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AUSTRALIAN CENTRE FOR GEOMECHANICS
NEWSLETTER

Deep and High Stress Mining 2007

7–9 November 2007
Perth, Western Australia

At Deep and High Stress Mining 2007 attendees will exchange views and expertise with their peers practicing the diverse range of disciplines involved in deep and high stress mining activities. Topics include:

- Numerical modelling
- Rock behaviour under high stress
- Rockburst and seismic monitoring
- Ground support
- Case studies

Early bird registration closes 1 October 2007.

www.deepmining07.com

What's in this volume?

The use of a rigorous design process to minimise the risks associated with seismicity due to deeper mining

By Richard King, associate geotechnical engineer, Coffey Mining Pty Ltd

The recent rise in resource prices has led to an increased focus on greater production from mines to capitalise on the boom. As a result, we as an industry are mining at greater depths, greater extraction is being undertaken, mining in challenging ground conditions is becoming viable and previously closed mines are being reopened. All of these factors have led to the potential for the increased incidence of seismicity and associated risks in underground mines.

Deeper mining in comparatively narrow deposits of relatively weak, friable, sheared and fractured rock contained within strong, massive host rock are especially prone to seismicity. The presence of very strong intrusives, such as porphyry dykes, cutting across the deposits often results in pillars being left, attracting stress due to their relatively high stiffness in comparison with the orebody. The high horizontal stresses, between two and three times the vertical stress, usually associated with these deposits, further exacerbate the problems.

Many mines are now beginning to experience minor seismicity and need to examine their ground control systems and mining strategies in order to minimise the risk to personnel and production. Present ground control systems are often based on experience of what has worked in the past, rather than on any comprehensive design technique. This approach is not realistic with the introduction of seismicity as the ground control requirements change fundamentally.

In order to properly address the issues, a rigorous design approach is required that will deal with the two main modes of damage associated with the sudden release of energy from the build-up of mining induced stresses; namely, seismic shakedown caused by far-field events (more than 10 m from the excavation, assuming relatively small event magnitudes in this environment), and strainbursts from near-field events. The shakedown event, usually caused by slip on a geological structure, results in the loosening of existing fractured or jointed rock and the propagation of fracturing into the surrounding rock. The strainburst, caused when the tangential stress around an excavation exceeds the rock strength or buckling threshold, results in sudden bulking and ejection of rock. A third mode of damage, whereby rock is ejected violently due to energy transfer from larger, nearby slip events, is rare in this environment.

Design

There are several well-documented design techniques available; the flowchart in Figure 1 maps out one design process to follow. Essentially, the support system selected must be able to control any anticipated demand that may be put on it and should, ideally, only need to be installed once, as soon as possible after the fresh rock is exposed.

Dynamic loading

In order to design ground control systems for dynamic loading, it is critical to know what maximum magnitude of event can be expected. To be able to predict this with any certainty, it is important to know the history of local seismic activity and the presence of structures and/or stress concentrations that may predicate events.

To acquire this knowledge requires a strategic approach to rockburst control, including the installation of a seismic monitoring system to measure existing seismicity, detailed mapping, interpretation of the geology and structure of the deposit and its surroundings,

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a record of the performance of existing support systems, and the behaviour of the supported ground.

Provided that a history of seismicity is available, the largest expected event can be estimated using the Gutenberg-Richter frequency-magnitude relationship, which asserts that there is a consistent relationship between the number of large and small events under the same conditions. Figure 2 gives an example of the relationship. In this case, the largest expected event would be in the order of 0.5 M_L, assuming that no significant changes were made to the mining layout or rate.

Shakedown and strainbursting require different ground control design processes due to the different effects each has on the rock surrounding an excavation. In addition, the seismic risk from strainbursting tends to be higher as it often occurs at the working face where personnel have a higher exposure in both time and numbers.

Shakedown

Seismically induced falls of ground can occur anywhere within an excavation, depending on the location of the event and local layout geometry. The occurrence of falls depends on the ground motion intensity (a function of the magnitude and proximity to the event), usually quoted in terms of peak particle velocity (ppv), and the static factor of safety before the event.

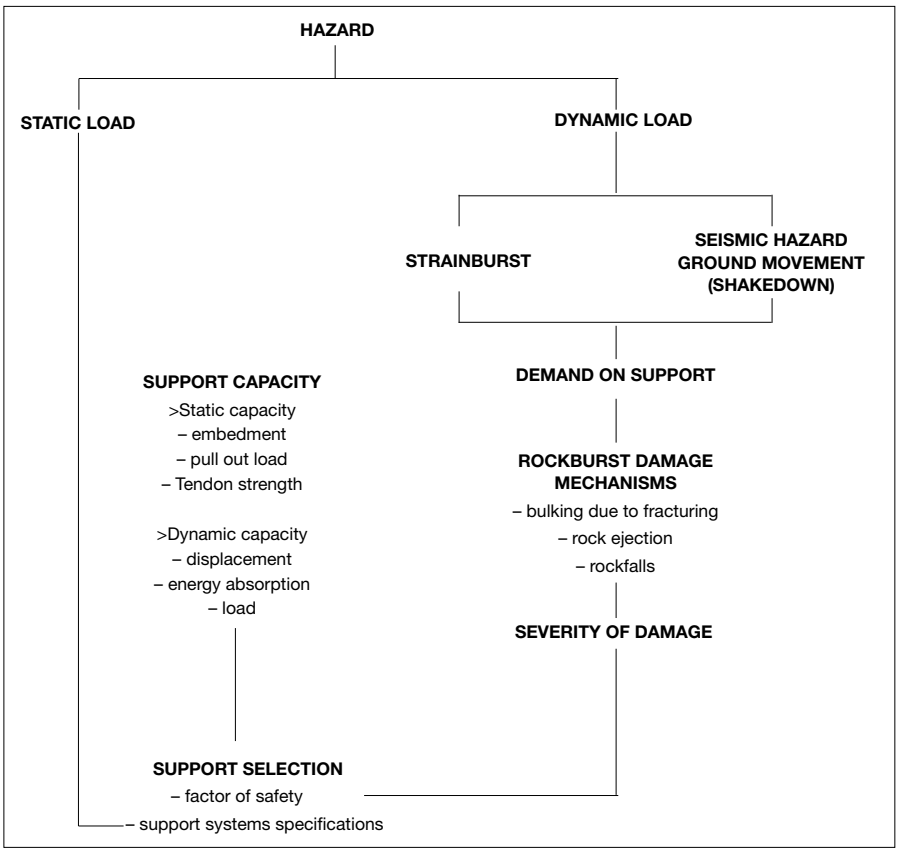

Figure 1 Ground control design process

Ground control design for this mode of failure is based on providing sufficient load and displacement capacity.

A design process for ground control for the shakedown case has been outlined by Peter Kaiser et al., in the "Canadian Rockburst Support Handbook", published in 1996 by the Geomechanics Research Centre in Sudbury. This process involves the following steps:

- Calculation of the required static factor of safety to survive a seismic event at varying distances from the event. This is a function of the event magnitude and distance and the energy absorption capacity of the support.
- Estimation of depth of fracture due to stress and the increase in depth of fracture owing to the dynamic loading due to a seismic event. This is a function of the size of excavation, the strength of the rock and the local stress field. The calculation includes a calibrated factor, C, which can be calculated from an estimation of the tangential stress at which the first signs of stress-induced failure are observed to occur. The stress may be obtained from numerical modelling and the rock strength from laboratory UCS tests.
- Selection of the design safety factor. The safety factor selected for ground control design depends on what reliance can be placed on the data used for calculation; a factor of 1.3 is common in mining.
- Ground control design for given support types against anticipated loads and displacements developed in a seismic event.
- Comparison of the required ground control with the existing minimum standard ground control designs to assess their adequacy against the shakedown mode of failure.

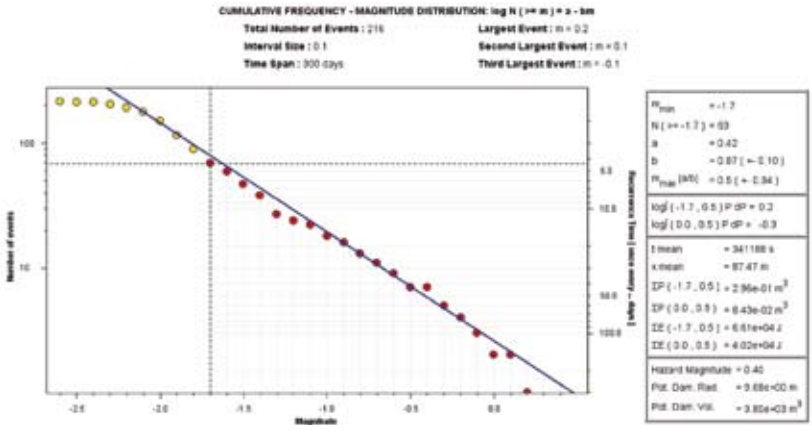

Figure 2 Gutenberg-Richter frequency-magnitude relationship

Strainburst

Strainbursting frequently occurs in areas of newly exposed ground where stresses are being redistributed. This can be exacerbated by the presence of adjacent rock types or intrusions of differing stiffness; the stiffer units attracting a higher proportion of the stress, overloading them. The presence of remnants or pillars can also create conditions for strainbursts if the stress exceeds the strength of the rock or the buckling threshold of the wall slabs.

Ground control design for this mode of failure is based on providing sufficient energy dissipation and thus displacement capacity. Much of the energy from the strainburst is consumed by friction within the broken rock and the rest must be dissipated by the support system.

However, the nature of strainburst events means that they often occur ahead of the permanent support in freshly exposed rock. This requires that a temporary support system should be in place to minimise the exposure of mine personnel to rock ejected during a strainburst. Steel fibre reinforced shotcrete is probably the most effective support type presently readily available for this duty, as no drilling is required to install it and it can be applied remotely.

It is impossible to directly determine the energy that is required to be dissipated by the support system from the magnitude of the strainburst event, due to uncertainties regarding the stiffness characteristics of the loading system and the failing rock. The ppv, as calculated in the shakedown assessment, bears little relationship to the actual velocity of rocks ejected from the skin of an excavation during a strainburst and does not allow the energy dissipation capacity requirement of the support to be calculated.

For the relatively small events ($M_L < 1.5$) that generally cause strainbursts, possibly the simplest way of estimating a maximum energy absorption requirement is by comparing the expected damage from the largest predicted event to the energy required to eject blocks of a similar thickness. The support design would then be required to provide sufficient load and displacement to control those blocks, including an acceptable safety factor.

If measurements of the thickness and velocity of rock ejected during a measured strainburst are available, the energy required to eject these rocks can be calculated and used to validate the energy assumptions.

Hazard control

A rigorous design process and the development of a sound ground control strategy must include an ongoing monitoring and recalibration programme to keep the design up-to-date and account for changes in depth, mining rate and layout. This would include the measurement of the static depth of fracturing, movement on defects, support loads and stress. This monitoring programme would have two components; a strategic part to update the ground control and layout designs, and an operational part to ensure the day-to-day safety of the operation.

To achieve the operational aspect certain controls need to be used on a daily basis before re-entry to any production areas or areas where increased levels of stress are predicted. Before re-entry to an operating production section, the information available from the various systems in place must be analysed to ensure that no unfavourable indicators are present. The systems and indicators that should be monitored are:

- Seismic system – change in rate, location or magnitude of events, large single events.
- Monitoring system – change in rate, location or magnitude of fracturing, movement or stress.
- Noise reports - change in rate, location or magnitude of noise or air blasts reported.

The effective use of this data requires that user-friendly, real-time monitoring and analysis systems are in place.

Conclusion

The nature of the mining environment means that all data collected is inherently unreliable as a basis for future predictions. The use of a rigorous design process, where design assumptions are clearly identified and tested, consistently applied with designs frequently updated from data collected from an effective monitoring programme can minimise the uncertainty and maximise ground control efficiency.

Reference

Kaiser, P.K., McCreath, D.R. and Tannant, D.D. (1996) Canadian Rockburst Support Handbook. Geomechanics Research Centre, Sudbury, Ontario, Canada.

Richard King,
Coffey Mining Pty Ltd

Mine seismicity and rockbursts – *Unleashing the Earth's Energy* training DVD

Anzac Day 2006 will long be remembered in Australia as the day the Beaconsfield mine in Tasmania experienced a significant rockburst. The sensational rescue operation of the two trapped mine workers brought rockburst to the forefront of world media. In the general community very little is known about rockburst and the media reports were confusing, as some referred to a cave-in, while others called it an earthquake. Whilst there is a general awareness of the rockburst phenomena in the mining industry, very few mine workers have an adequate understanding of mine seismicity and rockburst hazards.

A mine induced seismic event is caused by a change in stress due to mining, producing a fault slipping or a violent local stress fracturing of the rock. Technically, it is an earth tremor and the largest mine induced seismic events in the deep South African gold mines have reached up to five on the Richter scale. When seismic events cause damage to parts of the mine infrastructure, they are called a rockburst.

Understanding the complex issue of mine seismicity and rockburst is one of the biggest technical challenges facing the Australian mining industry today. As the country's mines push deeper, problems with the phenomenon are becoming more widespread and so is the need for research to assist the industry to effectively manage the associated risks. There is also an urgent requirement to equip mine workers with essential knowledge to understand this hazard, including understanding the difference between natural seismicity and mine induced seismicity, what makes a mine seismically active, the pre-cursors, and how to control seismic hazards. The workforce needs to be exposed to the sophisticated seismic monitoring systems that are operating in many of our mines.

To assist in managing seismic risks in underground mines, the ACG, with industry partners AngloGold Ashanti Australia Ltd, Barrick Gold of Australia, Beaconsfield Mine Joint Venture, BHP Billiton and Independence Gold – Lightning Nickel, is currently in the final stage of producing "Unleashing Earth's Energy", a training DVD for mine workers aimed at explaining the rockburst phenomenon.

Unleashing Earth's Energy will be available from the "ACG store" towards the end of 2007.

Welcome onboard Golder Associates Pty Ltd

Golder Associates Pty Ltd recently became a corporate affiliate member of the Australian Centre for Geomechanics. Golders sees the ACG as playing an important role in the development and education of the geomechanical engineering fraternity. Our intention is to contribute to this role, where possible, as well as gain knowledge and experience through our association with the ACG.

Golder Associates is a global group of consulting companies specialising in ground engineering and environmental services. With the resources boom taking place in Western Australia the need for technical engineering input to projects is increasing constantly. The Golder Perth team, which numbers 100+ comprising of engineers, geologists and scientists, is well placed to provide these services to our clients. The Perth team has vast experience in a varied and large number of mining, geotechnical and environmental projects. In addition, we can also draw from the international experience of the company.

The tailings and waste management team together with the mining environment team can provide solutions for our clients on all aspects of waste disposal and management. The team recently expanded its range of services to include slurry pumping and thickened tailings design. The group is headed up by David Williams, who has spent over 20 years in tailings engineering, with Liza du Preez specialising in municipal and industrial waste leading the waste services team, and Ed Clerk leading the mining environment services team.

For more information about the ACG's corporate affiliate programme, please contact the ACG.

Golder Associates' tailings and waste management team

Geosynthetic liners in mine, industrial and municipal waste – design and installation considerations

By Liza du Preez, senior landfill engineer, Golder Associates Pty Ltd

Introduction

The use of geosynthetic materials is becoming more and more prevalent in the mining, industrial and municipal waste industries due to changes in environmental legislation, environmental company policies and project economics. A wide variety of geosynthetic materials are available for use in liner design, which includes geomembrane, geotextiles, geogrids and geosynthetic clay liners amongst others. This article presents design and installation considerations for geomembranes and geosynthetic clay liners (GCL) only.

Purpose of a lining system

The purpose of a lining system should be considered during the early stages of the project design as it will determine the type of liner design that is implemented. The most significant purpose would generally be to reduce the risk to the environment by reducing the concentration or volume of contaminants released by the site to soil or water. In the instance of a tailings storage facility or heap leach pad the purpose will be to improve the recovery of leaching water, either for re-use or to extract the product that is in solution. The purpose of the liner system may also be to conform to the regulatory requirements of the area or country.

General issues

There are a number of issues to consider when the use of geosynthetic liners is considered for a project. The supply cost of these materials can be high compared to natural materials. It is therefore worthwhile to carry out a cost comparison between using natural materials (which may or may not be available locally) and geosynthetic materials. The *thickness* of an equivalent geosynthetic liner system is generally significantly less than a natural clay liner and therefore the storage capacity of a facility can be increased. This could be particularly significant for commercial waste disposal facilities that generate revenue through the airspace that is sold. The acceptable leakage through a liner system should be considered as it could affect whether or not the design objectives are achieved. In the instance of a tailings facility or heap leach pad the liquid lost through seepage could affect the financial bottom line in terms of recoverable product. Extensive site preparation is generally required prior to the installation of a liner system, either by compaction of the in situ material or the construction of a clay layer. The surface of the subgrade is required to be a smooth surface prior to the installation of either the geomembrane or GCL. The design life of the facility and therefore the life expectancy of the geomembrane or GCL under the given working conditions (environment or operational) should be taken into consideration for each project. Under very harsh site conditions the life of the geosynthetic can be significantly reduced. Storage ponds are used to store the leachate, or seepage liquid should have a liner system at least equivalent to the facility liner system.

Economic issues

A liner system can cost between A$20 to A$40 per m^2, depending on the level of redundancy and environmental protection required. Most of the geomembrane in Australia is imported from Asia and occasionally from the USA. The increase in storage capacity of a facility can result in a large cost saving or in additional income as is the case with commercial waste disposal facilities. If 1 m of clay is replaced with a 20 mm thick geosynthetic liner, the increase in storage capacity is approximately 10,000 m^3/ha. For mine waste facilities or heap leach pads, which can often cover several hectares, this is a significant number. Drainage systems could also be replaced with geosynthetic drainage materials which will result in additional storage becoming available.

Geosynthetic design considerations

Numerous issues should be considered during the design of the liner system of a tailings facility or heap leach pad. These include:

The *acceptable leakage rate* will be determined by the surrounding environment and the ability of this environment to attenuate the contaminants seeping from the facility. The acceptable leakage rate is determined by factors such as the hydraulic head on the liner, the installation process, the chemical composition of the retained materials and the seepage liquid, final thickness of the retained material, disposal or deposition method, meteorological conditions and regulations. Leakage rates are discussed in more detail further in the article.

Geomembrane is lighter than water, which means that it will float on top of leakage through the geomembrane if there is no load on top of the geomembrane to keep it in contact with the underlying low permeability layer. Geomembrane floating is specifically prevalent in liquid retention applications. It is therefore generally recommended that a ballast layer, which can double as a protection layer, be placed on the base of the pond.

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Minimum geomembrane thickness would depend on the performance requirements and there are several material thicknesses to choose from. The minimum practical thickness from an installation and performance point of view is generally 750 to 1,000 micron, depending on the geomembrane material type. Thinner materials are more prone to damage during and after installation.

Geosynthetic materials present a complex condition in terms of the *interface shear strength* between the materials. Interface shear strength values can also be very low which could result in the introduction of a weak plane at the base of a slope in a disposal facility. It could also influence the final geometry (and therefore capacity) of the facility as flatter slopes may be required to ensure stability.

In some instances a GCL may require *pre-hydration* with uncontaminated liquids. This is because the liquids with which the GCL may come into contact could affect its hydration rate and permeability.

GCLs require *confining pressure* to achieve the quoted permeability. If a GCL is allowed to free swell, the permeability can be significantly increased and it could lead to thinning in some areas if material is placed over it when it has been allowed to free-swell. It is therefore important to allow for a confining layer over the GCL in the design.

Leakage rates

Advection and diffusion

Leakage through the liner takes place according to two basic mechanisms, advection and diffusion. Advection is permeability dependant and is the main mechanism of migration through a compacted clay liner and GCL. Diffusion is concentration dependant, and is the migration through a liner system that is not linked to gravity or flow. The mechanism that dominates a liner system depends on the material of the liner system and the composition of the retained material in the facility.

Liner composition

Leakage flow rates through single geomembrane liners that have been poorly installed can be in excess of 50,000 l/ha/day, while a good installation can reduce the leakage rate to approximately 1,000 l/ha/day. Leakage through a composite liner that has been poorly installed can be in excess of 500 l/ha/day, while a good installation will reduce the leakage rate to approximately 1 l/ha/day. For dual composite liners the leakage rate through the primary liner is collected in a leakage collection layer below the primary liner, with leakage through the secondary liner being in the order of 0.01 l/ha/day. It is therefore clear that a good composite liner can significantly reduce leakage rates.

The permeability of a compacted clay liner is normally required to be around 1×10^{-9} m/s. The permeability of the compacted clay liner could be significantly reduced if the liner cracks due to desiccation. The permeability of GCL liners are quoted to be between 1×10^{-10} to 2×10^{-11} m/s.

Installation of composite liner system consisting of clay liner, geomembrane, cushion geotextile and drainage layer

Chemical changes

Chemicals with which the liner may come into contact either from the retained material or the seepage liquid from the retained material may change the permeability of the liner, which will affect the rate of leakage. Anion exchange can take place with clay minerals, which could increase the permeability of the clay. Organics in the seepage liquid may affect the hydration of clay minerals, which may result in an increase in permeability. Hydrocarbons may also impact on the durability of certain geomembrane materials.

Hydraulic head on liner

Hydraulic head on a liner results in a higher seepage rate through the liner system. To reduce the head a drainage layer is often installed. The purpose of the drainage layer can also be for faster recovery of the liquid seepage from a heap leach pad. The drainage layer over most geomembrane systems also provides some protection to the liner system to damage and reduce the risk of wind uplift.

Typically, drainage layers consist of a 300 mm thick layer of granular material, although geosynthetic drains can also be used. Geosynthetic drains have a thickness generally between 5 to 10 mm. When designing these drainage systems it should be recognised that the placement of the layer during construction presents a risk of damage to the underlying liner. These layers may also clog either mechanically (fine particles) or through chemical precipitation from the seepage liquid.

Installation of aggregate drainage layer over geosynthetic liner

Installation process

The installation process for geosynthetics commences prior to any construction being undertaken on site.

A part of the pre-construction process includes verification of material supply. Verification of the materials normally includes obtaining information of the Quality Control (QC) procedures at the factory or in some instances, if it is deemed necessary, visits to the factory to check the manufacturing process. Another important factor is the reputation of the manufacturer. It is normally good practice to obtain references from previously completed projects and also to obtain information from the manufacturer regarding the source of the raw materials.

During the construction period numerous factors can affect the installation. These include:

Construction equipment can damage the geosynthetics during off-loading from the truck and during deployment. Damage can also occur after installation of the geosynthetic when the subsequent layers are placed over it. The amount and type of damage is normally dependant on the method and the equipment chosen to place the subsequent layers.

Prior to installation the *subgrade surface* must be checked to ensure that it complies with the specification, that the surface is smooth and that the moisture content is not too high.

Care should be taken in the placement and preparation of *seams* as these form a critical part of the installation.

Other factors that affect installation would be *weather conditions* (welding cannot occur in wet conditions), presence of animals (damage of hooves or nails) and long *UV exposure* periods.

Construction quality control

Construction quality control (CQC) is required during installation to ensure that the liner system is installed in accordance with the specification and that the design objectives are achieved. CQC can include activities such as testing of the constructed clay liner, maintenance of the clay integrity, inspection of supplied liner materials, testing and minimisation of geomembrane seams, checking that the GCL is sufficiently overlapped and covered in a timely manner, providing supervision to prevent subsequent damage during placement of cover materials and documentation of the procedures and test results.

Successful installation of geomembrane liner prior to drainage layer placement

Environmental conditions

Environmental conditions that can affect the performance of the liner system include degradation of geosynthetics through heat, oxygen (oxidation of the antioxidants in the geomembrane) and ultraviolet light. Other factors are chemical attack of the geomembrane or GCL, drying and wetting of clay layers and surface erosion of GCL's and clay liners.

Operational conditions

Operational conditions that can affect the performance of the liner system include pressure on the base liner due to the thickness of retained material. Pressure on base liner can be as high as 1 MPa which would require a protection layer on the liner to prevent it from being punctured. Further factors to consider include the deposition or disposal method, either hydraulically in the case of tailings or mechanically in the case of waste or heap leach material. Hydraulic deposition can result in erosion of the drainage layers upon first filling.

Regulatory considerations

Although geosynthetic liners are not generally required for tailings storage facilities, some facilities are required to assess the environmental risk related to the retained material, which results in the need to line the facility. The risk based approach considers all the sources, pathways and receptors and the effect on each is assessed.

Conclusion

There are a number of aspects that should be taken into account when designing and installing a geosynthetic liner system to achieve an effective system that provides the environmental protection benefit to the owner of the facility.

Liza du Preez, Golder Associates Pty Ltd

Practical waste rock dump design for acid rock drainage control – the Savage River mine experience

By David Brett, principal engineer, mine waste management, GHD Pty Ltd

Introduction

The Savage River Iron mine is located in northwest Tasmania at an elevation of 100–350 m in rugged and mountainous terrain covered with dense rainforest, approximately 300 km northwest of Hobart. The climate of the area is characterised by cool temperatures and a high and consistent average annual rainfall of nearly 2,000 mm. Rainfall exceeds evaporation by a factor of at least 2:1.

To date, mining operations have generated in excess of 50 million m^3 of ore and 300 million m^3 of waste rock. Current mining plans allow for the potential of a further 100 million m^3 over the next 15 years.

The Savage River iron deposit is located within a narrow linear belt of Pre-Cambrian rocks, comprising principally of serpentinites, volcanics and schists with lesser dolomites, magnesites and amphibolites. The ore zone and enclosing sequence strikes north-south and dips near vertically. The main ore zone comprises massive and disseminated magnetite. The zone has a known strike length of 4 km and reaches a thickness of 100-150 m, but can occur as two or more thinner lenses. Down dip continuity is indicated to depths of at least 600 m.

The mine was initially opened in 1967, operating several open pits along the north-south trending orebody that crosses the Savage River. These pits have progressively been expanded and deepened with the mine recently announcing a further 15 years expansion programme.

The ore is concentrated at the mine site, then is transported as slurry in a pipeline 85 km to Port Latta on the coast. This pipeline in itself is a tribute to the engineering design and construction expertise of over 40 years ago, being still in use. At Port Latta the concentrate is pelletised prior to shipping to Australian and international customers who value the fluxing properties of the product.

Operations over the first 30 years of mine life caused environmental harm to approximately 30 km of the Savage River. This section was found in 1995 to have lost 90% of its invertebrate biodiversity and 99% of its invertebrate abundance. Savage River water quality reflected the influences of past mining, with suspended solids and acid rock drainage (ARD) containing elevated dissolved copper, aluminium, nickel and manganese. Pit discharges, surface runoff, waste rock pile seeps, and tailings dam seeps and discharges all contributed to the deteriorating water quality.

The high rainfall and low evaporation, in combination with steep topography, had

Figure 1 Overview of Savage River mine looking south from North Pit

Figure 2 Concentrate pipeline spanning the Savage River

resulted in erosion in disturbed areas, with increased sediment input evident in streams draining the area and in the Savage River itself. The ecosystem of the Savage River above the mine is also affected because the pollution prevents fish from migrating between the river and the sea, an essential part of the lifecycle of most Tasmanian native fish. Surveys show that the native fish fauna is severely depleted in the Savage River National Park, which is located above the mine (Kent et al., 2004).

Within this framework of environmental impact the mine changed hands in 1996. The new operators, Australian Bulk Minerals (ABM), commenced operations with a commitment to achieve "best practice" environmental management and, in addition, a new operator/government alliance was made in the form of the Savage River Rehabilitation Project (SRRP). The aim of the SRRP is to coordinate expenditure of an A$24 million fund for rehabilitation works of the historic impacts using financial contributions from both the previous and current mine operators.

Historical dump performance

During the first few years of the SRRP various studies were carried out to determine the sources of ARD and to look at feasible remediation methods. This determined that the majority of pollution was sourced from historic waste rock dumps. One of these, known as Hairpin Dump, became the first study of the SRRP.

Hairpin Dump was one of the last areas used by the original mine operators with waste from the eastern and western walls of North Pit being dumped there between 1993 and 1994. Since dumping ceased, the site has been used as a service site for drilling equipment. An investigation in late May 2000 involved: drilling five holes; sampling and testing for a wide range of physical and chemical properties and the installation of oxygen and temperature measuring probes. Hydraulic properties within the dump were determined from test pits and a range of permeability and infiltration tests. Bulk density and sizing trials were carried out on a large sample.

The geochemical assessment of the dump concluded that:

- Hairpin Dump is oxidising rapidly, with almost 30% of the sulphides in the dump already oxidised after only six years. If oxidation continued at the present rate, the sulphides would be exhausted in about 20 years. In practice, the rate of oxidation is likely to slow and oxidation will continue for longer.
- The effluent from the dump carries only a small proportion of the contaminants produced and the dump contained a very large store of readily leachable contaminants, which, if mobilised, could sustain present contaminant loads in the outflow for decades, even without further oxidation.
- Since oxygen ingress into Hairpin Dump appeared to be primarily by advection, covering the dump would quite likely reduce the rate of oxidation. However, because the contents of the dump are already appreciably oxidised and a large amount of readily leachable contaminants are stored in the dump, reducing the rate of oxidation may not lead to any appreciable reduction in contaminant load exiting the dump.
- If the present effluent quality is unacceptable for discharge to the Savage River, treatment is likely to be required, regardless of whether a cover is constructed or not.
- To the extent that a cover does reduce the rate at which the dump contents oxidise and contaminants leach out, this potentially increases the timeframe of ongoing contamination.

In summary, the capping of the historical dumps would not provide significant environmental benefit and could extend the period of environmental harm. However, it could be shown that capping does have the potential to have a significant impact on the economics of acid drainage remediation due to the potential for a major reduction in water flux and the physical infrastructure required to transport and treat seepage water. The proof of this behaviour is a very important part of the current consideration of water management and treatment options at the Savage River Mine with significant cost implications (Brett, 2006).

ABM dump design and operation

Australian Bulk Minerals had a good understanding of the ARD issue with the historic waste rock dumps and was therefore able to implement a disposal strategy to control the problem in the new dumps required for their operation. The strategy developed around three key features as follows:

- A rigorous rock classification system in the pit to assign waste classes.
- The development of "flow through dump" technology.
- The development of a practical capping process.

Rock type classification

The waste rock at Savage River has been identified as falling into four broad categories as follows:

A Type: Alkaline (non-acid forming – NAF) or very durable igneous rock.

B Type: Effectively neutral.

C Type: Clay or highly weathered rock.

D Type: Potentially acid forming (PAF).

The classification is undertaken by site geologists by inspection of drill cuttings from the blast holes in the pit prior to blasting. This classification is based on net acid generation (NAG) tests on rock types and from an assessment of the pyrite content. Following blasting, the geologists set up signage in the pit. The dumps are set up with similarly signed dump areas for strategic dumping of the various rock types. Training of operators in ARD issues has been very successful

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in ensuring compliance with the dump operations plan. The primary focus of the planning is to use "A type" for flow through construction as described later, or armouring and encapsulation of the "D type" PAF rock with clay.

Flow through dump technology

Due to the extremely rugged topography of the Savage River area, the siting of waste rock dumps is difficult and the main current waste rock dump, Broderick Creek Dump (Brett and Hutchison, 2003), has been developed in a valley adjacent to the northern pit of the mine. A "flow through" rockfill dam was used in the later stages of mining by previous operators to resolve erosion in Broderick Creek. This type of structure requires a free draining construction material with permeability consistent with the required flow capacity. Typically this has comprised rockfill, grading from 200 to 500 mm sized rock.

Broderick Creek has a catchment of 21.5 km^2 and a stream length of 12 km. The time of concentration has been estimated at 4 hours and 20 minutes. Average flow is approximately 0.7 cumecs. The initial flow through dam provided a permeable zone sized to cater for around 10 to 12 cumecs allowing pondage to develop upstream of the dam during peak flows. The total capacity of the dam allowed storage of a 1:500 year flood. An auxiliary spillway allowed overflow into the adjacent open cut pit during larger flood events.

By selecting only harder rock types and by controlling tipping and handling it was expected to produce a segregated coarse rockfill within the drainage zone with a maximum size of around 500 mm. The overall bulk permeability for this zone was expected to range from 0.2 to 0.4 m/sec with a void ratio of 0.85. During extreme flood events a head loss of around 50 m could develop over a flow length of approximately 150 m through the dam. This results in a hydraulic gradient of around 0.33 requiring a drain cross-sectional area of 160 m^2 to pass the design flow. In view of the uncertainty of exact permeabilities in the field situation, the design proposed a conservatively large permeable zone on the downstream side with the field testing during construction to determine the required nature of the "throttle zone". The downstream drain section was to be nominally 500 m^2 in area.

Approximately 4,200,000 t of rock was required to construct the initial "flow through dam" section of the dump resulting in a structure some 74 m above creek bed, completed by late 1994. The control of materials and placement had been carried out extremely effectively by the mining company and the permeable zone developed in accordance with design expectations. Rock in the "flow through zone" is almost exclusively carbonate-chlorite schist. The creek is flowing through the rockfill without any significant head build-up. A monitoring program set up to record head rise during higher flow events suggested a permeability in the range 0.5 to 1 m/sec which is in excess of design expectation.

ABM then developed a mine plan that covered over 20 years of mine life over the southern and northern ends of the previously mined areas. The plan resulted in the need to dispose of 200 million cubic metres of waste rock. This is a very significant quantity and poses real difficulty for disposal in the steep country in the vicinity of the mine pits. However, the success of the original "flow through" concept has allowed the development of an extended flow through zone under expanded dumps, which will span the complete breadth of Broderick Creek. As this will cater for the majority of planned waste rock disposal it has effectively made the mine viable.

The various rock types can be allocated into the dump zones, which allows

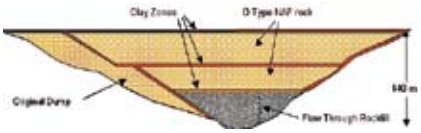

Figure 3 Cross section of Broderick Creek Dump

encapsulation of acid forming materials and a flow through zone in the creek bed.

Staged construction of the dump has taken into account the sources of rock available at any time, the need to maintain dump stability and the need to place hard, stable rock into flow through zones. Dump planning and operation needs to be necessarily flexible to allow strategic placement of available materials on a day-to-day basis. This has required commitment from management and attention to the training of operators. Waste placement plans are updated daily by mine geologists in accordance with predictions of the volumes of various classifications of waste to be moved.

ABM have maintained monitoring records of head loss and rainfall over the past few years which has shown an average hydraulic gradient of 1.1% and a characteristic permeability of 0.26 m/sec, given an effective area of 350 m^2 "flow through" zone.

Innovative clay capping system

Early designs for clay capping allowed for flattened dump batters, with a relatively thin compacted clay capping with soil overlay and revegetation. This proved problematical in practice with the high cost of reshaping dump faces, the difficulty in achieving compaction in the wet climate and erosion issues. This led ABM to develop a practical oxygen-limiting capping system involving dumping of a weathered rock ("clay") layer over the outer face of the D-type rock and stabilising this layer with a further layer of hard NAF (A-type) rockfill. Both the clay zone and A-type zones are 3-6 m thick and provide a significant barrier to oxygen flux even if the degree of saturation is below 80%. ABM use a relationship between the degree of saturation of the cover and its oxygen diffusion rate developed for them by Environmental Geochemistry International (EGi).

A field study has been set up on a section of cap on the western side of B dump to confirm the performance of

Figure 4 Broderick Creek Dump – rising 140 m above creek level

the cap system. The study was set up by trenching into the "clay" layer, measuring soil properties and physical dimensions, installing instrumentation and then completing the spreading of the A-type material. Instrumentation comprises moisture content and temperature monitoring equipment. The moisture content monitoring enables tracking of moisture content and degree of saturation to confirm the maintenance of sufficient saturation to prevent oxygen ingress. The temperature monitoring allows assessment of the extent of oxidation occurring. The installation site comprised a 15 m high face with the clay zone in place but the A-type final cover not yet placed. Two sites were instrumented with moisture probes and a third with temperature probes.

The cap material was found to comprise a well graded clayey gravel weathered rock and to be relatively loose at between 80 and 90% maximum dry density (standard), with initial moisture content of 10%–15% representing 60% saturation in both cases.

Saturation levels measured by the moisture probes ranged between 50 and 77% with the lower saturation levels corresponding to a higher level in the cap (i.e. closer to the surface).

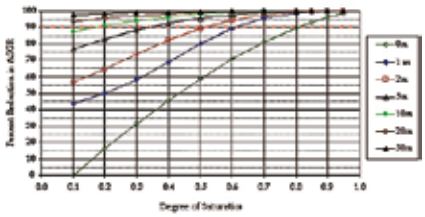

Figure 5 Reduction in acid sulphide generation rate for unsaturated soil covers (courtesy of Environmental Geochemistry International)

Field permeability testing indicated permeability was 10^{-7} m/sec.

The instruments have been installed and are working. The saturation levels in the cover material are consistently above 50% and typically above 60% at lower levels of the cap. Based on the Acid Sulphide Generation Rate (ASGR) chart presented by EGi these levels would reduce ASGR by in excess of 95%, confirming the effectiveness of the cover system. The Theta Probes appear to be presenting realistic results for volumetric moisture content. Monitoring of volumetric moisture levels will be used to confirm that the cap layer maintains adequate saturation levels over time.

Figure 6 Setting up the clay cap test site

Figure 7 Installing the Theta Probe moisture monitors

Conclusions

It is concluded that relatively simple construction techniques can be used to construct major waste rock dump structures that are environmentally stable and limit the risk of acid rock drainage impacts. However, a high level of commitment and field control is required by the construction personnel. In this case the flow through dump was instrumental in allowing economically viable mining and also the best practice environmental management of potentially acid producing waste rock. Similarly, a practical and effective capping system has been developed that suits the mines earthmoving operations. These techniques will ensure that the current mining operations do not leave legacies of degraded river systems as has been the case in the past.

Acknowledgement

The assistance of Australian Bulk Minerals in granting permission for the publication of this paper is acknowledged.

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David Brett, GHD Pty Ltd

First International Seminar on the Management of Rock Dumps, Stockpiles and Heap Leach Pads

5–7 March 2008, Novotel Langley Hotel, Perth, Western Australia

As mining practices result in deeper open pit and underground mines so does the need to effectively manage the resulting substantially sized rock dumps, stockpiles and heap leach pads. The potential harm that these landforms can cause to the surrounding ecosystems generates increased community concern. For industry to remain profitable and viable it must ensure that the management and rehabilitation of these landforms is proactive and responsible.

Rock Dumps 08 will provide industry with a forum to exchange views on the management of rock dumps, stockpiles and heap leach pads.

Seminar topics

- Slope failure.
- Environmental and rehabilitation issues.
- Landform modelling.
- Planning and economics.
- Acid mine drainage.
- Geochemistry.
- Hydrological implications.
- Backfill.
- Geosynthetics.

Key dates

Submission of abstract 1 October 2007

Planning for Stable Landforms workshop
4 March 2008

Rock Dumps 08 seminar
5–7 March 2008

For abstract submission details and event information, please visit www.rockdumps08.com

First Southern Hemisphere International Symposium on Rock Mechanics

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

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

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

SHIRMS will feature four main technical themes:

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

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

Key dates

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

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

For the first time, our region's rock mechanics researchers and practitioners from the different areas of earth science will meet to exchange ideas and lessons learnt, and to develop further collaboration and synergies

Challenges in deep and high stress mining

By Yves Potvin, director, Australian Centre for Geomechanics

Introduction

As the mining industry matures in many regions of the world and shallow reserves are being depleted, the future of the industry becomes increasingly dependant on its ability to exploit deep mineral resources safely and efficiently. The financial risks associated with deep and high stress mining is a concern to shareholders, but, more importantly, mining at an ever increasing depth and in higher stress environments often presents elevated risks to the workforce. Industry sustainability will undoubtedly demand innovations and excellence in mining practices. Therefore there is a strong requirement to build the engineering foundation for future deep and high stress mining. It is suggested that this process commenced well over a decade ago.

Addressing deep and high stress mining challenges

Since the late 1990s, there has been a concentrated effort to explore new technologies and address some of the ultra deep mining challenges in South Africa. Durrheim, 2002, describes the "DeepMine" and "FutureMine" collaborative research programme objectives as follows:

"The DeepMine Program was established in 1998 to develop the expertise and technology to mine gold safely and profitably at ultra-depth (3 to 5 km) in the Witwatersrand basin of South Africa."

"The DeepMine Program had a total budget of R66 million, a duration of four years, and covered a wide range of disciplines, including industrial sociology, physiology, mining and mechanical engineering, and the earth sciences. Over 250 researchers were involved."

"The FutureMine Program is the successor to the DeepMine Program. In an environment characterised by a volatile gold price, mature ore bodies and aging infrastructure, the gold mining companies recognized that the major challenges facing the industry are the reduction of working costs (from US$250/oz to US$170 oz or lower) and the improvement of health and safety."

The Canadian mining industry is also recognised for its deep underground mines and mining research efforts. Major research outcomes were produced from the Canadian rock mechanics research community in the 1990s. A comprehensive publication entitled "Canadian Rockburst Research Program 1990-1995" published by the CAMIRO Mining Division captured some of the important advances achieved during this landmark research project. In particular, the project addressed critical topics such as seismic monitoring, source mechanisms of mine seismicity, numerical modelling and ground support under dynamic loading condition.

During this period other Canadian research projects had a significant focus on developing mine automation with the objective to reduce workforce exposure to deep mining hazards while increasing productivity. Major mining houses such as INCO, Falconbridge and Noranda have been pursuing mine automation since the early 1990s.

Compared to Canada and South Africa mining has yet to reach significant depths in Australia, with the deepest mine delving around 1.5 km below surface. Nevertheless, many Australian mines are operating in conditions similar to deep South African and Canadian mines. This is due to the high stress and high temperature gradient existing in some regions of Australia.

The challenges of deep mining were fully realised in Australia towards the end of the 1990s, when several rockburst related fatalities occurred in the gold and nickel mines of Western Australia. These accidents triggered a rapid expansion of South African and Canadian microseismic monitoring technology. This is shown in Figure 1 which shows the progression in the number of operating seismic systems in Australia during recent years.

The ACG commenced the first phase of its "Mine Seismicity and Rockburst Research Project (MSRRP)" in the late 1990s in response to the rapid implementation of numerous seismic monitoring systems. This ongoing collaborative research programme is now in its eighth year of operation (third phase). A major outcome of this research is the "Mine Seismicity Risk Analysis Program (MS-RAP)"; a unique software designed to assist mine operators to address seismic risk. MS-RAP can manage seismic data, produce automated seismological analysis and reports, and generate seismic hazard maps and seismic risk maps, which can be updated continuously as more microseismic data is recorded.

Other Australian research initiatives directly relevant to deep mining challenges include the construction of a world class facility for dynamic testing of ground support by the Western Australian School

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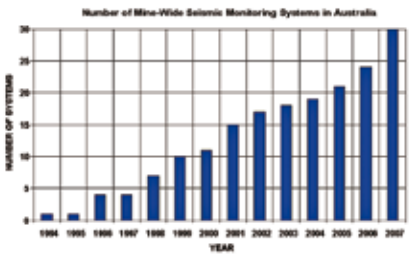


Figure 1 The number of mine-wide seismic systems operating in Australian mines since 1994 (after Heal PhD thesis; in preparation)

Continued from page 13

of Mines (WASM) in Kalgoorlie. WASM has also developed a very successful acoustic emission stress measurement research programme. The CSIRO has contributed to providing deep mining solutions through their comprehensive mine automation research programme operating since the late 1990s.

What is a deep mine and what is a high stress mine?

It is well known that in situ rock stress increases with depth. As such, it is expected that deep mines will generally operate in high stress environments. However, this relationship between stress and depth is neither simple nor consistent. The magnitude and orientation of the horizontal stress components in particular can vary widely within continents, regions and even within relatively small locations. There have been numerous relationships published between stress and depth, generally from compilation of stress measurement data from different regions of the world. There is a clear trend of stress increasing with depth. The high variability of the horizontal stress, however, may result in relatively shallow mines in some areas of the world experiencing stress conditions that are similar to deep mines. This has been observed extensively in many Western Australian gold and nickel mines.

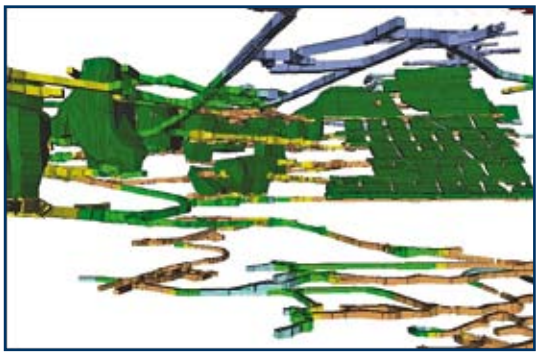
Apart from the South African gold mines, which are amongst the deepest in the world, very few mines operate at depth below 3,000 m. A number of Canadian mines and perhaps a few other operations elsewhere in the world are currently mining at a depth of between 2,000 and 3,000 m.

Mining at depth and in higher stress environments often present elevated risks to the workforce

Unlike mining depth, which is readily measured, it is not so easy to define a criterion to classify whether a mine is operating in a high stress environment. As mentioned before there is a complex relationship between depth and stress and therefore, stress alone is certainly not an acceptable "deep mine" criterion. Even using the stress magnitude is insufficient to classify mines as being in a high stress environment. For example, mines operating in a relatively high stress field may experience very little problems if the rock mass is competent and capable of carrying high loads. Such mines would not likely be considered high stress mines. Other mines with similar stress fields and poor rock conditions may in turn experience excessive failures and difficult conditions. They would naturally be classified as high stress mines. It is therefore the combination of the level of stress and the capacity of the rock mass to carry it that will define the "operating stress environment".

There is no recognised criteria that defines high stress mines but it is suggested that when mines experience stress driven failures in a significant proportion of their excavations they will generally be considered as operating in a high stress environment. Common threads of deep and high stress conditions generally include one or more of the following responses:

- A layer of shattered ground around excavations.
- Significant convergence.
- Ground support failures and frequent rehabilitation.
- Blastholes closure.
- Significant level of seismicity.
- Significant ventilation and refrigeration requirement.



The seismic hazard mapping technique in the ACG's MS-RAP programme provides a significant step forward for seismic data analysis in mines

Conclusion

Deep and high stress mining poses a number of formidable challenges. The ACG is currently developing a publication entitled "Challenges in Deep and High Stress Mining". This book will be the end result of a concerted effort undertaken by a large pool of authors to document industry state-of-the-art responses to these challenges. This special deep and high stress mining volume is a unique compilation of papers published at the three biennial international seminars held on this topic: Perth (November 2002), Johannesburg (February 2004), and Quebec City (October 2006). Although most of the articles originate from Australia, South Africa and Canada, the applicability of the book is nevertheless relevant to world wide deep and high stress mining challenges. *Challenges in Deep and High Stress Mining* is expected to be launched at the 4th International Seminar on Deep and High Stress Mining to be held in Perth in November 2007.

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Seeking industry sponsorship

The ACG is pleased to provide an opportunity for the major mining houses and service providers to sponsor our "Challenges in Deep and High Stress" publication. Sponsoring service providers will be listed in a "service directory", thus providing a ready reference to potential users. This directory will enable sponsors to have a valuable association with industry's increasing awareness of deep and high stress mining challenges. It is tended that all registered Deep and High Stress Mining 2007 attendees will receive a copy of this new publication. Please contact Christine Neskudla via acg@acg.uwa.edu.au for the sponsorship

Yves Potvin, ACG director and Dan Heal, project leader – Mine Seismicity and Rockburst Risk Management

Fourth International Seminar on Deep and High Stress Mining

7–9 November 2007, Novotel Langley Hotel, Perth, Western Australia

Mine seismicity and rockbursting have been traditionally associated with accidents and fatalities. As mines go deeper, so increases the challenge to provide a safer working environment, whilst ensuring the commercial viability of mines. Industry's future success is dependent on its capacity to adapt to this rapid evolution and implement the appropriate proactive measures and changes in mining.

In 2002, the ACG initiated a very successful series of seminars to provide a forum for industry to share its experiences and knowledge of mining in deep and high stress conditions. Following the South African and Canadian seminars, the ACG is delighted to host in Australia the Deep Mining 2007.

Attend the seminar and learn about:

- Numerical modelling.
- Rock behaviour under high stress.
- Rockburst and seismic monitoring.
- Ground support.
- Case studies.

Why should you attend?

- Your company's success may depend on its ability to proactively address the geotechnical challenges arising from deep mining activity.
- Gain knowledge of the ground support measures that best address rockburst and high stress disturbances to the rock mass.

Visit www.deepmining07.com for the preliminary seminar programme and for up-to-date event information.

Pre-seminar events

Hydraulic and Paste Backfill Seminar

5 November 2007
Novotel Langley Hotel

This one-day seminar will provide an introduction to the selection of an appropriate backfill system, and includes aspects such as choosing a relevant delivery system, deciding on applicable strength and how to achieve it, and steps to the correct design of barricades.

Managing Mine Seismicity Short Course

6 November 2007
Novotel Langley Hotel

The short course will equip attendees with the essential information to understand the capabilities and limitations of this rapidly evolving technology. It will cover introductory topics regarding mine seismicity, seismic monitoring and rockbursts, as well as techniques for managing seismic risks.

As more and more mines are driven to greater depths, it is necessary to identify the technologies that will facilitate safe and cost effective mining

Monitoring — a tool for design

By Johan Wesseloo, project leader, Australian Centre for Geomechanics

Quantifying the stability of rock slopes has, for many decades, been a source of headaches for rock slope engineers. It was with some surprise that the mining community faced the first large rock slope failures and the question: "How can rock that is strong be so weak?" sparked the very valuable research into the scale effects of rock mass strength and the effect of structures on the mechanical behaviour of the rock mass.

The rock mechanics community has come a long way since, and undoubtedly has developed a far greater understanding of *why* the rock masses behaviour is different to the tested rock sample. However, rock mass behaviour is very complex and as laboratory testing can only be performed on the rock material and not on the rock mass, we still struggle with quantifying the strength and deformational behaviour of the rock mass. Deciding on the appropriate constitutive model and associated parameters for quantifying the stability of rock slopes is still a very difficult and highly contentious issue – especially in the mining industry where undue conservatism is regarded as treason.

For some years now, it has been argued that the stability of the slope is not the most important issue, as stability has no intrinsic value. The important issue that should govern the design is safety and economic risk. This has, in the last decade or so, resulted in the focus of the slope design moving from the stability of the slope to the minimisation of safety risk and the optimisation of the economic risk-reward model.

This shift in the focus of the slope design, however, does not imply that the quantification of slope stability is less important. On the contrary, as it forms the backbone of the risk-reward analyses, the quantification of the stability of the slope is even more important than ever; poor stability assessment results in poor risk assessment and an ignorance of the true risk levels associated with the mine design.

The risk-reward design of mining rock slopes has one very important advantage, it forces the slope designer to communicate the design to management in a language that they are familiar with and it forces management to *accept and own* the risks associated with the rock slope. It does, however, place another stone in the shoe of the slope designers, that of the time dependent strength of rock masses. Current methods available to the rock slope engineers are time independent, while the economic evaluations are, by nature, time dependent. This is also true of the acceptance criteria for safety, and bridging the gap between the time independent and time dependent

The Design Cycle

domains is often done by making some awkward assumptions. One such assumption for instance is assuming the calculated probability of failure to be equal to the *yearly* probability of failure.

The importance of understanding the time dependent nature of rock masses stands in direct contrast to the little attention this issue receives, no doubt because of the difficulties associated with addressing it. As the economic depth of open pit mining increases, and with it, the design life of the slopes, this issue is becoming more important. Our lack in understanding the time dependent behaviour of the rock mass has hindered our understanding of the development of failure mechanisms and our general understanding of the stability of rock slopes. Most back analyses of failed slopes are performed as time independent events and often the mechanisms involved in the development of failure are unknown.

This somewhat bleak picture was sketched for the purpose of highlighting the importance of slope monitoring. Monitoring should form part of the design and the design should not be considered final until the desired structure is completed. This of course is the basic principle underlying the observational method of geotechnical design. The important link in the observational method often neglected in mining rock slope engineering is the closing of the loop, i.e. continually feeding the monitoring results back into the stability assessment process to:

- Reassess our understanding of the rock mass behaviour.
- Update current design models and assumptions.
- Update assessments of the stability and associated risk and, if necessary.
- Timeously make changes to the design.

Slope monitoring in open pit mines is generally designed and utilised for the purpose of the short-term management of slope instability with little attention being paid to understanding the failure mechanisms, updating the geotechnical model and enhancing the understanding of the rock mass behaviour. The monitoring is focussed only on the problem area, and then, only after the problem has already developed. Although this focussing of attention is certainly understandable and prudent, neglecting to use the monitoring systems for the purposes described above should not be allowed.

The carefully designed monitoring system will, apart from being a short-term management tool, also provide a tool for long-term management and allow better management of risk as it provides a platform for enhancing the understanding of the rock mass behaviour of the slope.

Johan Wesseloo
project leader – High Resolution Seismic Monitoring in Open Pit Mines

Johan joined the ACG in February 2007 after working as a geotechnical engineer with SRK Consulting, South Africa.

ACG board of management update

Farewell to a champion chairman

Andrew Grubb retires as ACG chairman

May 2007 saw the departure of ACG chairman Mr Andrew Grubb to a new, challenging position in Russia. Andrew has taken on a senior role in a strategic alliance between Polymetal, Russia, and AngloGold Ashanti, South Africa, based in St. Petersburg. Andrew's efforts as ACG chairman will be greatly missed and the ACG team and directorate extend their sincere appreciation to Andrew for his tremendous contribution to the operation of the centre.

Introducing our new chairperson

Ian Suckling, our new chairman

Mr Ian Suckling, director of Mining, Newmont Asia Pacific, who has been an industry member on the ACG Board since September 2005 was recently appointed the ACG's chairman. The ACG team and directorate welcome Ian to this role.

The Curtin University of Technology joint venture partner representative, associate professor Graeme Wright, previously executive dean, Division of Resources & Environment of Curtin University of Technology, has also resigned from the ACG Board of Management due to his appointment as director, Strategic Projects, Office of Research Development. Graeme has been replaced by associate professor Ian Fitzsimons, head, Department of Geology, Curtin University of Technology, who will be temporarily representing Curtin University until the new director of the WA School of Mines is appointed. The ACG team and directorate thank Graeme for his contribution.

The ACG board of management - I. Suckling (chair), M. Adams, M. Bush, S. Harvey, C. Neskudla, Y. Potvin and I. Fitzsimons

Slope Stability 2007 digs deep in Perth

The widespread challenges of monitoring and managing rock slope stability in open pit mines and civil engineering will be addressed by the international mining and civil engineering industries at the 2007 International Symposium on Rock Slope Stability in Open Pit Mining and Civil Engineering to be held at the Sheraton Perth Hotel, Perth, 12–14 September 2007.

Presented by the ACG, for the first time in Australia a range of targeted slope stability issues will be explored in an international forum.

A major engineering challenge in open pit mining is the design and management of rock slopes. The recent industry trend is to aim for open pit slopes that are deeper and steeper. This approach not only increases the financial reward of the mining projects, it also increases the geotechnical risks. Inadequate design and poor management of rock slopes can lead to unexpected slope failure and rockfalls with consequences that can be catastrophic in terms of mine safety and viability.

Slope Stability's technical programme will feature comprehensive and highly relevant papers emphasising innovations and the application of state-of-the-art technologies and monitoring and management strategies from around the world. More than 40 papers from leading local and international slope stability practitioners and strategists will be presented at this Australian-first event.

Symposium Sponsors

Major Sponsors

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RIO TINTO

Slope Stability 07 will examine the latest rock slope stability developments from throughout the world. Photo courtesy of Argyle Diamond Mines

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ADAM Technology

Geofabrics Australasia Pty Ltd

Maccaferri

GroundProbe

Rock Engineering

Slope Stability will take place concurrently with The AusIMM's Large Open Pit Conference to be held at the Sheraton Perth Hotel, 10–11 September 2007.

AusIMM Australasian Institute of Mining & Metallurgy

Slope Monitoring Forum

11 September 2007
Sheraton Perth Hotel

A one-day pre-symposium forum will explore existing and emerging slope monitoring technologies and, more specifically, discuss the strengths and weaknesses and applicability of monitoring systems such as digital photogrammetry, laser, radar and seismic monitoring applied to slope stability. The forum will also review commercial and R & D technologies.

Visit www.slopestability07.com for more information.

MINECLOSURE 2007

The growing importance of mine closure in the mining industry

ACG AUSTRALIAN CENTRE FOR GEOMECHANICS

CSIRO | Curtin University | University of WA Joint Venture

The University of Western Australia

CENTRE FOR LAND REHABILITATION

More than 150 abstracts were submitted to the Second International Seminar on Mine Closure organised by the ACG in collaboration with the Centre for Land Rehabilitation, The University of Western Australia, and Gecamin, Chile. This excellent response indicates the high interest which exists all around the world in this very important topic.

The closure challenge, when the mine has reached the end of its economic life, is becoming increasingly relevant for many mining companies. This is caused not only by increasingly stringent regulations applied by different countries, but is also due to industry's motivation to obtain higher health, safety and environment standards.

The mining industry has endorsed this commitment, fully aware that extractive activity can produce important environmental impacts. "Ore extraction produces impacts: it is like an elephant that cannot go walking without leaving tracks. We must minimise this, leaving the place, once production activity ends, almost equal as it was at the beginning: it's our responsibility" says Kenneth Pickering, vice president of Major Growth Projects, Technology & Closed Mines, Base Metals Group, BHP Billiton, and Chairman of Mine Closure 2007.

Today, closure programmes are part of any new mine planning. "If really, as miners, we cannot extract the resources without producing great damage to the environment, we cannot go ahead with the project. That's the idea", admits Pickering. However, that was not always the case in the past and mines which are now facing the stage of closure are mines from another time; 50 to 70 years ago. "That's where we find most of the closure problems", said Pickering.

The Mine Closure 2007 team

In the last 10 to 15 years an important process of integration and acquisition of companies occurred in the world mining industry. As a result, big companies such as Rio Tinto, Anglo American, Barrick, BHP Billiton and Newmont are today the visible faces of other older mining companies due to this fusion process. "We have inheritances of old mines which we are now closing and monitoring", says Pickering.

A good example is the closure programme of El Indio Gold Mine in Chile. El Indio was acquired by Barrick from Lac Minerals Ltd (Toronto) in 1994 and closed by Barrick in 2002. Barrick's subsidiary, Compañía Minera El Indio committed to an ambitious and comprehensive closure plan at the site under a voluntary agreement with Chilean authorities and invested more than US$ 50 million in closure activities and monitoring. El Indio is one of the site tours proposed during Mine Closure 2007.

This frame of "inherited" responsibilities, as part of the fusion and acquisition processes in the mining industry, has also resulted in some instances where the new controlling company must take on the responsibility to treat an old closed mine that is no longer part of the property but due to contract commitments requires ongoing site monitoring and treatment obligation.

continued page 20

Continued from page 19

In some cases, the cost of closure and ongoing control and monitoring is more than all the utilities produced during the production stage, so "it would have been better if the mine had never opened".

For this reason, in the design and construction of a new mining project or extensions of existing mines, every aspect that could produce an impact on the environment or neighbouring community must be evaluated, analysed and minimised. "But in the case of inherited mines, we cannot do that; we must advise and remediate on the best way" concludes Pickering.

Social impact

Social impact is another important issue to be considered. Twentieth century history has been marked by important social conflicts related to mine closure. The closure of many underground coal mines in Western Europe is an example of this. After World War II, numerous workers from Mediterranean countries moved to northern Europe (Holland, Belgium, France) attracted by higher salaries and the promise of a better life. This resulted in a labour force responsible for the intensive development of deep coal deposits. In the 1970s and 80s the high cost of coal extraction forced most Western European countries to close their coal mines. However, in some instances, closure was suspended during these years due to the high social cost of closure. A similar process took place in Chile in 1997 with the closure of Lota's coal mine.

Mine closure has also marked the social history of Chile during the past century. The nitrate mining industry, which once employed more than 45,000 workers, almost disappeared in the 1940s following the discovery of the synthetic nitrate process. In 2007 Chile remembers the School of Santa Maria de Iquique tragedy. At the end of 1907, nitrate mining workers living with their families in desert mining camps (called "oficinas") went on strike seeking better living conditions. They moved to Iquique, the main town on the North coast of Chile, where strike headquarters were established at the Santa Maria School. Approximately 4,500 strikers and supporters were housed in the school and another 1,500 camped in tents around the square. The army was called in and martial law was declared. Stores were locked and on December 21st at 3.45pm the slaughter began. The first to be shot were the committee members. Chilean, Argentinean, Peruvian, Bolivian and European workers were slain, along with their wives and children, with astonishing ruthlessness. The number of victims was estimated at 3600.

In regions where mining represents the main economic activity, mine closure activities have important social consequences that affect the whole community. A closure programme must be responsibly established to minimise its potential negative impacts. This is one of the main challenges to be faced by the El Salvador Division of Codelco Chile with the announced closure of its extractive activities in 2011. In the 1950s a unique town was built in the middle of the desert, near the mine. The town provides services and comfort to workers and their families. It once counted more than 15,000 inhabitants and today has a population of about 7,000. The destiny of this singular town is a challenge for El Salvador Mine closure ambitions.

Mine Closure 2007

The Second International Seminar on Mine Closure will be held from 16 to 19 October 2007 in Santiago, Chile. The seminar will cover a wide range of mine closure related problems and feature a number of specialists from very different disciplines.
Further details are available from www.mineclosure2007.com.

Please contact Irene at the ACG to order a copy of the First International Seminar on Mine Closure Proceedings (Perth, September 2006) or for information about our other mine closure publications.

Higher expectations of better environmental protection, attempts to further reduce human health risks, competition for land and the increasing value of the natural environment as the recreational space have led to marked improvements in regulatory requirements and mining practices in a number of countries

Rheology in the mining industry

By Paul Slatter, professor and head: Flow Process Research Centre, Cape Peninsula University of Technology, South Africa

Mine tailings becomes a very thick and viscous material at high concentration. Given the current pressures to use less water, and operate thickeners, slurry pumping lines and tailings disposal sites at higher concentration, it is critically important to understand the way in which the material's viscosity influences its behaviour.

Sir Isaac Newton was one of the first to describe the way in which fluids flow, and how this is affected by their viscosity. He suggested that we divide the flow into thin imaginary layers or *laminae*, and flows which approach this behaviour in practice are called laminar. The rate at which these layers increase in velocity over each other, is referred to as the shear rate. Newton hypothesised that for a perfectly viscous fluid, the shear rate would be directly proportional to the applied shear stress, and viscosity – the ratio between shear stress and shear rate – would be constant. For non-Newtonian materials, viscosity is not constant, and changes with shear rate open up the way for the science of rheology.

Rheology is that branch of science and technology which deals with the way in which materials deform and flow, when subjected to external forces. It is a relatively new discipline – the word "rheology" was coined less than eighty years ago by Professor Eugene Bingham, directly from the Greek words *rheos*=flow and *logos*=knowledge. Part of the reason that this subject area needed to be developed arises from a rather convenient half-truth prevalent in elementary school science – "all matter consists of solid, liquid and gas". The fuller truth is that as we delve deeper into what exactly a liquid or a solid is, we find that there is a rather grey area between them. There are many materials, such as toothpaste, paint, wet concrete and mine tailings, which fit on a spectrum somewhere between Hooke's law of perfectly elastic solids, and Newton's law of perfectly viscous fluids. Most real materials possess some of the properties that we normally associate with solids, and yet are able to flow.

One of the first attempts to describe this type of behaviour was developed by Bingham himself, and is called the Bingham plastic model in his honour. This is now one of a large family of so-called "visco-plastic" models, and is often used to describe the behaviour of mine tailings – at least as a first approximation.

Typical Bingham plastic behaviour is portrayed in Figure 1, on logarithmic axes.

At infinitely low shear rates, the material behaves as a Hookean solid, and at infinitely high shear rates, the material behaves as a Newtonian liquid, with constant viscosity. Because the viscosity decreases as we move to the right in Figure 1, these materials are also referred to as "shear thinning". The most important feature of Figure 1 is the boundary shear rate. At shear rates below the boundary shear rate, the behaviour is dominated by the yield stress. At shear rates above the boundary shear rate, the influence of the yield stress diminishes rapidly, and viscosity quickly approaches a constant value equal to the plastic viscosity. Constant viscosity, by definition, implies Newtonian behaviour.

The boundary shear rate is extremely sensitive to several material properties, and solids concentration is one of the most important. What happens is that the yield stress rises exponentially with concentration, rapidly pushing the boundary shear rate to the right in Figure 1. This has profound practical implications, because industrial flow processes usually occur at fairly standard, predictable and fixed ranges of shear rates. This means that flow behaviour, which occurs at a given fixed range of nominal shear rates – such as flow in a pipe, can be virtually Newtonian at low concentrations. This quickly becomes non-Newtonian as concentration is increased, and behaviour is increasingly dominated by the yield stress.

For engineering purposes, it is necessary to determine values of the yield stress and plastic viscosity. Traditionally, this is done by measuring the viscosity of a sample of the material over an appropriate range of shear rates. A graph similar to Figure 1 is then constructed and these rheological parameters extracted. A range of rheometers and associated computer

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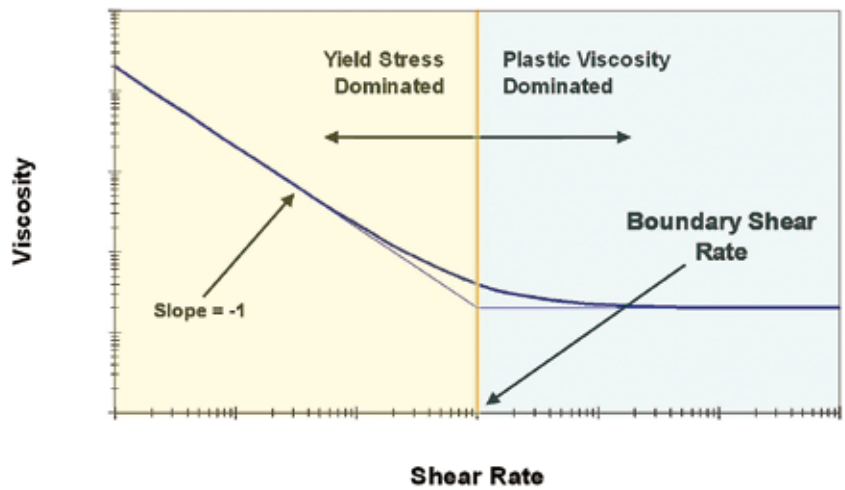

Figure 1 Typical Bingham plastic behaviour, on logarithmic axes

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software to perform this function are commercially available. More recently, independent methods of determining the yield stress have been developed, and the slump test is one of these. This test is particularly attractive in the context of thickened mine tailings, as the test can be performed easily on site. Although this test will only obtain a value for the yield stress, and not the plastic viscosity, this information is valuable for a flow process where shear rates are below the boundary shear rate.

For flow processes where shear rates are above the boundary shear rate, the behaviour approaches that of a Newtonian fluid, and well established design and operating protocols can be used. However, for flow processes where shear rates fall below the boundary shear rate, it is a case of "work in progress". Researchers and engineers are still grappling with the manner in which the yield stress influences the flow behaviour at shear rates that are below the boundary shear rate. The state of knowledge in this area is consistently improving with time, and it is important for those responsible for designing and operating tailings thickening and pumping plants, and disposal sites, to remain abreast of recent developments.

In summary, unless the viscosity of the material is known, it is not possible to thicken, pump or place the material in a reliable and predictable manner. Rheology is the tool that provides insight into the viscous behaviour of these materials which are neither solid nor liquid, but somewhere in between.

For further information please contact Paul Slatter via slatterp@cput.ac.za.

Paul Slatter, Flow Research Centre, Cape Peninsula University of Technology, South Africa

First International Symposium on Block and Sub-Level Caving, Cave Mining

8–11 October 2007, Cape Town, South Africa

Block and sublevel caving are mining methods that have been used for many years. Two of the largest underground mines in the world (by tonnage), El Teniente Mine in Chile and LKAB in Sweden are well established users of these methods. Recently, these methods have been increasing in importance as many open pit mining operations of massive orebodies are reaching their economic mining depth. Any continuity of operations has to consider underground operations if they wish to remain viable. Palabora, Cullinan and Finsch mines in South Africa are examples of current block caves that followed successful open pit operations, and planning is in progress for caving at Chuquicamata mine in Chile after the pit has reached its economic depth. Caving methods offer an attractive solution since they are low cost, high producers. In fact, production from block caving operations can rival that from open pits in some cases. Recent increased levels of mining, particularly in the base metals field (which involves massive mining), to satisfy the demand for minerals from China and India, has added to the renewed focus on caving methods.

This symposium is being organised as the first in a series of specialist symposia, dealing specifically with caving methods of mining. Quite rapid advances in the state-of-the-art of caving are being made, influenced by mechanisation and automation, improved monitoring methods such as seismic monitoring, and more capable numerical analysis methods, and the aim is to capture this specific knowledge on a regular basis.

The series of symposia are being organised under the auspices of the University of the Witwatersrand in South Africa, the Australian Centre for Geomechanics, the Universidad de los Andes in Chile and Laval University in Canada. There will not be a specialist symposium in 2008 since the series has been planned so as not to interfere with the MassMin Symposia, which are held at four year intervals and deal with the whole field of massive mining; the next being in 2008 in Sweden/Finland.

The beautiful city of Cape Town has proven to be an excellent venue for the symposium, and a wonderful location for technical and social interchange. The event is being organised through the Southern African Institute of Mining and Metallurgy (SAIMM) and information is available from www.saimm.co.za.

Caving methods present mining companies with a cost effective solution; they are low cost, high tonnage producers

Paste 2008 heads to South Africa

By Angus Paterson, director, Paterson & Cooke Consulting Engineers Pty Ltd, South Africa

It has been four years since the series of International Seminars on Paste and Thickened Tailings has been to South Africa. The last event was held in Cape Town in 2004. In May 2008 we are excited to be hosting the Eleventh International Seminar on Paste and Thickened Tailings in Botswana. Botswana is home to the world's largest diamond mines that contribute to nearly 33% of the country's Gross Domestic Product. With such a large contribution to the economy comes a strong commitment to long term sustainability and responsible mining. This is evident in the tremendous work that Debswana, a De Beers and Botswana government joint venture, has been doing in evaluating the impacts of diamond mining on water resources in a naturally arid country.

The objective of hosting this seminar in Botswana is to emphasise the importance of responsible water usage in arid regions. Botswana has invested in numerous water related projects over the years and water scarcity is a reality being dealt with on many fronts. The national water strategy guides the individual projects in the country and also predicts future water availability to ensure sustainable development of the country and the region. In a country that has unique natural resources such as the Okavango Delta, Makgadikgadi pans, the Kalahari Desert, and a small tropical area around the Zambezi River, as well as the persistent drought situation, this seminar will be of key national importance.
As an example, Paste 2008 will be hosted in a lush tropical area, surrounded by the arid Kalahari Desert. For this event, the following are envisaged:

- Over and above the paste and high density tailings papers normally presented on preparation, transport and placement, papers on water scarcity and global warming challenges in the world and how these are being managed will be of significant importance.
- International attendees will become aware of the challenges and successes in Botswana, and will be able to take these lessons back to their countries.
- Meaningful discussions and input from different perspectives will enrich the ability to solve specific problems regardless of location or source.
- The importance of harmony between resource development and nature will be emphasised at this seminar.
- Legislators are increasingly taking note of the environmental impact of resource development and will also participate.

In order to generate discussion and debate prior to the event, we will attempt to test the waters on different emerging issues on environmental management, legislation and other related issues through polls on www.paste08.com. We invite feedback and discussions in the months leading up to the seminar, and then the emerging issues will be used for workshop sessions at Paste 2008.

Venue

The seminar will be held in Kasane, on the banks of the famous Chobe River. As before, the first day of the event will be a workshop focusing on the environment and issues that need to be addressed for long term sustainability.

Site visit

The site visit will be to Orapa Diamond Mine, the second largest diamond mine in the world that has been operating since 1971. Orapa mine runs two plants treating up to 18 million tons of ore, producing approximately 17 million carats per year. The visitors will have the opportunity to see the huge mining operations as well as the two operating plants, a site for a future replacement plant to be commissioned in 2011, and work on paste thickening and residue dewatering investigations.

Key dates

Abstracts for this event are due on 30 August 2007, with final papers due on 2 January 2008. Visit www.paste08.com for further details.

The Paste 2008 seminar themes are expanded to address water scarcity and global warming challenges

ACG 2007–2008 Event Schedule*

Title	Place/Date
Blasting for Stable Slopes	Perth, 30–31 August 2007
Slope Monitoring Forum	Perth, 11 September 2007
International Symposium on Rock Slope Stability in Open Pit Mining and Civil Engineering	Perth, 12–14 September 2007
Hydraulic and Paste Backfill Seminar	Perth, 5 November 2007
Mine Seismicity Short Course	Perth, 6 November 2007
Fourth International Seminar on Deep and High Stress Mining	Perth, 7–9 November 2007
Practical Soil Mechanics in Mining Short Course	Perth, 4 December 2007
Total Tailings Management Seminar	Perth, 5–7 December 2007
Planning for Stable Landforms Workshop	Perth, 4 March 2008
First International Seminar on the Management of Rock Dumps, Stockpiles and Heap Leach Pads	Perth, 5–7 March 2008
Ground Support in Mining Short Course	Perth, 6–9 May 2008
Ground Control for Underground Operators Short Course	Launceston, 17 April 2008
Coal Tailings Impoundments: Risks, Responses and Alternatives Seminar	Sydney, 14–15 May 2008
Open Pit Slope Stability Short Course	Perth, 24–25 July 2008
From Rock Mass to Rock Model Workshop	Perth, 15 September 2008
First Southern Hemisphere International Rock Mechanics Symposium	Perth, 16–19 September 2008
Blasting for Stable Slopes Short Course	Perth, 23–24 October 2008
Underground Blasting Short Course (One-day Development Blasting, and one-day Stope Blasting)	Perth, 4–5 November 2008
Mining Methods Seminar (Caving, Open Stoping, Narrow Vein Mining and Open Pit to Underground Transition)	Perth, 6–7 November 2008
Tailings Management for Decision Makers Seminar	Perth, 3–4 December 2008

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

Tailings – From Concept to Closure

A training DVD for owners and operators of tailings storage facilities

This new ACG training DVD provides guidance to personnel involved in the management and operation of tailings storage facilities that will facilitate the adoption of accepted best practices for the management of mine tailings.

Topics include:

- Overview of tailings facilities types and construction methods used in various industries.
- Integrating operations into the tailings management Life Cycle.
- Risk management and geotechnical issues in tailings disposal.
- Potential modes of failure of tailings storage facilities.
- Operations Manual requirements.
- Current best practice and emerging technologies.

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