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AUSTRALIAN CENTRE FOR GEOMECHANICS
NEWSLETTER

Mine Closure 2006

13-15 September 2006
Perth, Western Australia

At Mine Closure 2006 attendees will exchange views and expertise with their peers practicing the diverse range of disciplines involved in mine closure activities: geotechnical, environmental, social, financial and regulatory. Invited speakers include: Clive Bell, Aust. Centre for Minerals Extension & Research; Gavin Murray, ANZ Banking; Graham Cobby, Dept. of Industry & Resources of WA; Ramanie Kunanayagam, Rio Tinto and Paul Dowd.

Early bird registration closes 31 July 2006. Contact the ACG to register

What's in this Volume?

The views expressed in this newsletter are those of the authors and may not necessarily reflect those of the Australian Centre for Geomechanics.

Filling the gap – a geomechanics perspective

By Andy Fourie, principal – environmental geomechanics, Australian Centre for Geomechanics, Matt Helinski, PhD student, University of Western Australia and Martin Fahey, associate professor, University of Western Australia

The School of Civil & Resource Engineering at the University of Western Australia and the Australian Centre for Geomechanics initiated a research project that is aimed at improving the understanding of the geomechanics of underground backfilling, ranging from applications of hydraulic fills through to paste fills.

The need for the project was identified after a number of failures of barricades had occurred at various mines around the world, with each of these failures resulting in inrushes of backfill to working areas. Further investigation of previous studies also showed other areas where the mechanics of underground backfill were poorly understood, such as why laboratory strengths regularly tended to underestimate the strengths achieved in situ, and the need for development of a constitutive model that could facilitate modelling of mining processes involving fill.

Methods currently used for the calculation of barricade loads tend to be simplistic, including those that use ultimate strengths to estimate stresses in a stable fill mass, where obviously ultimate strength is not mobilised everywhere. Particularly during the filling operations with fine grained material the application of these simple design approaches is fraught with problems and has now been shown to be inappropriate (Helinski et al., 2006). The reason is that we should not assume drained conditions (free draining of excess pore water). In fact, in extreme cases very little drainage occurs and there is therefore no consolidation of the paste fill (this is known as the undrained condition). With no consolidation there will be no arching. The consequence is that the full hydraulic load of tailings could be transferred to the barricades, resulting in much greater barricade loads than the simplistic (drained) approach would produce.

As an example of the importance of this distinction, Figure 1 illustrates the difference between adopting a drained or undrained assumption on the total vertical stress developed within a simple, hypothetical stope that is 50 m high. The material properties adopted for the fill in both cases is that of a fully hydrated paste.

Continued on page 2

Industry has witnessed an increased use of full-plant tailings as backfill. In some cases, cement and other binders are added to produce paste fill. Photos courtesy of St Ives Gold

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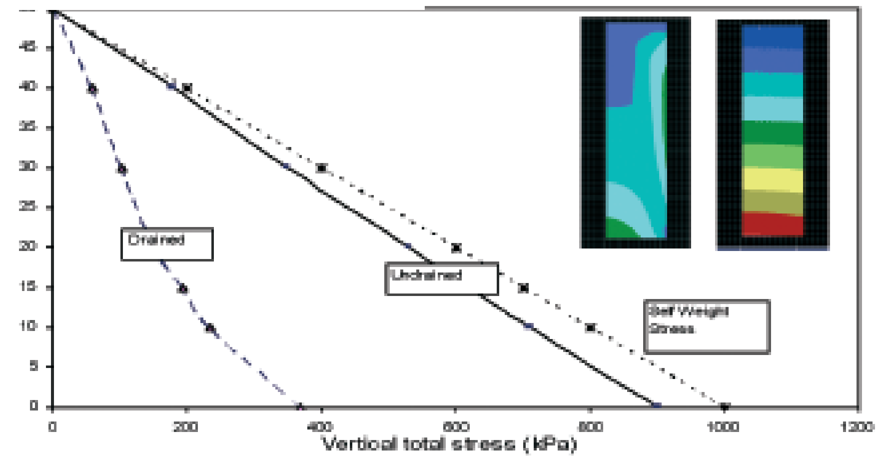


Figure 1 Predicted variation of vertical total stress along the centreline of a stope filled with uncemented tailings. Results are shown for the fully drained and the undrained condition

The inset shows contours of total vertical stress (for a case where a barricade is located in the bottom right-hand corner). The dashed line shows the maximum self-weight vertical stress (hydrostatic condition) and as can be seen, the undrained result is extremely close to this upper limit. In contrast, the drained analysis produces a variation of vertical stress with a depth that is much lower than these values. This example illustrated that stress distribution is dominated by pore water pressures and that if placed undrained, even fully cured paste will generate very high stresses.

The importance of this effect is even more pronounced when the impact on the barricade loads is calculated. Figure 2 shows this difference, with the drained analysis producing a barricade load of only about 80 kPa, while an undrained analysis produces a load of 800 kPa, i.e. a difference of one order of magnitude.

So which is the correct approach for a typical paste fill? It is probably true to say that it will be somewhere between the two, but it is not possible to say that the loads will always trend towards either of the extremes. This depends on factors that are fill-specific and depend in addition on how the fill is placed, the use of rest periods, etc. In other words, simple rules-of-thumb are unlikely to be adequate until a more fundamental understanding is developed that can be used to underpin such simplified approaches. A more rigorous approach requires that the consolidation process must be accounted for, with the degree of stress transfer to stope walls developed as a consequence of such consolidation. A preliminary study was therefore undertaken using the one-dimensional finite strain consolidation program Mintaco that was developed at UWA for the modelling of consolidation of tailings placed at a high void ratio.

An initial analysis of uncemented backfill was carried out as this was considered the most reasonable approach with existing technology. The results from this analysis are nevertheless instructive.

A vertical stope, 30 m high, was modelled. The parameters for the model were derived from published data on paste fill. The simulated filling sequence included an initial pour of an 8 m thick plug, followed by a curing period of 24 hours after which the remainder of the stope was filled at a rate of 0.4 m per hour. The predicted total and effective stresses and pore water pressure were monitored at a height of one metre above the stope floor. The results of this analysis are presented in Figure 3. As can be seen, virtually no dissipation of pore water pressure occurred during the ten day process, which would result in very large barricade loads and a completely unconsolidated fill mass. The lack of consolidation and instability are issues that most tailings engineers expect of a 30m high tailings dam filled in ten days. It may be argued that the one dimensional nature of the MinTaCo doesn't account for any stress redistribution (arching) to the surrounding rockmass. However, as shown in Figure 1 in order to generate any of this arching consolidation is required.

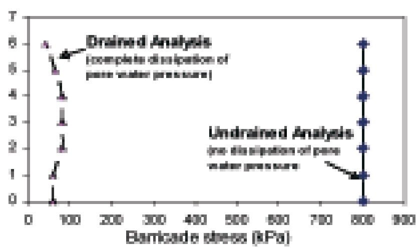


Figure 2 Estimation of barricade loads using drained and undrained analysis

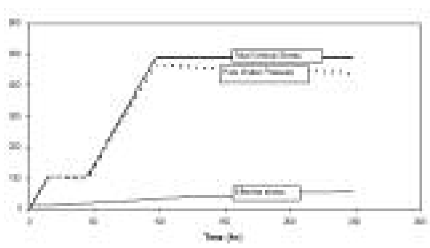


Figure 3 Consolidation analysis using uncemented tailings properties

A review of soil and cement literature revealed a number of important mechanisms that had to be incorporated into a model in order to adequately represent cemented fill behaviour. These were:

- increasing strength and stiffness due to hydrate growth,
- increasing strength and stiffness with increasing density,
- reducing permeability with time,
- reducing strength and stiffness due to hydrate damage caused by overloading at an early phase of strength development, and
- self-desiccation, which is induced by the reduction in volume caused by the cement hydration process (Helinski et al., 2006).

Models were developed and verified (using experiments on both hydraulic and paste fills) to represent the above mechanisms. These models were then coupled into a modified version of MinTaCo known as CeMinTaCo (Helinski et al., 2006). This model was compared with in situ data and shown to provide an excellent representation of in situ behaviour (Helinski et al. 2006). The simulation summarised in Figure 3 was repeated, with the difference that 5% cement was added to the fill. Two additional lines are shown in Figure 4, which again represents the development of pore water pressure within the hypothetical fill. The middle line shows the result when all of the above five factors caused by cement hydration, except for self-desiccation, are included in the model. The lower, dashed line has all these features included, plus it includes a simulation of the self-desiccation process. The differences resulting from accounting for hydration and factors such as stiffness increase and permeability decrease (the lower line), are dramatic. The pore water pressure (and by implication the loads on barricades) is substantially reduced, peaking at a value of only about 210kPa, compared with the same fill, but without cement, where the peak stress was about 480kPa. While it can be seen that the characteristics introduced due to hydrating cement can significantly increase the degree of consolidation, it is important to appreciate that any changes in the mix (or this hydrating behaviour) can dramatically impact on consolidation behaviour and therefore barricade loads. In an effort to demonstrate this, another analysis using a cement content of 2% was undertaken. The results of this analysis are compared with those for 0% and 5% in Figure 5.

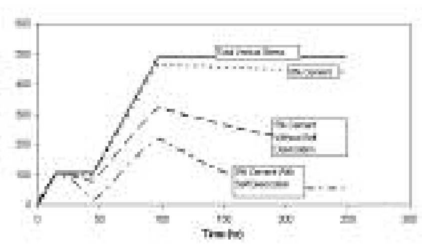


Figure 4 The impact of cement addition on the consolidation behaviour of a paste fill

Figure 5 indicates that simply reducing the cement addition can create significantly higher pore water pressures that would result in higher barricade loads. It should also be noted that changes to characteristics such as density, rate of hydration and self-desiccation will have a similar impact on the consolidation and therefore must be considered when estimating barricade loads.

Unfortunately it is not possible to simply take results such as those shown in Figure 5 and extrapolate to other sites, because of differences in fill type, particle size distribution, mineralogy and potential differences in binder type and process water. All of these factors can alter the cement hydration process and thus the rate of strength and stiffness gain, permeability decrease and the degree and rate of self-desiccation.

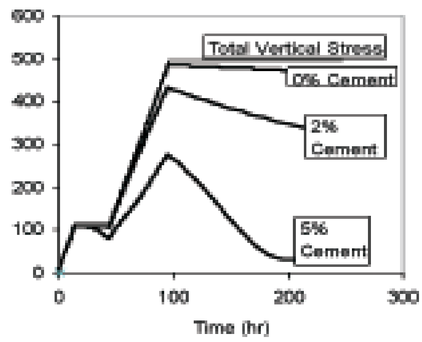


Figure 5 Impact of changes to cement addition

There may be combinations of fill, binder and process water that appear to provide strength increases but have a negative effect on self-desiccation induced pore water pressure reductions. An example being that the presence of excess silica due to the addition of fly ash or silica fume can generate a reaction that generates a volume increase (resulting in increasing pore water pressures) rather than a decrease. Therefore, while this binder may appear to provide an improved result (when considering strength gain) they may have a detrimental impact on the in situ effective stresses.

Laboratory strengths versus in situ strengths

It has been noted at a number of operations that the in situ strengths of a cemented paste fill are invariably higher than those obtained from laboratory strength tests on otherwise identical material. The discrepancy may be attributed to the fact that curing of a cemented soil under an effective stress (not total stress as suggested by some authors) will increase strengths. It should, however, be noted that the time this effective stress is applied (with respect to curing time) will impact on the result. For example, if the effective stress is applied prior to the commencement of curing, the strength increase will be greater compared with the application of stress after the completion of hydration. As the application of effective stress will be equal to the dissipation of pore water pressure this can only be calculated using a fully coupled model such as CeMinTaCo.

A significant outcome of the research already undertaken is the development of a simple sample preparation/curing technique that can be applied to achieve samples that are more representative of in situ material. It should however be noted that this type of preparation technique will only be suitable in some circumstances.

Exposure stability

As mining progresses deeper and ground stresses increase, the need to undercut fill masses increases. It is also frequently necessary to mine through a previously filled stope. In order to address these types of questions one needs to have a clear understanding of both in situ stress conditions as well as the material constitutive behaviour. Only by understanding the placement mechanics can one begin to approach these problems rigorously.

Future work

Work to date has concentrated on developing a one-dimensional model that adequately simulates the complex interactions that take place in a fill undergoing simultaneous consolidation and hydration. To address all the issues outlined in this article, the model has recently been extended to now simulate two-dimensional. When appropriately verified, existing uncertainties and misunderstandings about the in situ behaviour of cemented backfill can then be investigated, appropriate simplified analysis techniques can be developed and used appropriately, and management strategies can be provided to operators.

Other benefits of approaching mine backfill from this fundamental point of view are that it provides the opportunity to investigate the impact of using alternative binders, plasticisers and any other additives on the large-scale issues faced by operators. In conjunction with model development, an experimental program is currently underway to clearly define the fundamental differences that arise from these types of additives. These properties will then be input into the model to assess their overall impact on the desired behaviour.

Article references are available on request.

WASM static and backfill testing frame

By Ellen Morton, masters student, WA School of Mines, Curtin University

As part of the ongoing commitment to ground support in Australia, the Western Australian School of Mines (WASM) has recently designed and commissioned a new and innovative testing frame based in Kalgoorlie. The new facility has been designed to test the static response of large scale ground support panels and to test large scale backfill samples.

Funding for the facility was provided by WASM and CRC mining. A minor sponsorship was also received from Degussa and is greatly acknowledged.

Static ground support testing

The WASM static testing facility is complementary to the existing, award winning, dynamic testing facility. The new facility will provide data on current ground support systems prior to dynamic testing conducted at the existing facility. The new static facility (Figure 1) comprises of a steel frame, a clamping frame and five load displacement transducers. A mechanical displacement controlled loading mechanism has been designed to allow for greater displacements and accurate measured loading rates.

The facility is capable of testing shotcrete, mesh and spray-on liners with specimen dimensions ranging up to 1.6 m x 1.6 m in area. The deformation rate will be set to 4 mm per minute as per ASTM C1550 – 04. The total central deformation will be measured to over 350 mm. The load capacity of the system is set to 50 tonnes. The new testing facility has developed to conform to the requirements for round determinate panels (ASTM C1550 – 04) for shotcrete testing.

Backfill

As mining proceeds to greater depths (and hence higher stresses) in Western Australia, many mines are considering extraction methods and sequences that incorporate backfill as an integral part of the mining system. In some cases, entry under or alongside the fill may be required to enable the full extraction of the orebody. To ensure the safety of operators working under fill, the physical properties of the fill must be known.

The new WASM testing facility will allow a determination of unconfined compressive strength of large-scale samples where the specimen diameter will be much larger than the maximum particle size. It is envisaged that specimens 600 mm in diameter and 1200 mm high will be tested. Triaxial testing is also being considered for the future.

For more information, please contact Ernesto Villaescusa (E.Villaescusa@curtin.edu.au) or Ellen Morton (E.Morton@curtin.edu.au).

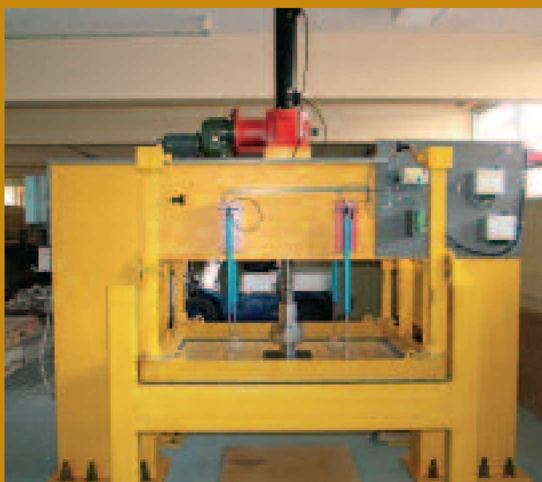


Figure 1 WASM's new testing facility.

Field inventory of abandoned mine sites in Western Australia

By Colin Strickland and Warren Ormsby, senior geologists, Geological Survey of Western Australia

Introduction

Mining has occurred in Western Australia for more than 150 years, resulting in many thousands of workings that were abandoned after exploration or mining (Figure 1). Until recently, few of these workings and other associated mine site features were documented.

The Western Australian State government has resourced the Department of Industry and Resources (DoIR) to compile an inventory of the abandoned mine sites for the State. The Geological Survey of Western Australia (GSWA) commenced the inventory in 1999, with the following objectives:

- to accurately locate and document abandoned mine sites,
- to document factors relevant to the public safety and environmental hazards they pose,
- to assess their state of preservation, and
- to quantify the aggregate risk associated with each site.

This inventory is intended to provide a sound basis for future planning of the necessary action and rehabilitation at high-risk abandoned mine sites.

The data within this document are sourced from a comprehensive document by Ormsby, W.R., Howard, H.M. and Eaton, N.W., 2003, Inventory of abandoned mine sites: progress 1999-2002. GSWA, Record 2003/9.

The inventory principally consists of individual mining-related features such as shafts, dumps and buildings that are commonly found at sites of historic mine production. Most of these sites have been non-operational since 1990 and are therefore considered to be abandoned. The principal clients of the inventory include the mining industry, local governments, WA Department of Conservation and Land Management, land leaseholders, Heritage Council of Western Australia, and the public.

A customised database was developed for the project, and to date a variety of hand-held personal computers have been utilised for data capture using both the Differential Global Positioning System (DGPS) and GPS for accurate locations. Both the database and the application have improved with increased experience and improved technology.

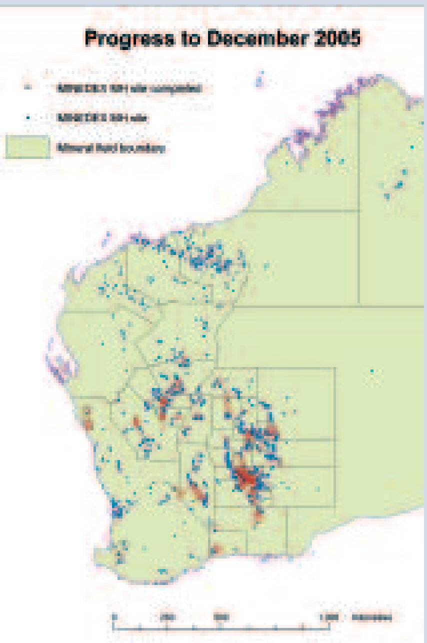
Methodology

DoIR's mines and mineral deposits information database (MINEDEX) contains all pre 1985 Historic Mine (MH) production sites for Western Australia. Work for the inventory of abandoned mine sites project was prioritised mainly on the proximity of MH sites to towns and main roads, reflecting the major safety objective of the project. High priority sites were defined as being within 10 km of major towns, 1 km of main roads and selected tourist routes, and within 5 km of smaller towns and communities.

A number of data sources assisted in the identification of abandoned mines or target areas for fieldwork in any given area. The most widely used tool was aerial photography, but other sources of information included historical maps, geological maps, historic tenement boundaries, data provided by mining companies, and orthophotography.

A purpose-made database was developed for the project, and an application was initially designed using Visual CE and MapPad software. Cassiopeia hand-held personal computers were selected for data capture using the DGPS for accurate locations.

Figure 1 Abandoned mine workings in Western Australia



Locations for completed MINEDEX MH sites in WA

Major improvements were made in mid 2002 with the acquisition of Symbol PPT2800 hand-held PCs and the LinksPoint clip-on GPS. The Symbol is designed to resist water and rough usage, and has a daylight viewable colour screen. The Symbol's colour screen enabled more flexibility in the display of point data. The display can be set at a fixed scale, and zoomed in or out with the use of toggle switches. Nevertheless, power management became an important issue during extended field operation, due to the power demands of the colour screen and the attached GPS. An external rechargeable lead-acid battery pack was upgraded in 2005 with the clip-on 2xr B5700 GPS receiver and lithium-ion battery pack which enabled 10 hours continuous data collection.

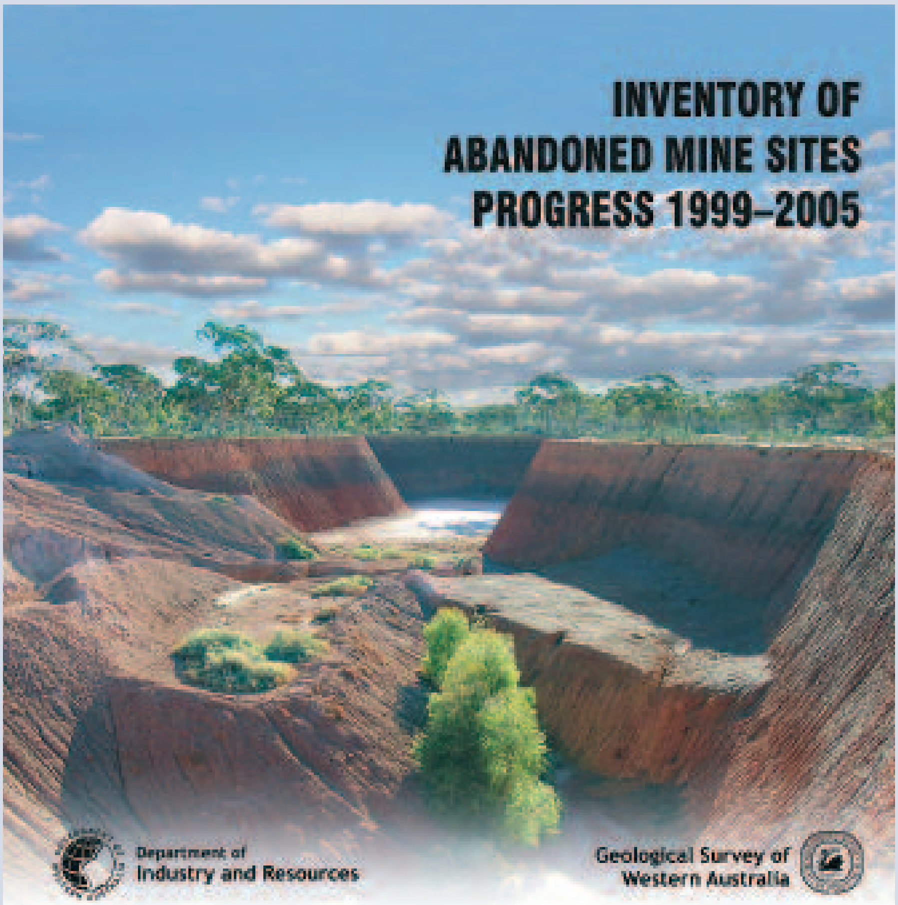
The utilisation of ESRI ArcPad 6 GIS software under Windows 2002 enabled modifications to the application, resulting in a several-fold improvement in the range of data collected, together with an increased data collection rate. Data are output as a dbf file and four ArcView shape files. Typing of comments into the Notes and Mine Notes fields of the database is simplified by the word recognition capabilities of the hand-held device.

The database itself was changed from the Microsoft Access 97 (MS Access)-based system to the Oracle system, and integrated with GSWA's Western Australian field observation database (WAROX). Digital photographs of selected feature types were collected from the outset. The use of photographs has subsequently expanded to provide more useful information. The photograph database is now fully integrated with WAROX.

Extensive database validation is routinely undertaken, and protocols have been established for the validation of new data and the extraction of data for clients and stakeholders. Each team member operates autonomously, but generally within the same region as the others for safety purposes. In addition, an EPIRB emergency satellite locator beacon is always carried, and, since 2002, a Globalstar dual mode GSM/satellite phone is carried to supplement normal GSWA safety procedures.

Spatial information sources

A combination of spatial information is used for planning, navigation, and targeting purposes in the office and in the field. Aerial photography was initially the main tool in combination with the MINEDEX MH sites, and historic geological maps, with spatial data provided by mining companies augmenting this approach. TENGRAPH plots of topography, MH sites, current mines, and mineral tenements were used routinely during the first three years. In 2002, orthophotography, digital historic tenement data and digital geological maps were sourced as valuable tools. The advent of the Symbol PC with LinksPoint GPS made in-field use of orthophotography and other images possible. Furthermore, flexibility with display point symbols and colours facilitated the use of multiple targeting data in the field.



Current edition of the "Inventory of abandoned mine sites: Progress 1995 – 2005 DVD

MINEDEX

The MINEDEX database was established by DoIR in 1985, and contains records of the locations and estimated mineral resources and ore reserves of mines and mineral deposits in Western Australia. The MINEDEX MH sites are the starting point for the prioritisation and planning of abandoned mine site field inspections, and are useful for measuring overall progress. Fieldwork has shown that each site may represent anything from a single shaft through to tens of individual mine workings and associated mine features.

The digital MH site data are viewed using ArcView GIS software on laptops in the office and in the field camp. They can also be loaded onto the hand-held computers carried in the field and used as a navigational aid to assist in locating areas of abandoned mine-related features.

There are 11,411 Historic Mine sites (MH) in the MINEDEX database (Figure 2), and 4,995 of these (44%) are categorised as a high priority for field data collection. As of 31st December 2005 a total of 5,120 MH sites had been completed (76% of high priority sites), with 163,364 mine site features mapped in the field, illustrated with a total of 41,961 digital photographs.

WABMINES application

The application form is displayed once the point is acquired using ArcPad, the user then records the appropriate attributes of the feature. Originally with the Cassiopeia PC there was a significant time delay between acquiring the point and the display of the application form. This time delay increased as the number of records increased, and ultimately became a limiting factor to the number of sites that could be recorded in a day. No time delay is experienced using the Symbol PC system. All dimensions are estimated, or measured from orthophotography for larger features, and the required attributes recorded by stylus on the touch-screen keypad. Orientation measurements where required are made using a compass. Detailed comments are typed into the Notes and Mine Notes fields of the database, assisted by the word recognition capabilities of the Symbol.

Digital photographs

Digital photographs are currently taken. Prior to the 2002 field season, one photograph was normally taken for all features more than 2 m deep, and most of these photographs were of shaft collars. In 2002, a new standard of two photographs per shaft was adopted. One photograph was taken a moderate distance away from the feature to highlight its visibility, and the other was a close up of the shaft collar. No limits are placed on the number of photographs, and they can be taken to illustrate any aspect of any feature. The unique photograph number is created in Oracle for each of the current 41,961 photographs stored in the database.

Data management

Currently data are downloaded daily from the Symbol PC to a field-based laptop. This data download is rapid, with the dbf file and shapefiles copied to the laptop computer using ActiveSync and MS Explorer. The dbf file is imported into MS Access, validated, and appended to an individual master file. Following validation or editing, the dbf file can be exported and loaded as a new table in ArcMap for viewing the data as an event theme. ActiveSync and MS Explorer are also used to copy a blank application table, and any other required data layers, back into the Symbol PC.

Conclusion

The use of innovative technology and approaches has made the WABMINES project a success in meeting its goals of effective and accurate field data collection. The team is now well positioned to continue capturing abandoned mine site features throughout the State, and to provide annual releases of the data on DVD, including thumbnails of all digital photographs, and an increasing number of GSWA Bulletins and accompanying georeferenced historical maps. The latest edition of the 'Inventory of abandoned mine sites: Progress 1999-2005' was released in February 2006 (Figure 3).

Acknowledgements

Colin Strickland and Warren Ormsby gratefully acknowledge the assistance of their colleagues within the abandoned mine sites project during the preparation of this paper. This paper is published with the permission of the Director, Geological Survey of Western Australia.

Mine Closure 2006 comes to town

The widespread challenges of closing mines in an environmentally and socially acceptable way will be addressed by the international mining community at the First International Seminar on Mine Closure planned for Perth, Western Australia in September 2006.

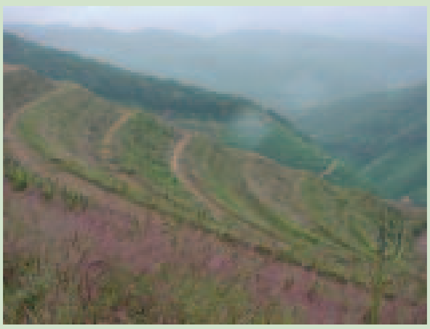
Hosted by the ACG and the Centre for Land Rehabilitation (UWA) this is the first time that a range of targetted mine closure issues will be explored in an international forum.

One of the greatest challenges facing the global mining industry is the issue of economic and socially acceptable closure of mine sites. The increasing attention being paid by the media to the legacy of abandoned mine sites has focused public interest on mine closure issues. In response, legislators and regulators are implementing various financial instruments to provide surety that closure will be affordable. These are often underpinned by various rehabilitation criteria that must be met to avoid financial penalties. An example is the environmental performance bond requirement in Western Australia, which is imposed to ensure that the state is not exposed to unacceptable costs should mine operators fail to meet the rehabilitation requirements of their lease. For tailings storage facilities, for example, the amount of the bond is AUD$12,000 per hectare.

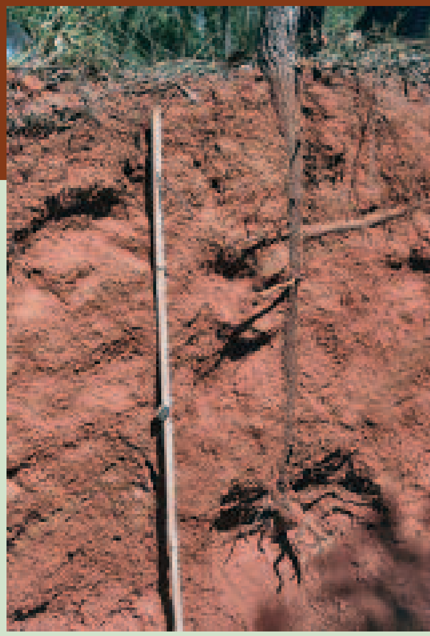
Planning for land rehabilitation and site closure from an early stage of a mining operation is an important way of decreasing the cost of the process.

It is also important to have clearly defined, unambiguous and appropriate criteria for what constitutes acceptable closure. Approval for future mining projects will more likely be obtained if the industry demonstrates it is able to close existing sites in a responsible and environmentally and socially acceptable manner.

The organisers are delighted that the world-first seminar will be held in Australia. It is hoped that the event will initiate an annual vehicle for legislators, mine owners and operators, consultants, service providers and researchers from throughout the world to exchange views on how best to ensure that future closure of mine sites is achieved at minimum cost, whilst ensuring that future environmental and social impacts are minimised. By using opportunities such as this for setting the agenda for future research and operational directions, the viability of mining operations can be ensured.



One of the greatest challenges facing industry is the socially acceptable closure of mine sites



Rehabilitation is a critical component of the mining cycle

The technical program will include comprehensive and highly relevant technical papers emphasising innovations and application of state-of-the-art technologies and closure strategies from around the world. More than 50 papers from leading local and international mine closure practitioners and strategists are expected to be presented at this unique, world-first mining event.

Visit **www.mineclosure.2006.org** for more information.

Testing and evaluation of corrosion on cable bolt anchors

By Rhett Hassell, PhD student, Ernesto Villaescusa, professor of mining rock mechanics, and Alan Thompson, senior research fellow, CRC Mining, WA School of Mines, Curtin University

Introduction

Corrosion of barrel and wedge anchors and the consequences for the entire cable bolt performance is poorly understood. Recent developments in cable bolt design have meant an increased reliance on anchors to be serviceable for long periods of time, especially for applications where the strand is decoupled from the cement grout. In particular, yielding bolts are customised in the toe and collar region.

Anchor failures after short time durations and under low loads have been observed in several underground mines in the Eastern Goldfields of Western Australia. Failure is often characterised by the barrel and wedge remaining intact after being found on the floors of drives with no evidence of strand rupture (Thompson, 2004).

These failures are attributed to installation practices and corrosion. The corrosion of barrel and wedge anchors is intrinsically linked to the environment in which they are installed. Circumstances where ground water is flowing or dripping over the exposed end of the reinforcement are considerably more corrosive than dry environments. However, corrosion in such instances is highly variable and difficult to predict accurately.

In an attempt to better understand the behaviour of cable bolt anchors, various barrel and wedge anchor configurations were placed within a corrosion chamber to simulate underground environmental conditions. Laboratory pull tests were used to determine the force-displacement response and the influence corrosion has on the load bearing capacity of the anchors.

Laboratory testing

Two basic barrel and wedge anchor configurations are presently used within the mining industry. These anchors incorporate either a flat ended barrel or a hemispherical ended barrel to be used with either a two-part or three-part wedge. In the tests described in this investigation, two-part wedges were used with the flat ended barrel and three-part wedges with the hemispherical based barrels.

Two different strand types were also examined. The standard plain strand and the deformed compact strand, which is incorporated with the yielding cable bolt under examination.

A number of corrosion protection methods were trialled. The methods included galvanising of the barrel and three simple and commonly found barrier corrosion inhibitors such as grease, bitumen and wax. Some tests were conducted with galvanised strand. The major focus of the testing was to determine the effectiveness of the various corrosion protection methods for the hemispherical barrel and three-part wedge used with compact strand.

Figure 1 is a schematic long-section representation of the testing system used. Following a grout curing time of 7 days, the plate and barrel and wedge were installed and the system loaded to 8 tonnes (~80 kN) using a hydraulic jack. Corrosion inhibitors were then applied to the appropriate samples. The majority of samples were placed in the Western Australian School of Mines (WASM) corrosion chambers with the remainder being tested to provide a non-corroded reference test.

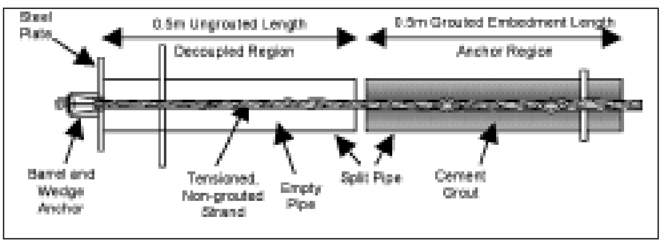


Figure 1 Schematic representation of split pipe testing system

Simulated underground environment

The everchanging nature of a working mine continually modifies the local environmental conditions. It is therefore impossible to maintain consistent environmental conditions for the extended periods of time necessary to study the processes and rates of corrosion for different reinforcement materials. To overcome this, corrosion chambers were designed and developed at the WASM to simulate the corrosive environment of underground mines.

The chambers maintain a constant temperature and humidity by use of an electronic sensor system independent of each chamber. Ground water was collected directly from the rockmass and transported to the corrosion chambers. An electronic pump is used to pump the water through purpose built reticulation providing a constant supply of dripping ground water onto the reinforcement and support being tested (see Figure 2). The water condition is monitored and the water is changed when the conditions depart from the underground situation.

The average temperature and relative humidity were maintained at 30°C and 90% respectively. The near neutral pH ground water is hyper saline with high concentrations of chloride and sulphide ions. The presence of these ions makes steel more susceptible to pitting corrosion. The extremely high Total Dissolved Solids (TDS ~230,000ppm) and moderate temperature have the

Figure 2 Corrosion chamber displaying barrel and wedge testing at rear

effect of reducing the dissolved oxygen content. This can reduce the corrosivity by limiting the amount of oxygen available to the electrochemical corrosion process.

Testing of the barrel and wedge anchors

Testing of the various barrel and wedge anchors was conducted immediately after initial anchor installation and at 3, 7 and 10 months of exposure to the conditions in the corrosion chambers. Testing involved subjecting the samples to tension loading to a maximum of 200 kN, provided by the hydraulic Avery machine located in the Rock Mechanics Laboratory at WASM. Three tests were conduced for each of the combinations.

Results of laboratory testing

Hemispherical barrel and three-part wedge with compact strand

The anchor configuration experienced failure in two of the three samples after 7 months and one sample after 10 months. Failure occurred at the wedge/strand interface with the strand pulling through the anchor and was associated with small wedge movement relative to the barrel. Failure took place at loads ranging from 22 kN to 111 kN that are significantly lower than the strand force capacity of 250 kN.

The internal section of the failed barrel and wedge anchor shown in Figure 3 displayed a build up of corrosion products on the internal surface of the barrel together with shearing of the wedge teeth. Anchors that perform properly displayed notably less corrosion accumulation (see Figure 4).

The absence of corrosion products on the non-failed samples strongly suggests that

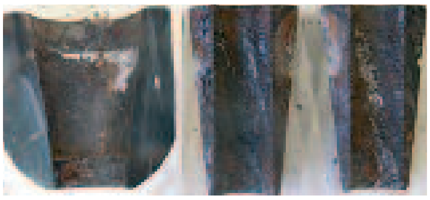


Figure 3 Internal condition of failed barrel and three-part wedge anchor. Note the corrosion on the barrel surface and the shearing of the wedge teeth

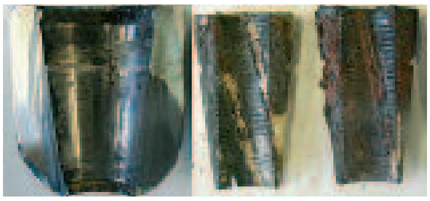


Figure 4 Internal condition of barrel and three-part wedge anchor that did not fail after 10 months in corrosion chamber

corrosion is responsible for failure. Corrosion products on the internal surface of the barrel increase the frictional resistance at the barrel/wedge interface and this prevents sliding of the wedge relative to the barrel. This in turn prevents the wedge from gripping the strand.

Barrier corrosion inhibitors

Anchors that were coated with grease, wax or bitumen had significantly fewer instances of failure. Of the three inhibitors used, only the grease coated anchor failed once after 10 months. Examination of the sample following testing indicated much higher levels of corrosion on the internal barrel surface than the non-failed counterparts.

The bitumen coating performed best at preventing corrosion occurring over the entire anchor. Specifically, corrosion on the critical internal barrel/external wedge surface was inhibited.

Hemispherical barrel and three-part wedge with black and galvanised plain strand

There was no failure of the barrel and wedge anchors used with either plain strand or galvanised plain strand. Low levels of internal corrosion were observed. When compared with the compact strand it appears that the modified geometry of the strand does not allow for a "tight" fit, allowing for higher levels of corrosion.

Galvanised hemispherical barrel and three-part wedge with plain strand

The anchor consists of the barrel galvanised to a thickness of 75 μm with the three-part wedge remaining uncoated. The galvanised anchor performed extremely poorly in the testing, with failure of one sample in the 3 month test and failure of all samples in the 7 and 10 month tests at very low loads (less than 50 kN). Inspection of the anchors revealed that steel corrosion of the anchor was low but oxidising of the galvanising was noted by the presence of zinc carbonate on the barrel surface.

The effectiveness of zinc galvanising to protect steel from corrosion is well known and documented. However, zinc metal is considerably softer and provides a rougher surface than the steel it coats. This has the effect of increasing the friction at the barrel/wedge interface due to the steel wedge digging into the galvanising. This prevents wedge movement and subsequently leads to shearing of the wedge teeth and strand slippage. It appears minor levels of zinc corrosion may further increase the problem.

Flat barrel and two-part wedge

There was no failure of the anchors that used two-part wedges for either the compact or plain strand. This may not always be the case. Previously reported test results showed that anchors with two-part wedges failed by slipping relative to the strand after 6 months of exposure to mildly corrosive environments (Thompson, 2004).

Impact of wedge movement

The long-term performance of a cable bolt anchor in a corrosive environment is controlled by the frictional resistance between the internal surface of the barrel and the outside of the wedge. Corrosion and galvanising of this surface increase the frictional resistance restricting wedge slip and minimising gripping of the strand, which leads ultimately to premature anchor failure, often at low loads.

Another factor that influences the ability of the wedge to slide relative to the barrel is the inherent roughness of the contacting surfaces. The smoothness of the inner surface of the barrel and the

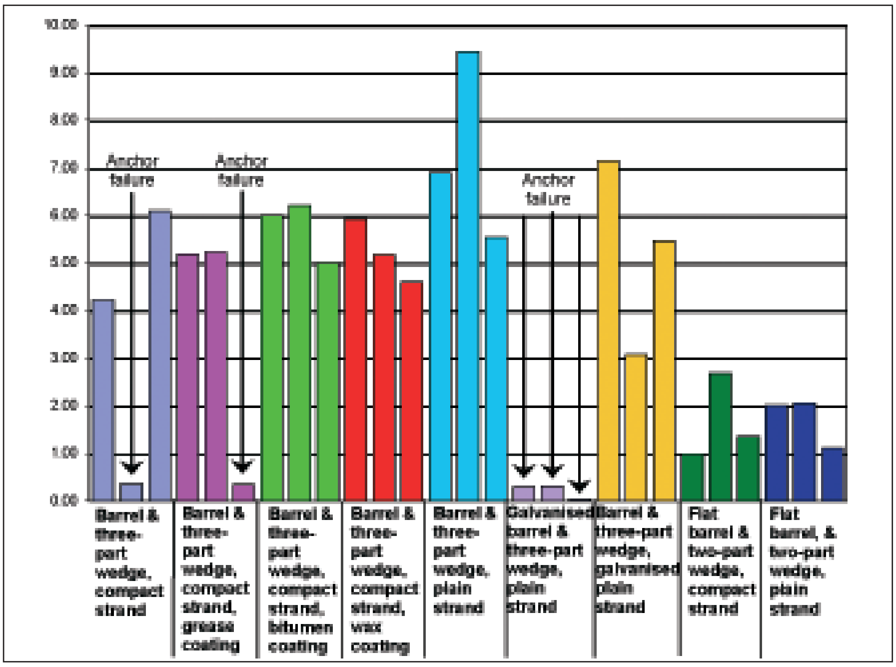


Figure 5 Total wedge movement of anchors after 10 months in the corrosion chamber

outer surface of the wedge vary between batches from the different suppliers. In some instances, the roughness from machining is clearly visible and easily felt by running one's finger over the surfaces.

Figure 5 summarises the measured wedge movements for each of the 10 month tests. Anchor failure can clearly be seen to correlate with minimal wedge movement.

Summary and conclusions

The current anchor assembly employed with a commercially available yielding cable bolt has a predicted anchor life of less than 7 months in a hyper saline ground water affected environment. The service life can be extended to greater than 10 months by the application of simple barrier corrosion inhibitors such as bitumen.

The anchors with two-part wedges demonstrate a greater resistance to corrosion than those with three-part wedges. In addition, they also showed a stiffer response when load is applied. The two-part wedges have fewer pathways for the ground water to infiltrate the internal section of the barrel, as well as having a closer fit at the barrel/wedge interface.

Those anchors tested in combination with plain strand display less corrosion on the internal section of the anchor than the anchors used with compact strand. The modified geometry of the compact strand appears to allow for greater corrosion to occur. This was observed with both the three- and two-part wedges.

Experience from this testing has shown that the external condition of the barrel does not give a conclusive indication to the amount of internal corrosion of the anchor. Therefore, a visual assessment system cannot be used to determine the extent in which corrosion is influencing the capacity of an anchor.

Finally, and most importantly, it is critical in service that the ability of the wedge to slide relative to the barrel is maintained so that more tension can develop in the reinforcement to resist rock movement. Galvanising of the anchor is not recommended due to the soft zinc galvanising coating increasing the sliding resistance at the barrel/wedge interface. This prevents the barrel and wedge anchor from being effective. It is therefore strongly recommended that a high quality and long-lived lubricant is placed at the barrel/wedge interface during installation to provide a low friction interface that also assists in corrosion protection.

Acknowledgements

The authors acknowledge the support of Goldfields Australia, St Ives Operations in the implementation of this work.

The authors also wish to recognise the support of the Minerals Institute of Western Australia (MERIWA), BHP Billiton Ltd, Placer Dome Asia Pacific, Barrick Gold Australia, Degussa, Strata Control Systems and AVKO Drilling.

Article references are available on request.

Table 1 Summary of test results

Barrel and Wedge Anchor Combination			Initial Failure Age (months)	Failure Mode	Failure Load (kN)	
Anchor	Strand	Coating			Min	Max
Hemispherical 3-part	compact	none	7	Wedge/strand slip	22	111
Hemispherical 3-part	compact	grease	10	Wedge/strand slip	27	27
.Hemispherical 3-part	compact	bitumen	No failure			
Hemispherical 3-part	compact	wax	No failure			
Hemispherical 3-part	plain	none	No failure			
Hemispherical 3-part	galvanised plain	none	No failure			
Hemispherical 3-part	plain	galvanised	3	Wedge/strand slip	21	47
Flat 2-part	compact	none	No failure			
Flat 2-part	plain	none	No failure			

What's shakin' your pit?

By Gordon Sweby, project leader, Australian Centre for Geomechanics

The ACG research project "High Resolution Seismic Monitoring in Open Pit Mines" commenced in 2005 and seeks to explore and further understand the complex nature of slope movement in active Australian open pit operations. With industry backing, the project aims to provide a better tool to minimise the financial and safety risks associated with potential slope failures by the early detection and analysis of the microseismic warning emitted by the failing rock.

The project has moved into its next phase, with the installation of two more trial arrays at BHP Billiton Nickel West's Mt Keith operation in addition to an existing array (see Figure 1). These three arrays will be monitored over the next few months after which a decision will be made as to what trial site will be upgraded to a full 16-sensor system, based on recorded seismic activity.

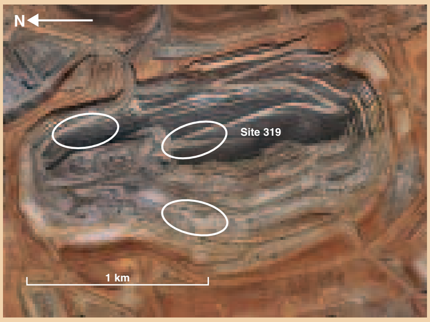


Figure 1 Location of trial arrays at Mt Keith open pit

From March to September 2005, a total of 270 seismic events were recorded by the ESG Paladin system at the 319 trial site (see Figure 2). The activity rate is best depicted in a Magnitude-Time plot as shown in Figure 3. Changes in the activity rate can be correlated with significant external events, for example, a rainfall event corresponded to a significant change in the slope of the curve.

Preliminary data analysis suggests that the seismicity is dominated by volumetric or dilatational deformation, as opposed to fault-slip. This could imply that rockmass deformation at this site is characterised by intact rock failure rather than slip on discrete structures.

Preliminary numerical modelling studies

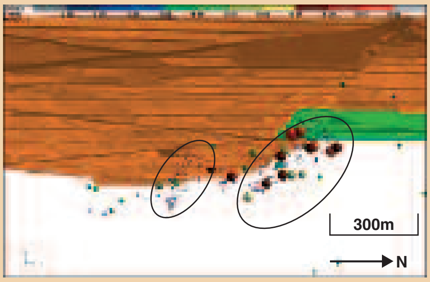


Figure 2 Total events recorded over the monitoring period, scaled to Moment Magnitude and with significant clusters highlighted

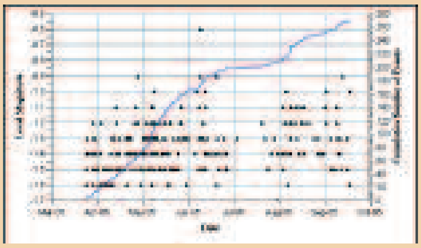


Figure 3 Magnitude-Time plot showing activity rate over the monitoring period. A change in slope of the activity rate curve corresponds with a high rainfall event

highlight a spatial correlation between one of the identified clusters and a zone of volumetric strain change (see Figures 4a and 4b). This finding further suggests that the seismic deformation is related to pit geometry and mining induced stress changes.

At Xstrata Zinc's Black Star open cut (Mount Isa), the sensor array design has been finalised (see Figure 5) and the ISS system hardware is ready for installation.

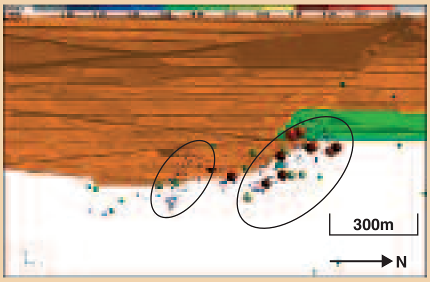


Figure 5 Planned seismic array at Xstrata Zinc's Black Star open cut. The planned pit geometry in relation to the known subsurface cavities is as shown

The Black Star system offers the opportunity to study the interaction between pre-existing underground cavities and the developing pit.

This ACG research project aims to deliver solutions that could become critical to the success of Australian and global deep open pit operations. The direct benefits of enhanced slope monitoring capabilities will be a more progressive slope design and a diminished risk of failure. The early detection of slope movement will also allow for a tactical response to avoid or manage loss of slopes.

Acknowledgements

The significant contributions made by the project sponsors, BHP Billiton Nickel West, Xstrata Zinc and the Minerals and Energy Research Institute of WA, both towards project justification and funding, and the efforts of the site personnel, are greatly appreciated.

For more information about High Resolution Seismic Monitoring in Open Pit Mines, please contact Gordon via acg@acg.uwa.edu.au.

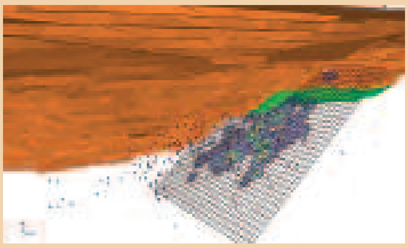


Figure 4a Oblique view of a best-fit plane through seismic cluster, showing contours of cumulative seismic potency

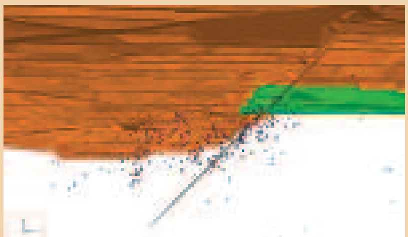


Figure 4b Alignment of best-fit plane with local pit geometry

Pressure grouting – the end of insanity

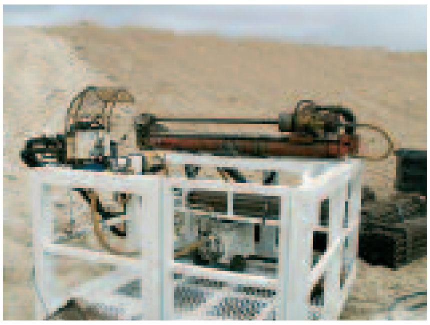
By Kate Williams, senior geotechnical engineer, Ballarat Goldfields NL

Introduction

Two falls of ground in one development heading at Ballarat East mine and increasingly weathered ground conditions had the mine's technical staff searching for smart mining solutions.

The vent access drive was designed to connect the mine's development to the base of the exhaust shaft. As the shaft was being excavated as a conventional shaft sink, the vent access was designed as an incline through slightly and moderately weathered ground conditions. The primary reason for mining the access as an incline was to reduce the shaft sink depth and decrease the scheduled time to breakthrough. Breakthrough into the shaft was considered a critical path for ramping up production at Ballarat East.

The initial fall of ground was within the first 20 m of the vent access. The heading was passing through a 45° west dipping fault when it began to self mine. The second fall of ground occurred another 50 m along the drive when a second fault was being



Drill rig set-up in IT basket

cut across. This fault differed to the first, being a sub-vertical cross course fault.

With two failures and no reason to think there would not be more with a conventional mining approach it was time to do something drastic. Recovering falls of ground was delaying the mining schedule and increasing development costs. As Einstein once stated, "Insanity is doing the same thing over and over again and expecting different results." The current methods of spiling through the faults and reducing the cut lengths were no longer working; a new pre-support method was required for these fault conditions in moderately to highly weathered rock.

Ballarat East geological and geotechnical characteristics

Ballarat East is situated entirely within Lower Ordovician cyclic sandstones, siltstones and mudstones that have been weakly metamorphosed and tightly folded about north-south trending axes. The interbedded sediments are intensely weathered to a depth of at least 100 m below surface; these rocks are typically very weak with unconfined compressive strengths of less than 5 MPa.

Below this depth the weathering decreases and the strength of the rock increases. However, extremely weathered rock can persist to around 300 m below surface, typically controlled by structural features.

The 45° west dipping faults are spaced from 5 to 70 m apart striking approximately north-south. The faults are identified by quartz veining and associated carbonate veining, arsenopyrite alteration and rotated cleavage. Fault thicknesses range from 1-10 cm, with veining around the fault extending over 10 m away from the fault in the form of tension veins. Around the intersection of these 45° west dipping faults and fold axes or and/or stratigraphic units the Ballarat East mineralisation is found.

The cross course faults at Ballarat East are large fault structures that cross cut the stratigraphy at regular intervals. These faults are typically sub-vertical and are identifiable by their puggy clay brecciated appearance and chloritic alteration. The faults typically do not rotate the bedding and the cross cutting faults tend to be more oxidised than other structures. The faults can be up to 40 cm thick with a zone of broken and weathered rock

Blocker grouting at the face

surrounding the fault from 1 – 20 m wide. The weathering halo decreases with depth, and from around 300 m below surface is insignificant. These fault structures can exhibit up to 50 m of lateral offset along the fault.

Where the weathering halo occurs the rockmass is extremely broken (RQD = 0), the rock strength is significantly decreased and the ground conditions go from poor ground to extremely poor ground. This rockmass is then not self supporting in a 5 m x 5 m development heading and typically unravels in the first hour after firing.

Geotechnical probe drilling

The geological structural models used at Ballarat East were extrapolated from mapping of the historical underground workings and then projected across the Ballarat East mining area. Cross course faults are not linear features and the projected models were in many cases up to 50 m out. When mining through these zones it is critical to know the exact position and width of the fault to ensure that the correct support is used going into and through the fault.

Geotechnical drilling in front of the decline became vital for determining both the location and width of these faults. It was important that the drilling followed

Ground conditions at Ballarat East are constantly challenging the geotechnical team

the exact line of the development as the faults tended to change characteristics along strike. In other areas of the mine where the same faults were developed through, the faults exhibited different characteristics even when the drives were only 20 m apart.

Geotechnical probe drilling along the length of the vent access indicated that another four cross course faults were to be intersected before breaking through into the shaft. Ground conditions were expected to deteriorate as the drive inclined into the more weathered rock.

Pressure grouting

It was at this stage that pressure grouting was suggested as a possible solution. This met with the usual "that's too expensive to use in a mine" and "that's not used in hard rock metalliferous mines". We were slowly coming to the realisation that the rock was not hard, especially around the weathered faults where it more resembled clay.

The next fault along the drive had a 20 m wide weathering halo according to the geotechnical probe drilling. It was at this stage grouting expert Bruce Grant, Mulitgrout Australia, was called in to determine if pressure grouting was applicable in the faulted ground conditions at Ballarat East – it was.

Initial pressure grouting trial

This began our foray into the world of pressure grouting. Based on the size and location of the fault, a pattern of holes was designed that would consolidate the ground around the designed drive profile, concentrating on the areas of shoulders, backs and upper part of the face.

Drilling was undertaken using the onsite production drill rig with the maximum hole length at 20 m. It took three shifts to bore the holes then three shifts to grout.

The grouting system utilised was a specially developed system, "MultiGrout®", developed out of civil tunnelling practices in Norway. An ultrafine cement product was used with the maximum particle size <15μm giving improved penetration into fine cracks. A product called GroutAid® was used as a stabiliser, Groutaid® is a specially processed microsilica based slurry and it allows extremely "thin" or wet grouts to be injected without problems with bleeding and fluid loss. This slurry adds a large number of extremely fine spherical particles of high specific surface area. When this high surface area is incorporated with the high internal attraction forces, the cement and microsilica particles remain suspended without settling. This means that high water cement ratios can be achieved with enhanced grout flow and penetration properties.

Each of the drillholes were packed close to the collar using mostly mechanical packers. The occasional hole required a hydraulic packer because the drilling had enlarged the hole collars. Grouting began in the holes at the centre of the face and slowly worked up into the shoulder holes and then onto the back holes. As each hole was grouted, grout connections to other holes were carefully managed to ensure each grout hole was kept "alive" and that each hole was pressurised. Because of the blast damaged rock within the first metre at the face, it was difficult to control grout leakage from the face. Despite the face condition, maximum pressures achieved were around 4000 kPa (40 bar). Grout usage was around 2.5 times the hole volume; whilst large amounts of grout were not required for joint/void filling, the high pressure injection squeezed and consolidated the clay rich weathered rock.

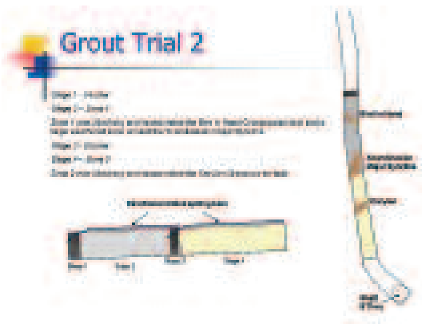
Grout trial one grout holes

Mining commenced two shifts after grouting completed. Previous experience with self mining headings dictated a cautious approach to development. Grouted rebar was still being installed as spiling and cut lengths were shortened from 3 m to 1.5 m. Improvements in the ground conditions were visible even in the first cut. Comments from the operations team were that this was the best ground that had been mined in the drive so far. Drilling had shown this was the worst ground encountered thus far. Conditions had improved so much that it was decided half way through the treated zone to increase cut lengths from 1.5 m to 2 m. All was going fine until the grout curtain was exceeded. The first cut into the untreated ground unravelled. This gave the final conviction that the pressure grouting had worked.

Second pressure grouting trial

Subsequently, two more sections of this drive (an additional 73 m) were treated with pressure grouting, though instead of spilling in the development cycle, spiling bars were installed above the drive profile and pressure grouted through.

Iain McPhedran, Eastern Mining Services, worked on the first pressure grouting trial



Grout trial two spiling and fault locations and suggested a process that he was using in underground coal mines. It involved pressure grouting through preinstalled spiling bars developed specially for this type of work. The spiling bars were pushed into a predrilled hole by a small air rig. Eastern Mining Services adopted their current drilling equipment to fit inside an IT basket so that drilling could take place as close to the backs of the drive as possible. This created a grouted canopy to mine beneath, significantly reducing the risk of a failure within the drive. It also removed the requirement for spiling during development, greatly decreasing the mining cycle time. Where the spiling bars sat within the drive profile the bars were made of polypipe and when they sat above the drive profile the bars were manufactured from steel.

These holes were not sealed with packers, breather valves were grouted into the collar of each hole and then the grout was pumped through the spile tubes in the same manner as the initial trial. Pressures of around 4000 kPa were achieved once again.

Another improvement on the initial trial was to seal the blast damaged rock at the face by drilling short holes into the face (7 m long) and then injecting a fast setting grout into this zone. The spilling back holes were then drilled through this short pre-grouted zone. This allowed the pressures to be built up behind the initial blocker grout zone.

Once again the improvements in the rockmass were noticeable with previously difficult mining conditions becoming manageable.

Conclusion

The experience at Ballarat East illustrated the importance of looking for solutions outside of our industry. The ground conditions at Ballarat East are constantly challenging and a large variety of support techniques are used.

Pressure grouting has allowed mining to progress in extremely poor ground conditions with little affect on the development cycle. Previously, mining through the faults slowed development down to 1 m/day, with the pressure grouting this increased to 2 m advance per day.

Pressure grouting has been successfully trialled at Ballarat East in extremely poor ground conditions and is a ground control management tool that will be utilised where geotechnical drilling reveals large weathered fault zones or difficult to manage ground conditions.

Acknowledgement

I thank Bruce Grant from MultiGrout Australia and Iain McPhedran from Eastern Mining Services for their assistance in relieving our insanity and to Ballarat Goldfields NL for permission to publish this article. For further information, please contact Kate Williams at kwilliams@ballarat-goldfields.com.au.

EAGCG Workshop and Technical Inspections

"Hazard Identification & Risk Management for the Mining Industry"

31 May – 1 June 2006, Broken Hill, NSW

Discussion on Ground Control Management Plans Call for Presenters

- How do you manage major hazards at your site?
- Do you have risk management systems or strategies that you would like to share?
- An opportunity for operations to share ideas and experiences.

Preliminary Program

Wednesday 31 May – Workshop and EAGCG Meeting

Session 1: Jim Joy University of Queensland and John Moss, NSW Dept. of Primary Resources.

Session 2: Case studies, presentations and discussions.

Session 3: EAGCG meeting

Thursday 1 June – Mine Site Visits

To register your intent to present or attend this forum, please contact Uday Singh, EAGCG Secretary via singhu@newcrest.com.au.

CSIRO researches open pit techniques

By John Read, research director – Mass Mining projects, CSIRO Exploration and Mining

A group of 10 mining companies representing the majority of the world's production of diamonds and base metals are working with the CSIRO Exploration and Mining to develop new and better methods of predicting the reliability of rock slopes in large open pit mines. This innovative and timely research project is well underway and is expected to be completed within the next two years with funding of more than $2.6 million.

Background

Historically, the largest open pit mines have been from 300 m to 500 m deep. In the past 10 years, some open pit mines have reached up to 800 m deep, and depths are expected to exceed one kilometre within another 10 years. The inadequacy of current slope design in this inverted 'high rise' environment has been exposed by a number of slope failures. These failures have resulted in multiple fatalities and production losses.

Over the years the slope design process in large open pit mines has been hampered by critical gaps in our knowledge and understanding of the relationships between the strength and deformability of rockmasses and the likely mechanisms of failure. Particular complications arise when the rockmass are neither homogenous nor isotropic and low stress regimes encourage large deformations. We usually manoeuvred around these difficulties by smearing the whole system and assigning 'average' strength properties to the rockmass, calibrating it using existing slope movement data, and performing parametric studies to isolate what we judge to be the more unlikely events. Although this is accepted practice, it has some distinct disadvantages. Notably, by approximating the behaviour of the whole system we may have totally masked a critical variation in the geotechnical model. Additionally, the procedure does not overcome the fundamental issue of accounting for anisotropy and large deformations. Last but not least, by calibrating against a known event we may in fact be limiting our chances of reliably predicting a future event.

CSIRO's research seeks to develop new and better methods of predicting the relability of rock slopes in large open pit mines

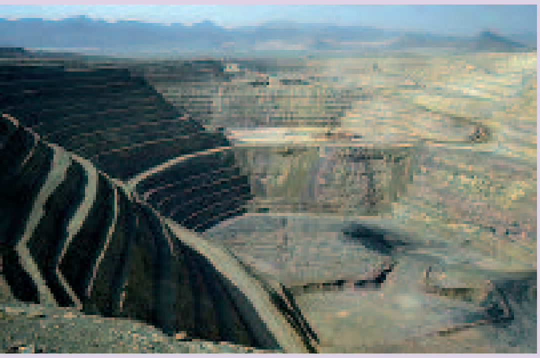
Collectively, these anomalies have generated a need to step outside the box and reassess the fundamentals of rockmass strength and slope failure mechanisms from first principles. With financial support from a number of international mining companies with interests in open pit mining, CSIRO Exploration & Mining has initiated a research project which has this objective.

The project is also supporting parallel streams that seek to bring into the public domain the outcomes of the research, together with all current knowledge about geotechnical data collection and manipulation, uncertainty analysis, slope stability analysis, and risk management via updated pit slope design and risk management guidelines. Existing manuals such as that produced by CANMET almost thirty years ago remain as valuable literature references, but the time has come for a new generation guidelines that detail accepted practice for today's practitioners.

Research objectives

Research in the Large Open Pit project is examining the attributes that control the strength of the structured rockmass as it deforms in the stress environment of a deep pit and how candidate failure surfaces may propagate through the dilating rockmass along the path of least shear and/or tensional resistance. The research includes three complimentary research streams:

1. Preparation and publication of an authoritative new generation Pit Slope Design guidelines that links innovative mining geomechanics research together with accepted practice. The guidelines will incorporate a database of pit design, performance and operational issues, including topics such as hands-on and remote data acquisition, rockmass characterisation, and the appropriateness of different design approaches.
2. Research that provides vital new knowledge and design criteria that describe the critical gaps in our current understanding of rockmass failure in large open pit mine slopes. Research tasks will be directed at enabling the effective use of geological and geotechnical data in assessing rockmass characteristics, 3D modelling and simulation of slope failure mechanisms, design analyses, and uncertainty analysis.
3. Development of practical risk management criteria focused on the relationship between risk reduction and the uncertainties of slope design and their impact on pushback strategies, equipment selection, costs and benefits, and mine performance criteria.



Some open pit mines have reached up to 800 m deep, and depths are expected to exceed one kilometre within another ten years

Outcomes

The outcomes will be used by the Sponsors to set practical slope design criteria and methods of analyses that describe the reliability of pit walls, helping to prevent costly failures.

Project sponsors

- Anglo American PLC, London, England
- Barrick Gold Corporation, Toronto, Canada
- BHP Billiton Innovation Pty Ltd, Melbourne, Australia
- Corporacion Naciónal Del Cobre De Chile ('Codelco'), Santiago, Chile
- Compania Minera Dona Ines de Collahuasi SCM, Iquique, Chile
- DeBeers Group Services, Johannesburg, South Africa
- Newcrest Mining Ltd, Melbourne, Australia
- Newmont Australia Ltd, Perth, Australia
- Xstrata Queensland Ltd, Brisbane, Australia
- Debswana Diamond Co, Gaborone, Botswana

For more information, please visit www.lop.csiro.au

2007 INTERNATIONAL SYMPOSIUM on the Stability of Rock Slopes in Open Pit Mining and Civil Engineering

12 – 14 September 2007, Sheraton Perth Hotel, WA

Following on from the very successful 2006 International Symposium on the Stability of Rock Slopes in Open Pit Mining and Civil Engineering Situations hosted by the SAIMM in South Africa last month, the ACG is delighted to bring this innovative event to Australia for the first time. Co-Chairs, Yves Potvin, ACG, and John Read, CSIRO Exploration and Mining, look forward to presenting a symposium that will explore the significant developments in the design, analysis and excavation and management of rock slopes.

Symposium objectives

Slope Stability 2007 aims to:

- document information on state-of-the-art rock slope design and excavation,
- provide a forum for the latest information on the application of probabilistic and risk analyses of slopes, and current and new slope monitoring and maintenance techniques to be presented and explored, and
- present relevant and interesting case studies.

Who should attend the symposium?

All open pit personnel, mine management, blasting specialists, slope stabilisation and monitoring service providers, road and rail authorities, civil engineers, OH&S personnel, researchers, consulting engineers and contractors.

Topics

Papers are invited on any aspect relevant to rock slopes, including:

- slope failure mechanisms,

Slope Stability 2007 will explore the significant developments in the design, analysis, excavation and management of rock slope

- slope design criteria and design methods,
- risk analysis and numerical stress analysis,
- slope monitoring techniques,
- slope excavation – blasting techniques,
- support and stabilisation of slopes,
- ground water implications,
- financial aspects and slope stability and
- rockfalls – analysis and control.

Key Dates

Submission of abstract
26 February 2007

Submission of paper
21 May 2007

AusIMM Large Open Pit Mining Conference
10 – 11 September 2007

ACG Sirovision User's Conference – Open Pit and Underground Applications
11 September 2007

ACG Rock Slope Stability Symposium
12 – 14 September 2007

The ACG is also pleased to announce that the symposium will be held in conjunction with the AusIMM's well established and highly regarded Large Open Pit Mining Conference. Contact Josephine at the ACG for more information.

Endeavor Mine shines with an integrated geotechnical service

By Wouter Hartman, associate geotechnical engineer, Coffey Mining

Consolidated Broken Hill (CBH) Resources is accessing new primary ore sources at their Endeavor Mine in Cobar, New South Wales. During this development phase the bulk of production is obtained from pillar extraction. This presents a technically challenging environment, especially considering the backlog of open voids inherited by CBH from the previous mine operators.

The skills shortage, effecting most Australian mines, has also added a degree of difficulty in providing the depth of geotechnical experience in-house within CBH to meet these challenges.

The geotechnical challenges at Endeavor were highlighted by the crown failure of the 6z2 stope in October last year. Since the collapse, CBH has returned the mine to production. Through an innovative approach, Coffey Mining and CBH have worked together to put in place geotechnical management strategies to extend the mine's life.

Under an innovative geotechnical services arrangement, the companies have provided the necessary depth of experience to support the Endeavor mine. This also provides mentoring and training to develop the in-house capability of CBH staff.

A long-term relationship such as this has mutual advantages to both companies. It enables the full depth of experience of Coffey Mining experts to be focused on specific geotechnical problems. These specialists also retain their operational edge by temporarily filling technical services production roles during CBH's recruitment phase.

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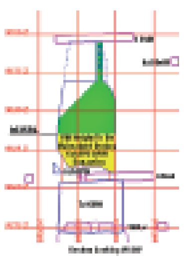


Figure 1 View of 6z1 A-Pillars

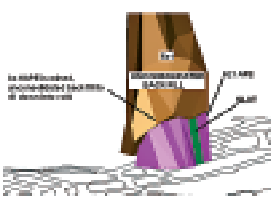


Figure 2 Cross section looking West – South west, showing fill height to be maintained during 6z1 A-Pillars extraction

By providing this continuity, a seamless integration with the CBH technical services team is maintained. As well as achieving a high degree of knowledge sharing and transfer between team members, the arrangement also allows Coffey Mining staff to provide site coverage enabling CBH staff to work on specific projects.

Work has commenced to extract the A – East and West pillars from the 6z1 stope. A high level of geotechnical focus was required for mining of this stope due to its relative position with respect to the previously failed 6z2 stope.

Integrated services process implementation

Example – integrated process

One such case of a fully integrated geotechnical service (i.e. inclusive of backfilling consisting of dry fill) was the mining of the 6z1 A-pillars (see Figure 1).

The process involved in preventing potential extensive overbreak around the 6z1 stope is outlined below:

- All the geological and geotechnical hazards (e.g. major regional fault structures and rockmass conditions) have been assessed on-site. This information was forwarded to a senior geotechnical engineer off-site for review and evaluation. This information was combined with a fully representative rockmass model numerically analysed to determine the stress condition prior, during and after extraction.
- To evaluate and control the potential for massive overbreak, an unconsolidated waste fill height within the stope above was required to be maintained at a certain level (see Figure 2). Maintaining the waste fill height had other implications in diluting the recovered ore, hence the introduction of proper controls to ensure a low risk operation.
- These controls, e.g. modified blast rings, were evaluated and reviewed on-site during a senior geotechnical consultant site visit, which resulted in a final alternative blast ring design, reduction in blast ring quantity and strategically placed cable bolt design (see Figure 3).

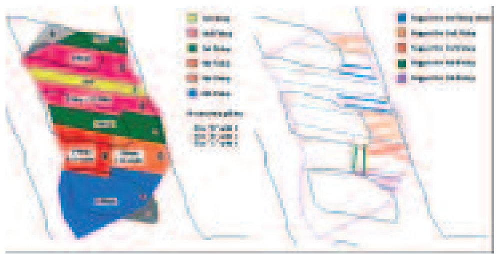


Figure 3 Plan view of alternative ring design and cable bolt reinforcement for 6z1A-Pillars

- The necessary controls were implemented, (refer to Figure 3 for ring design and cable bolt reinforcement and Figure 2 showing a cross section indicating fill height maintenance), to ensure the risk of extensive overbreak is mitigated and potentially eliminated.
- Feedback on the success of controls (i.e. maintaining fill height) being implemented is discussed every day at production meetings through a reconciliation process of tonnes drawn versus waste tonnes filled.

Aspects critical to the success of this integrated process, which supported the above case, are highlighted below:

- 3-Dimensional numerical analysis consisting of block model construction representing different rock material properties experienced at Endeavour, combined with the site geological and geotechnical information was used in the detailed assessment to identify potential overbreak in the 6z1.
- Extracting the A-Pillars of the 6z1 will have possible stability implications when extracting the 7z1 crown pillar below and the introduction of monitoring equipment in the form of SMART cable bolts and SMART "MPBX" extensometers to provide information regarding rockmass response.
- In order to ensure that other stopes similar to the 6z1 are monitored for ground movements, rockmass response and subsequent seismic activity, the current seismic system was reviewed and developed into an expansion project (see Photo 1).

Photo 1 A geological engineer inspects the ESG Paladin seismic network

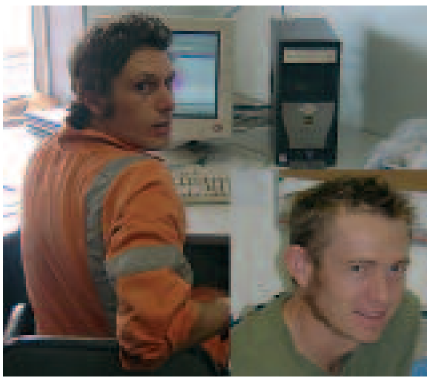


Photo 2 Good communication and teamwork are necessary to ensure continuity across roster changes

- The geotechnical data that was necessary to complete the 6z1 assessment was obtained during the geotechnical site coverage (see Photo 2). This site coverage involves good communication and teamwork, which is necessary to ensure continuity across roster changes in order to thoroughly assess blast ring design, draw point and access stability, which was indicated as critical for 6z1.
- One of the most important aspects of the integrated service is the variety of geotechnical experience exposure to the CBH site geotechnical engineer, especially in the late stage of mining.
- Mining of stopes like the 6z1 has an impact on regional stability. It is critical not to just assess the local instability when reviewing the stope for mining but to incorporate the detailed backfill assessment highlighted below.
- Backfilling the historic mine voids or maintaining fill height is another key challenge of the project and consists of:
  - I. Local surface material property evaluation for dry fill placement.
  - II. Local surface material property evaluations for paste fill design and placement through a dedicated paste fill reticulation system from a surface paste fill plant.
  - III. Studies into cement binder quantity to ensure paste fill stability and local material interaction impact.
  - IV. Dry fill placement risk assessment for high fine material content which form part of Endeavor Mine's risk management process.

Meeting the geotechnical challenges at Endeavor requires close co-operation between the geotechnical group and the mine planning engineers. Mining engineers from Coffey Mining and CBH have worked closely together to develop the mine plans and operation schedules that will underpin the future production at Endeavor.

Risk assessments, which form a key part of the planning and operations approach, have brought together expertise from CBH, Coffey Mining and other stakeholders. Discussions covered the recovery process from the October 2005 stope crown collapse. A comprehensive risk assessment process (for the planned rehabilitation of the damaged pastefill reticulation system) from the extensive overbreak in the 6z2 stope was recently completed. This risk assessment process involved senior mining and maintenance personnel from Endeavor Mine and Coffey Mining, highlighting the extent of the integration model.

Technical service integration process

All the above activities involved in the geotechnical integration process require thorough co-ordination in order to provide an unconstrained flow of information to and from mine personnel. More important is the flow of accurate information between off-site and on-site personnel to ensure prompt reporting for scheduling purposes. The integrated geotechnical service success is maintained by regular and detailed communication.

With the current skills shortage it is difficult for companies to fully staff their operations and maintain site information continuity which is vital to ensure operational risks are at an acceptable level. Traditional high level consulting can sometimes suffer from a disconnection with the operational practicalities of a producing mine environment. The project staffing model developed between CBH and Coffey Mining overcomes these issues by working as an effective team with a common focus.

This model's strength lies within the degree of shared knowledge that is built up over time and used when required, on a long-term basis.

For more information, please contact Wouter_Hartman@coffey.com.au.

Acknowledgements

Coffey Mining thanks CBH Resources – Endeavor Mine, Mr. Mike Fischer (general manager) and Mr. Stuart Pether (manager mining) for their continued support and permission to publish this article. Also a special thanks to all on-site Endeavor personnel for an extremely cooperative working environment.

Strategic versus Tactical 2006

promoting best practices in strategic planning activities in Australian mines

More than 150 mining professionals attended the seminar

The First International Seminar on Strategic versus Tactical Issues in Mining was hosted by the SAIMM in South Africa in September 2005. For the first time ever, the mining industry was brought together to reflect and exchange their perceptions on how strategic thinking and planning processes are handled by different mining organisations and bodies, from global mining houses to small consultancies.

Following on from the success of the South African seminar, the ACG was delighted to host the Second International Seminar on Strategic versus Tactical Approaches in Mining in Perth in March 2006. This seminar provided a unique forum for local industry to share their experiences, their successes and also some of the opportunities that they may have missed due to a lack of a long-term focus.

As Perth turned on its autumn charm, almost 150 mining professionals, consultants, researchers and suppliers gathered to explore the different theories and applications used by operations to achieve their long and short-term goals. Dr Bruce Hobbs, chief scientist of WA and the executive director of the Office of Science and Innovation, Dept. of Premier and Cabinet opened the proceedings with a keynote address questioning if industry can be predictive in mineral exploration. The answer was a resounding yes as long as the understanding is that by predictive, we mean calculable or computable.

The first day featured sessions on strategic issues and general management and economics, and comprehensive case studies from BHP Billiton Nickel West and Anglo Platinum Ltd.

On day two, the highly respected industry sage Dr Oskar Steffen, SRK, presented a keynote address that reviewed strategic planning processes and criteria for strategic planning. Steffen concluded that numerical values that are meaningful can be successfully applied to mining plans and projects, and outcomes should be stated in terms of economic and risk results, however, the adoption of an acceptable result is dependent upon the company's appetite for risk versus rewardn

Day two sessions focused on environmental and open pit strategies and comprehensive case studies from Newcrest Mining Ltd and Xstrata Zinc George Fisher Mine.

The presentations on the final day included an overview of WA's resource sector by Mr Tim Shanahan from the Chamber of Minerals and Energy of WA. According to research conducted by the John Curtin Institute of Public Policy, the output of the resources is likely to grow by 50 to 75 percent over the next decade. Such growth will ensure that the resource sector remains the key driver of the WA economy into the future.

Day three sessions included general strategic planning, caving strategies and underground mining case studies, including a detailed case study from BHP Billiton Cannington. Those attending departed to the four corners of the world, having gained a shared knowledge and further insight into the planning strategies of their industry and research peers.

The ACG was able to host the seminar with the generous support and encouragement of its sponsors, namely, BHP Billiton Nickel West, Barrick Gold of Australia, SRK Consulting and Bosfa/Sika Australia.

ACG 2nd International Seminar on **Strategic versus Tactical Approaches in Mining Proceedings**

The Second International Seminar on Strategic versus Tactical Approaches in Mining Proceedings contains 600+ pages featuring more than 40 papers.

Mining presents significant risks related to uncertainties, but potentially extraordinary rewards for shareholders, industry stakeholders and society. To maximise these rewards over the lifetime of our precious but limited mineral assets, a clever strategic approach to mining must be carefully developed and systematically implemented.

Papers from leading experts and top practitioners, including: Bob Adam (BHP Billiton), Bruce Hobbs (Dept. of Premier & Cabinet, WA Govt.), Michael Hood (CRCMining), Peter McCarthy (AMC Consultants), Tim Shanahan (CME) and Oskar Steffen (SRK Consulting).

To order your copy, please contact Jill at the ACG.

3rd International Seminar on Strategic versus Tactical Approaches in Mining

The Third International Seminar on Strategic versus Tactical Approaches in Mining will be held in Canada in 2007. For more information, please contact John Hadjigeorgiou via John.Hadjigeorgiou@gmn.ulaval.ca.

At the conclusion of the third and final seminar, the ACG will produce a hardbound publication featuring the highest quality papers from the 2005 to 2007 seminars.

Jo, this page very tight, had to delete a couple of pics and still needs editing

Paste and Thickened Tailings Update

paste/ perst/ n.

1 a mixture of flour and water, used for sticking paper.

2 any material or preparation in a soft mass: a toothpaste.

3 Colloq. to beat and scold someone.

4 Paste07 – the evolution of paste technology

The ACG is delighted to bring the 2007 International Seminar on Paste and Thickened Tailings to Perth. Paste07 will explore the latest advances in the preparation, transportation and deposition of paste and thickened tailings (P&TT) that will be reinforced by current case studies. This seminar will also address the important part that P&TT plays in incremental rehabilitation and its impact on mine closure goals.

The seminar will provide a forum for P&TT practitioners, consultants, researchers and suppliers worldwide to exchange views on best practice and state-of-the-art technologies. These seminars set the agenda for future research and operational directions, and ensure the ongoing viability of the mining industry.

Key Dates

Submission of abstract
7 August 2006

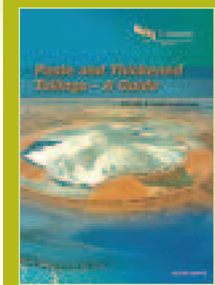
Submission of paper
9 October 2006

ACG Rheology Workshop
12 March 2007

ACG Paste07 Seminar
13-15 March 2007

Waste

Paste and Thickened Tailings – A Guide (Second Edition)



The ACG was delighted to launch the *Paste and Thickened Tailings – A Guide (Second Edition)* at the Ninth International Seminar on Paste and Thickened Tailings held in Limerick, Ireland in April 2006. An essential source of information on the technology and management associated with paste and thickened tailings (P&TT), this revised, full colour second edition features two new chapters on slurry chemistry & reagents, completely rewritten chapters on surface disposal, mine backfill and transport, the inclusion of filtering equipment for thickening and a number of new case studies.

The ACG is grateful for the outstanding contributions made from well known industry practitioners and experts from throughout the world. Our thanks are also extended to the guide's sponsors for their financial support and encouragement to bring this publication to fruition.

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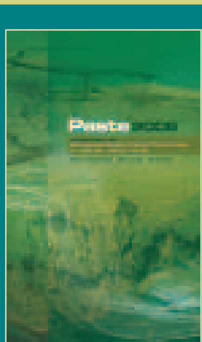

ACG Paste05 and Paste06 Seminar Proceedings

Keep abreast of the latest P&TT technological advances and best practice by accessing the ACG's P&TT publications including the Paste05 and Paste06 seminar proceedings. To find out why the global mining industry turns to the ACG as the main source of P&TT knowledge, contact the ACG for a detailed list of P&TT publications and seminar/ workshop proceedings.

Paste 06 – goes the distance

The grey skies of south-west Ireland cleared during the week of 3rd to 7th April, providing an ideal welcome to delegates attending the 9th International Seminar on Paste and Thickened Tailings (P&TT). The seminar was held in Limerick, which provided an extremely appropriate setting, with two operations utilising high density tailings within easy reach of the city.

Although Europe may no longer be the centre of mining activity, the seminar content was clearly enough motivation to attract a large gathering of delegates from around the world. The number of delegates had to be capped at 175 and according to the conference organisers they could have taken at least another 50 bookings. This level of interest is a clear indication of the ongoing interest in the technology of high density tailings preparation, transport and management. If anything, interest is likely to increase in the future, with regulatory requirements for the management of mine tailings becoming ever more severe.

The seminar programme included keynote addresses by: Peter Scales, University of Melbourne, on *Understanding the thickening process*; Ted Lord, Syncrude Canada and John Oxenford, John Oxenford & Associates, on *Canadian Experience in the application of paste and thickened tailings for surface disposal;* and Dave Landriault, Golder Paste Technology Ltd, on, *They said it will never work – 25 years of paste backfill 1981-2006.* As indicated by the titles, these three presentations covered most of the primary areas of interest of delegates attending the seminar; from advances in understanding the thickening process (where Peter clearly pointed out some of the deficiencies in our understanding as well as some of the successes), through surface disposal in sometimes hostile circumstances, to making underground backfilling using paste technology work in circumstances where it had been rejected by all but the most ardent believers in the technology. The technical programme that followed, included over 30 presentations on topics related to the above keynote lectures, as well as issues of safe and economical transport of high density slurries.

Paste 2006 presented an insight into tailings activities in Ireland

Paste07 will explore the latest advances in the preparation, transportation and deposition of P&TT. Photo courtesy of De Beers

An interesting aspect of the presentations was the number of operations that are now either using high density thickened tailings for surface deposition, or are in an advanced stage of implementing the technology. Only a few years ago people were asking, 'show me where it is working?', whereas now the questions are more likely to be, 'how well is it working?' or, 'how much water are you actually saving?'. Many of the presentations at the seminar provided answers to some of these questions and it was pleasing to see that some of the touted benefits of P&TT are indeed being realised, such as very significant water savings in some instances. Another enduring criticism of P&TT that was shown to be incorrect is the supposition that the technology can only be applied to new operations (green field sites). At a number of operations, particularly in Canada, existing conventional tailings management operations have been converted, very successfully, to high density thickened tailings operations.

Advances in thickener technology were discussed at some length and interesting developments in the ability to pump higher and higher yield stress materials using centrifugal pumps were presented. Clearly the technology continues to improve at a rapid rate. Improvements in our understanding of post-deposition behaviour of thickened tailings on surface are being made possible by the extensive monitoring and testing that is occurring at some sites, and some very useful information was presented during the seminar. It also appears that designers are coming around to a better understanding of the risks posed by the potential liquefaction and instabilities of the deposits that result from the implementation of P&TT on surface.

The seminar was preceded by a one-day workshop on the intricacies and delights of rheology, with an opportunity to play in the mud (in the laboratory of course) being provided during an afternoon session hosted by the University of Limerick. These workshops are becoming a regular feature of the seminars and provide an ideal opportunity for those who are relatively new to the field of P&TT to quickly get up to speed before the start of the seminar proper.

The week was rounded off by two site visits. The sites visited were the Aughinish Island alumina refinery site, where bauxite from Brazil and west Africa is refined to produce alumina and the residual red mud is managed using an innovative thickening and disposal operation, and the Lisheen mine, where paste tailings are placed underground at a very high rate, with the final goal being in excess of 80% tailings going back underground. Both operations exhibited highly advanced implementations of the latest technology and, in the case of the surface deposition of red mud, showed that the technology can indeed be made to work in (very!) wet climates and still be viable.

The seminar organisers, in particular Phil Newman from Golder Associates, Liam McNamara of Dorr-Oliver Eimco and Simon Lawson from the Industrial Centre of Particle Science and Engineering at Leeds University, are to be congratulated on facilitating a gathering at which an enormous amount of valuable networking and sharing of experiences was made possible, during both the formal sessions and the equally valuable breakout sessions and social functions.

Next year P&TT goes back to its roots, with the 10th International Seminar to be held in Perth from the 13th to 15th March 2007. The historic city of Fremantle will provide the venue for what is likely to be a vibrant and valuable seminar, with many more new and innovative technologies and case studies being showcased. Once again, the venue size will be limited so early registration for this event is advisable. For further information, visit www.paste07.com.

Update

Group Control Group of Western Australia

The Ground Control Group of WA's (GCGWA) first meeting for the year was held in Kalgoorlie in March. The group meets three times a year as an independent and impartial body enabling underground and open pit geotechnical engineers to meet, discuss and exchange ideas, techniques and experiences in a technical yet informal setting. It also provides a forum for attendees to discuss ground conditions specific to their own sites and to seek the opinions and recommendations of their peers.

At last month's meeting the group decided to retain the independent and impartial status of the group, in that membership is limited to mining practitioners only. However, membership is now open to industry professionals that either work for, or are a representative, of a mining company.

Additionally, mine training departments will be encouraged to view GCGWA membership as a means of advancing staff development through networking and interacting with peers from other sites.

For more details about the March meeting or to register your interest to attend the next meeting to be held in Kalgoorlie in June/ July 2006, please contact the ACG.

ACG 2006 – 2007 Event Schedule*

Title	Date	Where
Development and Production Blasting in Underground Mines	2-3 August 2006	Ibis Perth Hotel, WA
Preparing and Implementing a Tailings Storage Facility Operations Manual	11 September 2006	Sheraton Perth Hotel, WA
First International Seminar on Mine Closure	13-15 September 2006	Sheraton Perth Hotel, WA
Blasting for Stable Slopes	5-6 October 2006	Ibis Perth Hotel, WA
Ground Support in Open Pit and Underground Mines	31 Oct-3 Nov 2006	Ibis Perth Hotel, WA
Geosynthetics in Mining Seminar	6-8 December 2006	Ibis Perth Hotel, WA
10th International Seminar on Paste and Thickened Tailings	13-15 March 2007	The Esplanade Hotel, Fremantle, Perth, WA
2007 International Symposium on Rock Slope Stability in Open Pit Mining and Civil Engineering	12-14 September 2007	Sheraton Perth Hotel, WA
Economic Risk & Project Evaluation, and Geomechanics Risk Management	21-23 February 2007	Novotel Brisbane, Qld
Caving Geomechanics	1-2 March 2007	Ibis Perth Hotel, WA
10th International Seminar on Paste and Thickened Tailings	13-15 March 2007	The Esplanade Hotel, Fremantle, Perth WA
Stope Planning and Design and Case Histories	2-4 May 2007	Ibis Perth Hotel, WA
Water Management Seminar	12-13 June 2007	Ibis Perth Hotel, WA
Mine Closure for Decision Makers	14-15 June 2007	Ibis Perth Hotel, WA
High Density Transport	1-2 August 2007	Ibis Perth Hotel, WA
Mine Fill	3 August 2007	Ibis Perth Hotel, WA
International Symposium on Rock Slope Stability in Open Pit Mining and Civil Engineering	12-14 September 2007	Sheraton Perth Hotel, WA
Sirovision User's Conference – Open Pit and Underground Applications	11 September 2007	Sheraton Perth Hotel, WA
Advanced Ground Support	6-9 November 2007	Ibis Perth Hotel, WA
An Introduction to Soil Mechanics	5 December 2007	Ibis Perth Hotel, WA
Tailings Management and Decommissioning	6-7 December 2007	Ibis Perth Hotel, WA

** The ACG event schedule is subject to change.*

Paste 2007

13 – 15 March 2007, Perth, WA

logo to be added
once finalised

Abstracts due Monday 7 August 2007

Paste07 will explore the latest advances in the preparation, transportation and deposition of P&TT that will be reinforced by current case studies. The part that P&TT plays in incremental rehabilitation and its impact on mine closure goals will also be addressed. Contact Andy or Jo at the ACG for further details.

www.paste07.com

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