

ADVANCED NUMERICAL MODELLING FOR MINING PROJECTS

John Albrecht

Geomechanics is a key component of most mining studies, and numerical modelling is increasingly used in conjunction with empirical techniques and site experience to assess geotechnical issues. Proper assessment of geotechnical issues is an essential part of mine optimisation and risk management.

For all but the simplest problem geometries, a mine scale three dimensional model is required to reliably represent the mining geometry and site investigation data. For cases where significant rock mass yield is expected and a simple elastic assessment is no longer appropriate, a more advanced "inelastic" or more specifically "elasto-plastic" model is required.

However the difficulty with elasto-plastic models is the requirement for more input parameters, many of which cannot be measured or even reliably estimated or verified. Such difficulties have long been known and twenty years ago the insightful paper by Starfield and Cundall (1988) on modelling methodology recommended a staged approach, where the initial model should be as simple as possible, while still answering the underlying rock mechanics questions posed by the problem. Even with the improvements in computational efficiency and to solids modelling capabilities seen in recent years, it is easy to spend large sums building large and sometimes unnecessarily complex models, which may not provide a better answer than a simple elastic model. Also, additional complexity can actually reduce the reliability of numerical models.

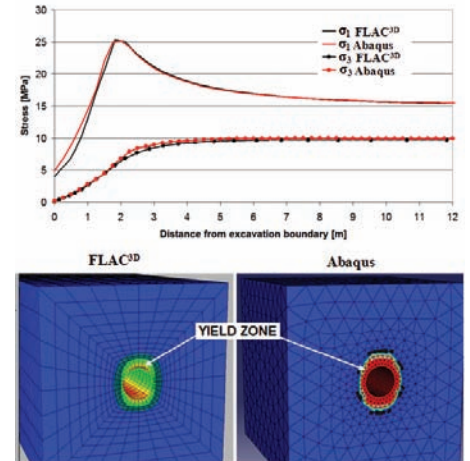
With the above issues in mind, AMC uses a wide range of numerical tools, including FLAC^{3D}, 3DEC, Map3D, and most recently Abaqus. Over the last 18 months AMC, in association with the University of New South Wales and SIMULIA Australia, has developed our Abaqus software capability. This follows increased interest and demand by the mining industry for application of the finite element method.

AMC is now one of a small number of mining consultancies offering a diverse range of elastic and inelastic modelling capabilities. An important part of our capabilities is having available a number of different software codes that allows us to compare modelling results between codes to give greater confidence that the model results are correct. By not being limited to one particular package, AMC can give objective advice about which code best meets the requirements of the project.

To ensure that the Abaqus software was appropriate for mining rock mechanics problems, AMC carried out extensive modelling trials prior to commercial use of the software. As part of the

software testing, the modelling results for a number of simple excavation geometries were compared using FLAC^{3D} and Abaqus software. The following figures illustrate a simple test conducted by AMC.

Comparison of FLAC^{3D} and Abaqus modelling results for a simple excavation shape



This process of 'validation' or verification of modelling codes is a basic but important step when new software is being assessed for its suitability for an application where other codes have demonstrated their capabilities. For the majority of problems assessed in the trial assessment, Abaqus produced comparable results to other codes.

However the current version of the software does not include a tensile cut-off for the Mohr-Coulomb yield surface, nor is the Mohr-Coulomb model available in the explicit version of the code. While the software allows for the development of user defined constitutive relations, the current geomechanical constitutive models available in Abaqus are not considered appropriate for most mining situations where the limiting tensile strength of the rock has a significant influence on modelling results. As such, AMC is working with UNSW and the developers of Abaqus to update the currently available constitutive models to develop mining specific user routines which are more appropriate for mining rock mechanics problems.

Applications where AMC have already applied Abaqus software include:

- Surface subsidence modelling and assessment of surface displacements at critical infrastructure locations at caving operations
- Undercut and extraction level design for block caving operations
- Assessment of cavability for block and sub-level caving operations
- Pit wall stability assessment for a large open pit

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OPTICAL AND ACOUSTIC TELEVIEWERS – EXTRA TOOLS TO DEFINE THE ROCK MASS

Andrew Weir

Introduction

Operational tempo often prevents mine geotechnical engineers from researching and trialing new techniques – sometimes even those that may save time, money and increase understanding of the rock mass. AMC recognises this conundrum and provides this article as a ready reference describing optical and acoustic televiewers (OTV and ATV) and the conditions in which they may be used.

Underground geotechnical investigation is typically centered on diamond drilling and the examination of core. Significant sums of money are spent on triple tube, oriented drilling techniques to locate and identify geological features in order to characterise the rock mass for design purposes. The irony is that the areas of most interest, the zones poor ground, do not allow orientation of discontinuities and typically the core delivered for logging is more broken than the in situ material.

The OTV and ATV provide a tool with which to complement data obtained through oriented drilling.

The Televiewer

OTV and ATV provide a magnetically oriented, 360 degree image of a borehole wall. Images are typically displayed as an “unfolded” drill hole projection that has been split along the north line as shown in Figure 1.

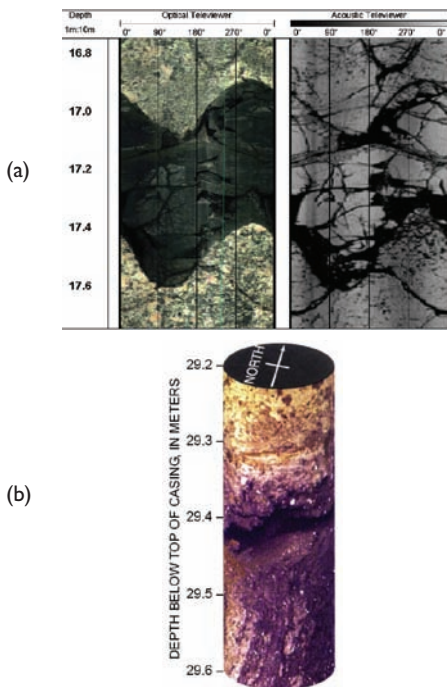


Figure 1: Televiewer results – (a) OTV (left) and ATV images showing diorite dyke cutting through granite; (b) virtual core showing fracture at the contact between pegmatite and gneiss.

OTV use a digital camera that allows direct viewing of a 360 degree slice of the drill hole wall, creating a high resolution, colour image. The image can be used to identify features such as fracture

orientation, lithology, infill, alteration and oxidation.

Resolution is system dependent, but common vertical and horizontal resolutions are 0.5, 1 or 2mm and 180, 360 or 720 pixels per line respectively. Logging rates are of the order of 1–3 metres per minute. OTV surveys at Diavik Mine resolved fractures as narrow as 1mm with radial resolution of 1°.

OTV probes collect images in air or clear water filled holes. Their use is limited by turbidity of drill fluid and surface coating on hole walls. Probes range 1.4–2.8m in length and 40–50mm in diameter.

The ATV measures the reflection of an ultrasonic source from the wall of the hole. Conventional systems employ a rotating transducer. Fixed transducer systems use a rotating reflector to bounce the beam from the transmitter onto the hole walls.

A conventional, digital, low frequency transducer can achieve vertical resolution of 5–7.5mm with a maximum hole diameter of 230mm. Fixed high frequency systems have vertical resolutions of 1–2mm and can be employed in holes of up to 400mm. ATV images are based upon the transit time and amplitude of the reflected acoustic signal. As the acoustic wave travels outwards from the source, changes in hole diameter caused by geologic features scatter energy from the acoustic beam, reduce the signal and produce recognisable features on the image. Even where there is no change in diameter, part of the wave can be reflected from geologic interfaces where sufficient differences in acoustic impedance occur. For acoustic logging, wave amplitudes are greatest in hard formations and weakest in soft formations such as coal. Travel time measurements allow for recreation of hole shape – essentially a 3D caliper of hole. ATV probes can be used in cased or uncased drill holes containing water or light mud. Survey speeds vary between 1.3–3m/min. Probes typically range between 1.7–3.7m in length and 40–50mm diameter.

Image Orientation

Image orientation is provided by a 3-axis Magnetometer and accelerometers. Data is adjusted for magnetic north and drill hole deviation. In the case of steel casing or ferromagnetic mineralisation, image orientation can be achieved by aligning the image with the high side of an angled hole or through using gyro survey data.

Determination of structural orientation

Planar features intersecting the hole present as a sinusoidal curve in the unfolded televiewer image (Figure 2). The amplitude of the sinusoid gives dip and the position of the lower side of the sinusoid defines dip direction. Specialised software allows automated interpretation of structural features.

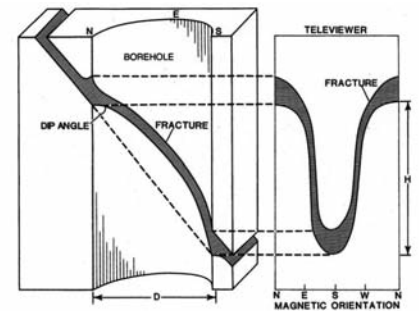


Figure 2: Cut-away three dimensional view of a drill hole and the resultant televiewer image showing sinusoidal curve.

Usage Examples

Televiewer use has been documented from the following sites:

- Diavik – 2005
- Blezard and Totten, Ontario; and Voisey Bay, Newfoundland-Labrador (Inco) – 2002
- BHP Billiton Iron Ore – 2003 and 2005; Olympic Dam 2007

The benefits and limitations below are drawn from Diavik, Inco, BHP Billiton and Maptek published works.

Benefits

- Data shown in-situ. Ambiguity over natural versus induced breaks reduced. Allowed measurement of in situ joint aperture.
- Provides oriented information in poor ground where conventional orientation fails.
- At Diavik, several iterations of comparison of core from high confidence, conventionally oriented intervals with televiewer images indicated that televiewer results could be used, virtually eliminating the requirement for oriented core.
- Reduction in oriented core requirements at Diavik translated to less people in camp, increased logging rates and reduced drilling and logging costs.
- Diavik concluded that improved differentiation between mechanical and natural breaks led to more accurate determination of RQD. (Conversely Inco found the opposite. At depth, fewer fractures were identified by the televiewer than by core logging. They proposed that higher overburden stresses clamped discontinuities and prevented the identification by the televiewer at the resolution used. Caution was advised in using televiewer data for RQD determination).
- Bore hole breakout identified in televiewer logs provided information pertaining to the local stress field during trials at Voisey Bay.
- OTV/ATV can orient discontinuities in vertical holes.
- BHP Billiton Iron Ore used OTV in open holes to define in situ conditions at significantly lower cost than diamond drilling.

MESSAGE FROM THE MANAGING DIRECTOR



The rotary clothes line was invented by an American in 1855, and was produced in the USA by the Hill Dryer Company and others, long before Lance Hill produced his Australian version in 1945. Rotary lawn mowers were developed in the 1930s by Power Specialties Ltd and by CC Stacy, an American farmer, at least ten years before the first VICTA design. The first Holden car, the 48-215 or FX, was originally designed as a Chevrolet by American engineers working for General Motors. Most Australians are disbelieving when told these facts about our "Australian" icons.

Similarly in mining it is difficult to identify any significant innovation originating in Australia, despite the prominent role mining plays in this country. There are some in mineral processing, notably the flotation process, although this is disputed by Americans. The various innovations in trucks, loaders, rockdrills, rockbolts, electric hoists and every other key item of mining equipment were developed outside Australia. The first autonomous (driverless) underground truck ran at the Rudtjebacken Mine in Sweden in 1972.

Why has mining innovation been so unsuccessful in Australia? I would argue that innovation comes

out of commercial competition between manufacturers and not out of mining companies. Mine operators have enough project risk to deal with and will avoid technological risk. Leading Australian mining companies have in the past admitted that they will not risk being the first to try a new technology. So the great new ideas come out of the countries that make the machines and have supportive taxation regime. The value to the nation of manufacturers in Sweden and Finland, for example, is well recognised by their governments.

If it was properly drafted, a flow-through share scheme could benefit not only exploration but also research and development. Private capital is currently pursuing successful mining service companies but is still wary of early-stage R&D.

Caterpillar has dropped the Elphinstone name from the website describing its Australian manufactured underground range and is now manufacturing part of the range in South America, so could we claim as Australian a new Cat machine? We are unlikely to see breakthrough ideas in rockdrills developed in Australia, but companies like Gekko Systems and Innovative Conveying Systems International could

put us on the map. Whether a successful small company would remain Australian owned is another matter.

What is the modern mine going to look like in 2030 and is Australia going to become a leader in developing and supplying the technology? It is time to get mine owners, suppliers, academics, consultants, regulators and other relevant parties together to develop a road map to put Australia in the forefront.

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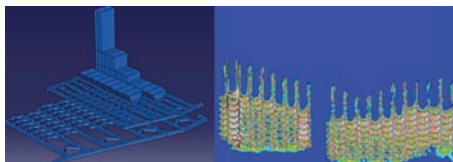
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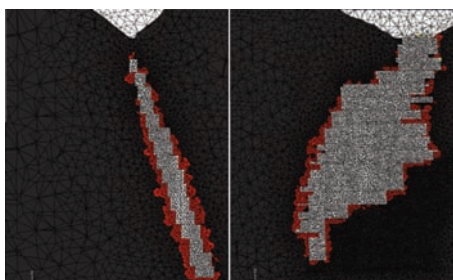
For the caving studies conducted, AMC has adopted an integrated modelling approach using both Finite element or Finite Difference codes and material flow codes to better simulate the caving phenomenon. In house material flow software codes such as CAVESIM and MFLOW are used to assess the expected draw profiles and to model life of mine production schedules.

The following figures show examples of the Abaqus modelling conducted by AMC.

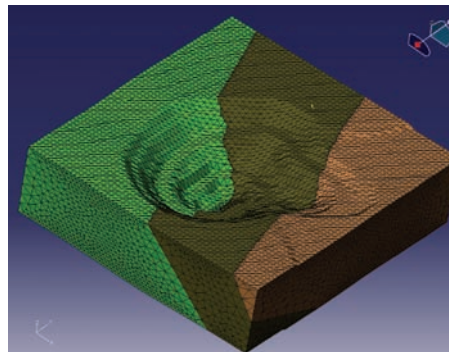
Zone of plastic strain on a block cave extraction level modelled using Abaqus



Zone of plastic strain around the stoping void at an SLC operation modelled using Abaqus



Partial view of an Abaqus model showing an open pit with different lithologies



AMC is currently conducting commercial inelastic modelling using Abaqus of a large sub-level open stoping mine. The aim of the study is to assess the extent of rock mass damage around the existing stopes and to assess regional pillar stability. In addition the modelling results are used to correlate the timing and location of plastic damage in the model to the recorded population of seismicity. The results of this study are being used to assess the seismic hazard potential of future extraction sequences.

As the reliability of the modelling results is dependent on the quality of the input data, AMC encourages clients to collect, where possible, detailed material property data and stress measurement information, coupled with physical

displacement measurements and observations of rock mass damage. This information is used to calibrate the modelling results to actual behaviour to ensure the best possible modelling results. AMC can assist clients in setting up suitable data acquisition programmes that are properly focussed on collecting suitable data for input and calibration of numerical modelling studies.

William Gibson (AMC Principal Geotechnical Engineer) and Dr John Albrecht (AMC Senior Geotechnical Engineer) have lead the development of AMC's advanced numerical modelling capability in the companies Perth office, in conjunction with Dr Glenn Sharrock from UNSW. AMC plans to further expand the company's capability into our other offices in the near future.

For further information regarding AMC's modelling capability, or if you are interested in becoming part of our advanced rock mechanics team, please contact AMC.



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Starfield A.M, Cundall P.A. 1988. Towards a Methodology for Rock Mechanics Modelling. Int. J. Rock. Mech. Min. Sci. & Geomech. Abstr. Vol. 25, No. 3, pp.99-106, 1988. Printed in Great Britain.

NEW EMPLOYEES



Jon Priest

Jon recently joined AMC's UK office as Principal Mining Engineer. Jon has joined us from ArcelorMittal's Head Office in London where he was employed as Manager (Mining) working within the Mergers and Acquisitions department in London. Jon has a

broad-based mining experience including most bulk commodities, precious metals and diamonds in open pit, underground, alluvial and marine environments. Jon has operated in operational and project capacities, including managing new technological developments for marine diamond exploitation systems and new underground block-caving mining methodologies for De Beers. His solid experience in M&A agreements, feasibility studies, due diligence, strategic planning and project portfolio management complements and enhances AMC's broad range of expertise. Jon is a Chartered Mining Engineer and a Certified Professional Project Manager.



Chris Arnold

Chris recently joined AMC's UK office as Principal Resource Consultant. Building on a practical background in exploration and mine geology, Chris has spent the last fifteen years operating out of Perth as an independent consultant, providing resource evaluation and review services within Australia, Africa, South America and Asia. His experience spans a diversity of commodities and he particularly enjoys working closely with operations to optimise their evaluation and production systems.



Sharron Sylvester

Sharron recently joined AMC's Adelaide office as Principal Geologist. Sharron's expertise is in the assessment of geological data, orebody modelling and resource estimation. Her professional experience spans 18 years and includes various in-house resource geology roles and 10 years consulting with Hatch Associates, from which she has gained extensive experience in a wide variety of commodities and geological regimes. Sharron is excited to be returning to Adelaide at a time when the South Australia's minerals industry boom is gaining momentum.



Hua Liu

Hua recently joined AMC's Brisbane office as Principal Mining Consultant. He holds a Ph D in Engineering with research and teaching experience covers a wide range of engineering fields using numerical analysis, mathematical modelling and computer simulation. For the last 14 years he has gathered extensive experience in a broad range of mining practices from geological databases to mine scheduling, predominately in coal.



Pier Federici

Pier was recently promoted to Principal Mining Engineer. Pier's primary expertise is open pit mine planning. Pier's broad experience covers gold, base metals and mineral sands including dredge operations. Pier joined AMC in 1996 with a strong production background. Since then Pier has developed his technical skills in strategic mine planning and optimisation. He has been involved in numerous mine planning and optimisation studies. Pier has specialist expertise with the mineral sand operations of Western Australia, Murray Basin and Queensland.

EXCELLENCE IN MINERAL RESOURCES ESTIMATION - THE ROLE AND RESPONSIBILITY OF COMPETENT PERSONS

1-5 September 2008, Brisbane Australia

AMC is pleased to present this five day intensive short course aimed at those geologists with responsibility for estimating mineral resources and including staff with 'Competent Person' accountability with respect to JORC Code and other international reporting codes.

This course is not a 'how to' manual for estimating mineral resources. It is designed to provide the knowledge to allow geologists to deliver resource estimates that are industry best-practice, irrespective of how they have been estimated.

The course will be presented by AMC Principal Consultants Peter Stoker, Mark Berry, Mark Sweeney, Tim McManus and Brian Hall, supplemented by guest presentations covering sample preparation and analysis issues, QA/QC and Australian Securities Exchange requirements.

For more information and registration enquiries contact Chris Stapleton. Email: cstapleton@amcconsultants.com.au www.amcconsultants.com.au

OPTICAL AND ACOUSTIC TELEVIEWERS - EXTRA TOOLS TO DEFINE THE ROCK MASS

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- BHP Billiton integrated televiewer data into Vulcan mine planning software at Olympic Dam.

Limitations

- Deploying probe in poor ground conditions can increase risk of tool loss and add extra rig time to ream through hole blockages.
- Misinterpretation of structural features is possible in ATV/OTV image. Minimised at Diavik by logging hole in conjunction with interpreting image.
- Selection of resolution is important. Low resolution images can result in structures not being identified.

Conclusion

Televiewer techniques have the potential to improve geotechnical data collection programmes by providing a means of examining in situ conditions alongside recovered drill core. Where geological confidence is high, televiewers can be used in open holes in place of diamond drilling with a lower drilling cost. Televiewer imaging provides a means to orient and characterise discontinuities in poor ground where traditional orientation methods fail.

Although the televiewer can provide additional in situ data, its true value can only be achieved through careful interpretation of results alongside all available data and the application of sound engineering judgment.



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