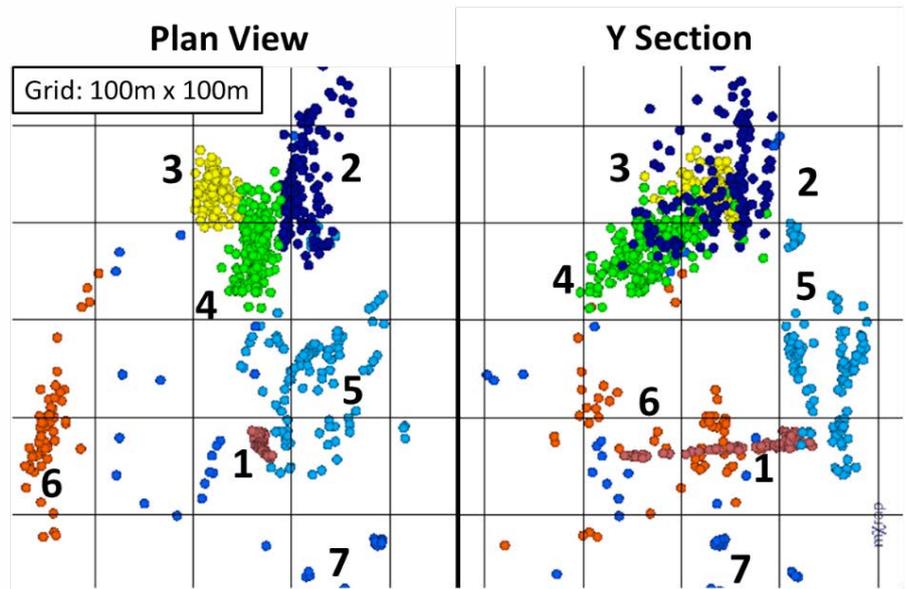
Figure 3   Spatial locations of geotechnical domains are shown on a plan view (left) and Y section (right). Each sphere is an individual seismic response
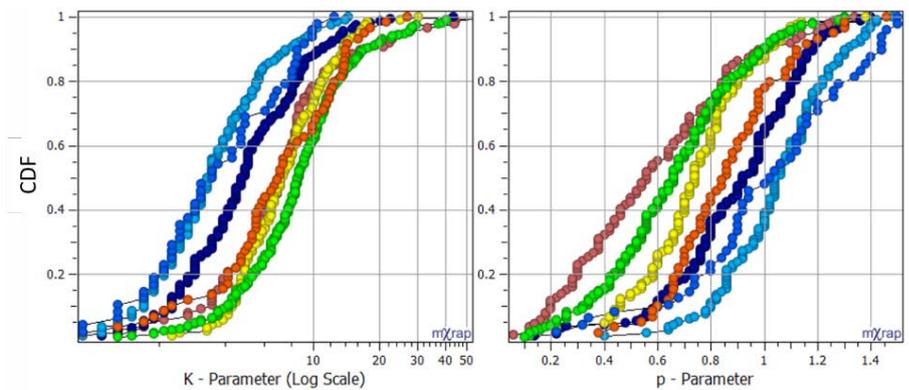

Figure 4   Cumulative density functions per geotechnical domain for the K parameter (left) and p parameter (right). Markers are coloured corresponding to the spatial plot

ACG Ensuring High Quality Seismic Data for the Mining Industry Workshop

27 March 2017 | Novotel Perth Langley Hotel | Western Australia

Hardrock mines in deep and high stress environments often require the use of seismic systems to enable operators to manage seismic risk posed to the workforce, the mining investment and environment. Seismic data is also used in assessing the rock mass response to mining activities where source parameters are used in the interpretation of rock mass failure mechanisms, the calibration of numerical modelling, and the interpretation of failure mechanics of the rock mass.

High quality seismic databases are of the utmost importance. In rock engineering the transfer of empirical knowledge from one site to another, or between different time periods at the same site, is crucial for good decision-making in complex situations. The complexities involved in the design, installation and maintenance of seismic systems and the challenges imposed on processing the data can result in noise and poor quality data contaminating the databases; adversely impacting on decision-making.

This workshop will provide a forum to discuss the different aspects that impact on data quality with the aim to provide mine site rock engineers and seismologists with practical knowledge to ensure the highest quality data for the site and to identify problems impacting on the industry which need to be addressed with focussed R&D.

To view the workshop programme, please visit www.deepmining2017.com/associated-events

BASF seeks to evaluate polymer performance in tailings treatments

by Lewis Utting, BASF Mining Solutions, Australia

Traditional management of tailings involves disposal of plant-generated slurry to surface tailings dams. Tailings dams can have a large environmental footprint, often retaining substantial volumes of water that ideally could be recycled.

The most troublesome tailings often have a low particle specific gravity and a high gravimetric water content, especially if this is combined with a bimodal distribution of particle size. If enough suitable real estate is available then air drying can be incorporated into the design. Although the water may not be returned to the plant, the water content of the tailings is reduced to a level closer to or even past the plastic limit. Another solution, although CAPEX intensive, is the mechanical dewatering of tailings which is growing in popularity. It is possible to achieve a low water content while also allowing for significant amounts of water to be recovered for reuse. In recent times, the use of polymers has also grown in popularity and has shown to be another viable method for dealing with this challenge by significantly increasing initial dewatering while, in some cases, also achieving a higher final density.

The mining industry's most common exposure to the use of polymers in tailings treatment is either for sedimentation in a thickener or tailings filtration, as is common in the coal industry. Thickener laboratory testing by thickener vendors relies primarily on dynamic testing, where a sample is fed into a column with a certain loading (flux, t/m^2/unit time) and an offtake exists on the bottom of the column to pump the underflow. As the vessel is filled, a number of predetermined mud bed heights are used to find the permeability limit of the tailings through the rise rate of the bed. Given the significant number of thickeners that exist in the field and the relative ease by which empirical field data can be gathered, these assessments can be defined as being fit for purpose.

A common approach in evaluating polymers for use in tailings treatment post thickener is to use empirical data from field observations or conduct pilot scale trials, which can be expensive and time consuming. Developing a dynamic laboratory evaluation program, as robust as is used in thickener evaluations, would be ideal and in the case of polymers being used, is a technology gap that BASF and its partners have been addressing.

One barrier to establishing good engineering metrics, for use in tailings dam design, is the ability to conduct meaningful laboratory based studies. Capturing the changes in fabric and permeability that occur when a polymer is added to tailings is challenging, as these initial changes typically take place at moisture contents well before the liquid limit of the tailings is reached. This part of the dewatering process typically takes place before self-weight consolidation occurs, something not typically captured in traditional geotechnical testing.

Review of existing laboratory methods

Empirical field data exists to illustrate the benefit of polymer addition, along with varying laboratory techniques ranging from static sedimentation to more dynamic consolidation testing. However, many of the techniques used for this purpose do not always provide for data that best represents the dynamic processes that tailings undergo in the field.

Traditional static settling test

Typically this method relies on a slurry being placed into a settling column of varying height to diameter ratios, with the tailings slurry allowed to settle over time. Once settling has ceased and there is no further movement of the mud line, the final density is recorded. Where polymer is concerned, this method illustrates that, given an infinite amount of time, the settled dry density achieved by untreated tailings surpasses that of polymer-treated tailings, with the exception of highly dispersed mineral suspensions. This method relies on a single upwards drainage path with a single fill of the column and a portion of the material at the base of the column undergoing some self-weight consolidation. The addition of stress on the material, as well as the ability to measure pore pressure inside the column, is not possible.

Conventional oedometer test

Testing usually commences at densities much higher than those typically encountered from the thickener as stipulated in most testing standards. The test itself involves applying constant loads to a soil sample and measuring the resulting settlement with time. This allows for the compressibility or void ratio versus effective stress to be determined. The permeability or void ratio versus hydraulic conductivity is then calculated using the small strain consolidation theory from rate of consolidation. Tailings slurries at low densities undergo large strains, consolidating significantly due to self-weight, and have highly non-linear permeability and compressibility relations. This makes the standard oedometer not applicable for such materials. More suitable test devices have been proposed, including the Rowe Cell and Slurry Consolidometer, which better accommodate the large strains, self-weight effects, and non-linear compressibility and permeability relationships of a material commencing testing as a slurry.

Hydraulic load cells (Rowe Cell, Slurry Consolidometer)

Typical hydraulic load cells, such as a Slurry Consolidometer or Rowe Cell are
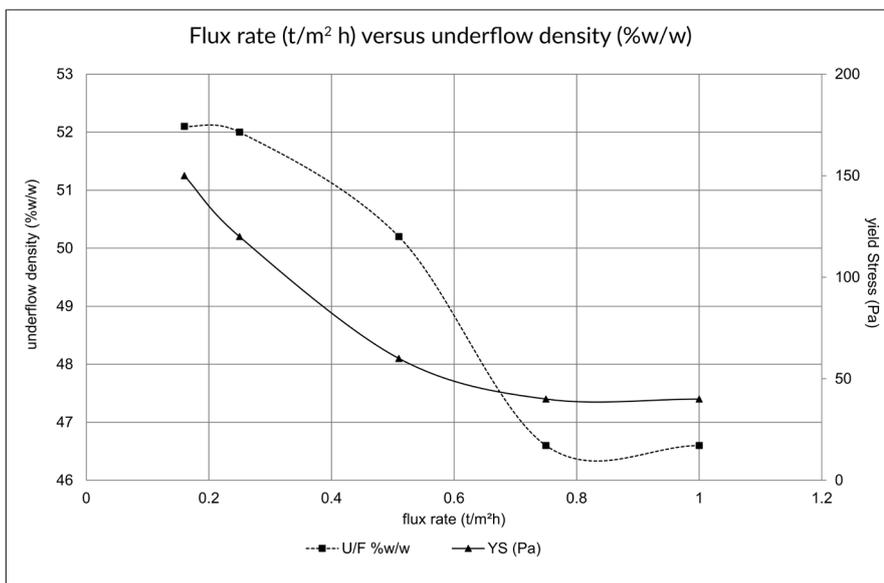

Figure 1   Batch settling flux

quite different to a standard oedometer. One main difference is that hydraulic cells have the ability to measure permeability directly through the use of a constant head test. In this test, a known pressure head or gradient is applied to the slurry sample and the flow rate across the sample is measured. The effective stresses for the Slurry Consolidometer range from 5 kPa to above 400 kPa. The lower effective stresses are limited by the accuracy in measuring very small flow rates for permeability measurements. In addition, the higher effective stresses are limited to the time required for consolidating the low permeable tailings to those higher stresses. In typical tailings applications where polymer treatment may be considered, densities are often low and the initial increase in density, whereby volumes decrease by one third to one half of the original volume, occur at stresses not captured by either piece of traditional consolidation equipment.

Collaborating to develop robust testing methods with specialised consolidation equipment

Being able to predict field performance, where chemistry is used to change the engineering properties of tailings, has many advantages but in order for these to be realised, new testing methods are needed. BASF have recognised the need to support the mining industry in this field and, in conjunction with global partners in academia and engineering houses, have taken practical steps toward improved procedures through the construction of specialised testing equipment, such as the Seepage Induced Consolidation Test (SICT). The SICT allows for the direct measurement of compressibility and permeability of low density slurries without any of the limiting assumptions required in conventional testing that rely on small strain consolidation theory.

Seepage induced consolidation test

This test is similar to the hydraulic cells in that it employs a step loading scheme procedure. However, there are some differences which make this test more suitable for soft soils, dense slurries and potentially also for dredge spoil.

Compared with conventional consolidation test methods, the SICT can determine the permeability for high void ratio tailings in a span of days. It also allows for the accurate determination of consolidation at the point at which effective stresses are generated in the sample and consolidation starts to occur.

The testing procedure consists of three steps. In the first step, the void ratio at the effective stress starting point is

determined by allowing a slurry column to consolidate under its own weight. This is the Self-Weight Consolidation Phase (SWCP), the duration of which is terminated at the discretion of the user when the sample compaction rate plateaus. In the second step, on completion of the SWCP, the Seepage Induced Consolidation Phase (SICP) commences, wherein seepage at a constant flow rate is applied through the soil by means of a flow pump and the sample is allowed to consolidate completely under the gradient, i.e. until the steady state is reached. The steady state is determined from the pressure difference across the sample that is continuously monitored during the test. At steady state, the pressure difference and the final height of the sample are recorded. It is recognised that during this phase of the test, the void ratio within the sample is non-uniform and this is correctly accounted for in the test analysis. In the third step, on completion of the SICP,

the Step-Load Consolidation Phase (SLCP) commences wherein specific loads are applied and maintained upon the sample with sample differential pressure and displacement continuing to be monitored. This phase is generally conducted with a sample seepage velocity in an order of magnitude lower than for the SICP. This is currently considered to be at the limit of current technology and its application. The termination point of the SLCP is again at the discretion of the user but generally conforms to the same criteria as the SICP.

The procedure is based on the inverse solution approach and the theory used is compatible with the finite strain non-linear consolidation theory (no simplification or restrictive assumptions are made in the analysis). The output gives five parameters; A, B, Z, C and D that define the consolidation properties for the sample. The compressibility and hydraulic conductivity relations with the five parameters are
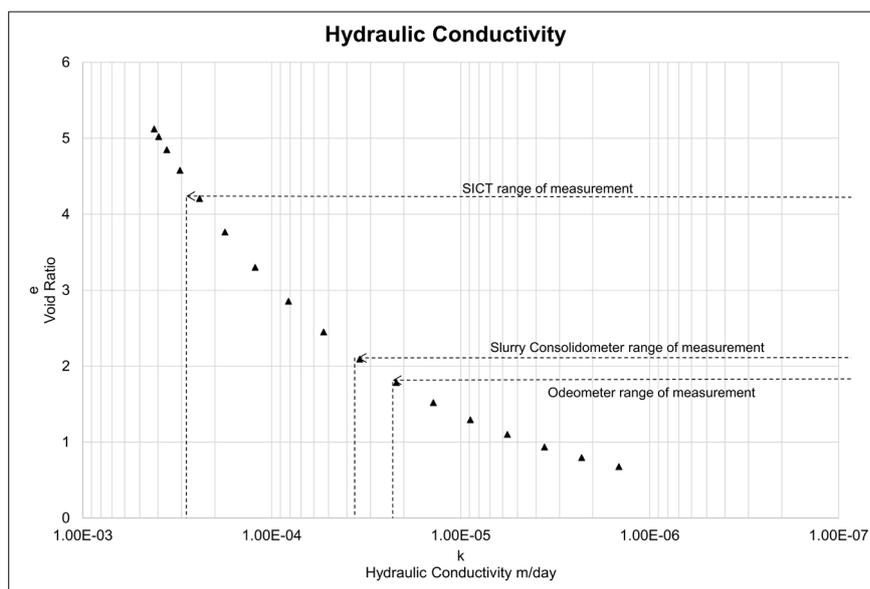

Figure 2   Permeability resolution comparison for each piece of equipment discussed
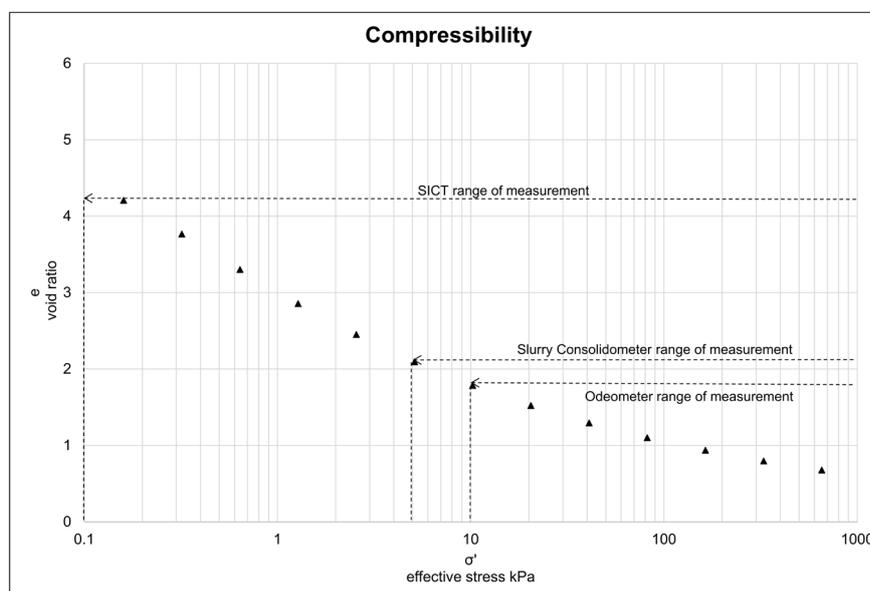

Figure 3   Compressibility resolution comparison for each piece of equipment discussed

defined as:

$$\text{Compressibility } e = A(\sigma'+Z)^B$$
$$\text{Hydraulic Conductivity } K = Ce^d$$

Applying an Excel based tool, such as Condes0 or a more involved pseudo 3D consolidation modelling analysis, makes it possible to apply important field inputs, like dam rise rate, to the compressibility and permeability relationships to predict field performance. Where polymers are concerned, the impact of polymer on tailings density along with measuring performance differences between polymer types is also a useful tool to help cross the laboratory to field gap.

This testing and subsequent modelling is a very useful process to make the connections between the physical chemistry (nano- and micro-behaviour), rheology (meso-behaviour), and consolidation mechanics (macro-behaviour) of tailings where polymers are concerned.

Being able to provide a more accurate estimate on the chance of success where polymers are considered for use, to decide if further resources should be invested in field scale evaluations, is another lever that can be used when working through technology option studies for challenging tailings.

Article references are available at http://acg.uwa.edu.au/newsletters-annual-reports/

Lewis Utting
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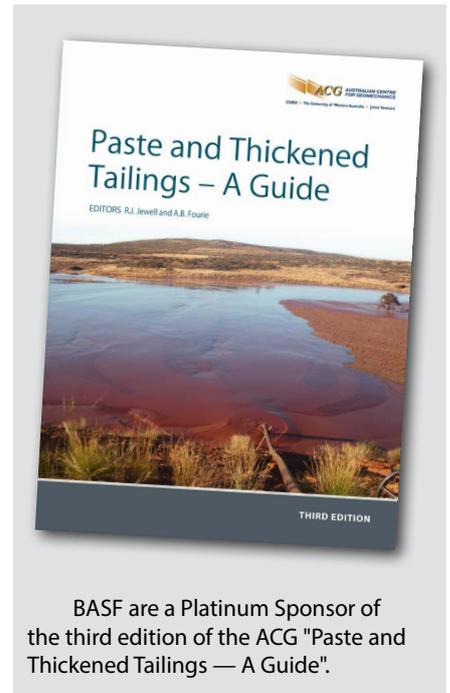
BASF are a Platinum Sponsor of the third edition of the ACG "Paste and Thickened Tailings — A Guide".

ACG Tailings Management: Practical Considerations Seminar & Workshop

26–28 April 2017 | Perth, Western Australia

This event will comprise a one-day hands-on static liquefaction workshop, and a two-day seminar on the management, operation and relinquishment of tailings storage facilities (TSF).

Static Liquefaction Workshop | 26 April 2017

- CPT live demonstration and interpretation of results
- Static liquefaction mechanism – theory and case studies
- Laboratory demonstration of static liquefaction with explanation and context

Management, Operation and Relinquishment of Tailings Storage Facilities | 27-28 April 2017

- TSF design issues
- TSF construction control
- Filtered tailings
- Water management considerations
- Tailings consolidation and slurry testing
- Regulators' expectations
- Legal perspectives
- Closure considerations – decommissioning and rehabilitation
- Relinquishment of contaminated sites
- Case studies

Facilitators:

Professor Andy Fourie, *School of Civil, Environmental and Mining Engineering, The University of Western Australia* (Days 2 and 3)

David Reid, *Senior Tailings Engineer, Golder Associates Pty Ltd* (Day 1)

Objectives:

This ACG workshop and seminar will address the issues facing site personnel involved in the day-to-day management of tailings storage facilities and the obligation to comply with the relevant operating standards and closure requirements.

The event aims to explore the innovative solutions utilised in different mining operations and environments and will include case studies, specialist presentations, hands-on practical and discussion sessions.

Who should attend?

Mining and tailings consultants, operators of tailings storage facilities, and regulators.

See www.acg.uwa.edu.au/events/ for more information.
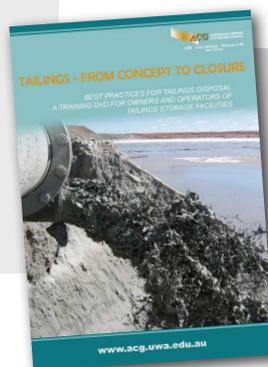
Tailings - From Concept to Closure Training DVD

A training DVD for owners and operators of tailings storage facilities.

Available for purchase at www.acg.uwa.edu.au/shop

The ACG's onsite training courses seek to deliver the latest technologies and information to the mining workforce in accordance with site specific requirements and applications. Our training and further education platform provides a solid base for the transfer of technological developments and practices based on knowledge gathered from local and international sources.

ACG Onsite Training for Underground Mines

Several hundreds of jumbo operators, front line supervisors, mining geotechnical engineers and mine geologists have already benefited from unique ACG onsite training programmes. The training content is generally customised to suit local mining conditions and specific ground control challenges.

- **Ground Awareness Training for Jumbo Operators and Front Line Supervisors**

This training is often delivered at a mine site for groups between 10 and 20 operators, over a six to eight hour training session. Recognised geomechanics techniques to assess ground conditions are explained in simple language that is familiar to mine operators.

Since 1999, over 700 mining personnel attended this onsite training course.

- **Rock Engineering Training**

Rock engineering onsite training is designed to upgrade the practical skills of geotechnical and mining engineers, as well as geologists involved in geotechnical work.

ACG Onsite Geotechnical Training for Open Pit Mines

The ACG's one to three day onsite training courses are designed for practical operational personnel, mine planners, mining engineers, geologists and anyone involved in day-to-day open cut metalliferous and coal mining operations.

- **Ground Support in Open Pit Mining**

This training course examines ground support and its application in open pit mines from design through to implementation and monitoring/reconciliation.

- **Geotechnical Engineering for Open Pit Mines**

This training course discusses geotechnical management plans and risk analysis; structural geology and geotechnical implications; pit slope stability; and managing ground water. Case studies feature slope monitoring and instrumentation techniques.

- **Introduction to Geomechanics of Open Pits**

The training modules can be adapted to site requirements by adding or subtracting topics.

Management and Operation of Tailings Storage Facilities

Many high-profile failures of tailings storage facilities have occurred internationally during the last decade. Some have released large volumes of tailings resulting in environmental pollution, fatalities, huge clean-up costs and financial loss. These can be very damaging to the company concerned. In some cases, these failures have been attributable to lack of knowledge of the mine tailings' engineering characteristics and the possible implications for the design and operation of disposal facilities.

While to a large extent favourable conditions have protected Australia from such a large failure to date, this could change and have a severe impact on the industry, and it must be avoided.

This onsite training course provides training in the management and operation of tailings and mine waste disposal facilities.

The course seeks to improve the standard of mine waste management in order to improve the safety and reduce the environmental and other liabilities associated with these facilities.

For more information or to request a quote, please email info-acg@uwa.edu.au or visit www.acg.uwa.edu.au/onsite-training/

Upcoming non-ACG events

12th International Symposium on Mining with Backfill	19–22 February 2017	Colorado Convention Center	Denver, Colorado, USA
Paste 2017	16–18 June 2017	Beijing Conference Center	Beijing, China
AFRIROCK 2017	2–7 October 2017	Cape Town Convention Center	Cape Town, South Africa
Slope Stability 2018 Symposium	9–13 April 2018	Seville, Spain
12th International Conference on Mine Closure	September 2018	Leipzig, Germany

For more information, please visit www.acg.uwa.edu.au/non-acg-events/

Welcome onboard New Concept Mining

The ACG is delighted to introduce its newest Corporate Affiliate Member — New Concept Mining

Founded in 1986, New Concept Mining is an international group of companies that focusses on the design, manufacture and supply of underground roof support products to meet the most challenging mine support requirements. New Concept Mining has an intensive research and development programme which is closely aligned with the ACG's mission "to add value to and create a safer environment within the Australian and international mining industry" and, as such, is proud to be the newest ACG Corporate Affiliate Member.

With a proud history of supplying roof support to the world's deepest mines, New Concept Mining has extended its international footprint to now include operating subsidiaries in South Africa, Canada, Peru, Chile, Zambia and India. With extensive inhouse rock engineering, mining and engineering experience, New Concept Mining has the technical competency to deliver onsite expertise to its customers. By partnering with customers to develop solutions and services to unique mine support challenges, New Concept Mining has been successful in assisting customers with improving safety, reducing

mining cycle times and increasing overall productivity.

With an existing product portfolio that includes dynamic and static roof bolting systems, aerial coverage and roof monitoring systems, current research projects are focussed on mechanised support systems for dynamic and static conditions with a dual emphasis on

increasing safety underground and efficiency of the mining cycle.

New Concept Mining is confident that its affiliation with the ACG will further the company's mission to continuously develop improved roof support products for the global mining industry in increasingly difficult mining conditions.

ACG Corporate Affiliate Memberships

ACG Corporate Affiliate Memberships allow your company to gain exposure to industry leaders while also providing savings on our well-known and respected further education and training platform. Email josephine.ruddle@uwa.edu.au for details.

2016 Corporate Affiliates

Introducing our new ACG Board of Management members

The ACG Board of Management meets three times a year to present strategic direction for the Centre, review and approve activities and operations, and to provide counsel.

During 2016, the Board was delighted to welcome Michael Dunn and Nan Wang as ACG Board members.

Michael Dunn

Group Manager – Geotechnical, Evolution Mining Ltd

Michael has 22 years of mining geotechnical engineering experience in operational, corporate and consulting roles. He has experience in a variety of underground mining methods and open pits in South Africa, Australia, New Zealand, Indonesia, Ghana and the USA. He was the director geotechnical engineering (Asia Pacific and Africa) for Newmont Mining Corporation. In 2013, he joined SRK Consulting in Perth as a principal consultant. In 2015, he joined Evolution Mining as the group manager – geotechnical. He is a fellow and chartered professional of The AusIMM and has published 26 technical papers.

Michael noted that, "when I was invited to join the ACG Board of Management, I had no hesitation in accepting the role. I'm both happy and proud to be associated with an organisation that, since the 1990s, has provided focussed, practical and high quality geomechanics research, as well as invaluable training to geotechnical engineers across the industry. Coming from a background that is very much focussed on mining operations and supporting those operations, I realise how important the ACG contribution has been towards improving geotechnical engineering in the pursuit of safe and economical mining."

Michael Dunn

Nan Wang

Group Mining Manager, MMG Limited

Nan has more than 17 years' management, technical and operational experience in the mining industry. He has a wide range of exposure to the following areas: open pit, underground, drilling and blasting, contract mining, contract management, highwall mining, equipment selection; and has procurement experience across a range of commodities including: coal, copper, zinc, lead, and silver. Nan has held various positions in major mining companies prior to MMG, including: Peabody Energy, Rio Tinto, Anglo Coal, Downer EDI and BHP Billiton.

Nan is delighted to be part of the ACG Board of Management, and says that, "the ACG has extensive industry and academic geomechanics knowledge. The Board's vision is well aligned with industry requirements, in that it aims to provide the principles and practices of geomechanics solutions to aid safe and productive operations within the resource industry."

Nan Wang

ACG staff update

Welcome

The ACG welcomed a few new faces to the team in 2016, and among them are Jenny Collins and Candice McLennan.

Jenny Collins

Administrative Officer

Jenny commenced with the ACG in January 2016. Her primary role with the ACG is supporting both the business and marketing managers with the mXrap consortium and corporate affiliate memberships, as well as the financial administration of ACG events including registrations, invoicing, general administration and event communications.

Candice McLennan

Marketing Officer (Digital)

Candice began working with the ACG in March of 2016. Her duties involve the marketing of ACG conferences and publications which include event coordination, graphic design, copywriting, website maintenance and social media management. Her previous experience includes roles in advertising, media, online marketing, administration and events.

Jenny Collins   *Candice McLennan*

Farewell

With much regret, we farewelled two of our professional staff this year. Both Maddie Adams and Lou Dowd were highly valued and much respected team members and our warm wishes are extended to both in their future endeavours.

Maddie Adams

Maddie joined the ACG in 2012 as our marketing and communications assistant and was an invaluable coordinator of many ACG training and further education events. Maddie was also instrumental in creating our promotional collateral and developing and maintaining key relations with ACG clientele.

Of her many achievements, most notable were the production of the ACG "Paste and Thickened Tailings – A Guide (Third Edition)", and the marked upgrade, in terms of usabilty and professionalism, of our various event websites.

Lou Dowd

Commencing in 2008, Lou provided dedicated administrative support and was the sponsorship coordinator of our international mining events. Lou's positive energy and professionalism were not only respected by the ACGers, but also by our many event sponsors and exhibitors.

Maddie Adams   *Lou Dowd*

ACG event schedule*

ACG AUSTRALIAN CENTRE FOR GEOMECHANICS

CSIRO | The University of Western Australia | Joint Venture

2017

Ensuring High Quality Seismic Data for the Mining Industry Workshop	27 March 2017 | Perth, Australia
Eighth International Conference on Deep and High Stress Mining www.deepmining2017.com	28–30 March 2017 | Perth, Australia
Developments in Rock Stress Measurements and Monitoring Seminar	31 March 2017 | Perth, Australia
Tailings Management: Practical Considerations Seminar and Static Liquefaction Workshop	26–28 April 2017 | Perth, Australia
Instrumentation and Slope Monitoring Seminar	2–3 May 2017 | Perth, Australia
Management of Moving and Unstable Slopes Workshop	4 May 2017 | Perth, Australia
Blasting for Stable Slopes Short Course	6–8 June 2017 | Perth, Australia
Ground Support in Open Pit and Underground Mining Short Course	23–25 August 2017 | Perth, Australia
Strainburst in Mining Seminar – How to Mitigate the Consequences	10 October 2017 | Sudbury, Canada
First International Conference on Underground Mining Technology www.utm2017.com	11–13 October 2017 | Sudbury, Canada

*The ACG event schedule is subject to change.

www.acg.uwa.edu.au/events

UNDERGROUND MINING TECHNOLOGY 2017 CANADA

FIRST INTERNATIONAL CONFERENCE ON UNDERGROUND MINING TECHNOLOGY

11–13 October 2017 | Radisson Hotel Sudbury | Ontario, Canada

ABSTRACTS DUE 25 JANUARY 2017

The ACG team wishes you and your loved ones a

Merry Christmas and a Happy New Year

Our office will be closed from Saturday 24 December 2016,
reopening Monday 9 January 2017

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BASF seeks to evaluate polymer performance in tailings treatments

by Lewis Utting, BASF Mining Solutions

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