

DESIGNING NARROW UNDERCUT BACKFILL EXPOSURES - STIFF ROCK OR SOFT PASTE?

AMC has recently worked on a number of projects in Western Australia requiring the design of undercut backfill exposures in steeply dipping narrow orebodies. When mining from the bottom up, occasional sill pillars are left separating each production area. When mining top down, fill is exposed in the undercut of every lift. It would be expected that for wider spans, higher fill strengths are required. This is generally true but we find that for the narrowest exposures of less than five metres or so, smaller spans may require higher strengths. Why is this so?

Mitchell and Roettger (1989)ⁱ describe six failure mechanisms to be tested in 2D plane strain to ensure stable undercut designs. The failure mechanisms are flexural bending, caving, crushing, sliding, shearing and rotation. For steep dipping orebodies with widths of five metres or more, AMC finds that caving tends to be the dominant failure mechanism. The tensile strength (σ_t) required for caving stability with a wet bulk density (γ) and a span of (l) is given by

Equation 1

$$\sigma_t = \frac{\gamma l}{2.5}$$

Since tensile strength of fill is difficult to measure and rarely reported, it is common to use a ratio of between 5 and 8 to convert the required strength to unconfined compressive strength (UCS). The formula shows a simple relationship between strength and span for a given backfill density. For an assumed semicircular failure surface, the analysis shows that the minimum thickness of cemented backfill should be at least one half of the span of the orebody. In practice this thickness should really be between 0.75 to 1.0 times the span, to compensate for variable fill quality.

For narrow spans of five metres or less, AMC finds that crushing is the dominant mechanism when wall closure becomes significant. Mitchell and Roettger (1989) show the lateral closure stress (σ_c) for fill with elastic modulus (E) and wall closure (δ) is given by:

Equation 2

$$\sigma_c = E \frac{\delta}{l}$$

Stability against crushing failure is then given by:

Equation 3

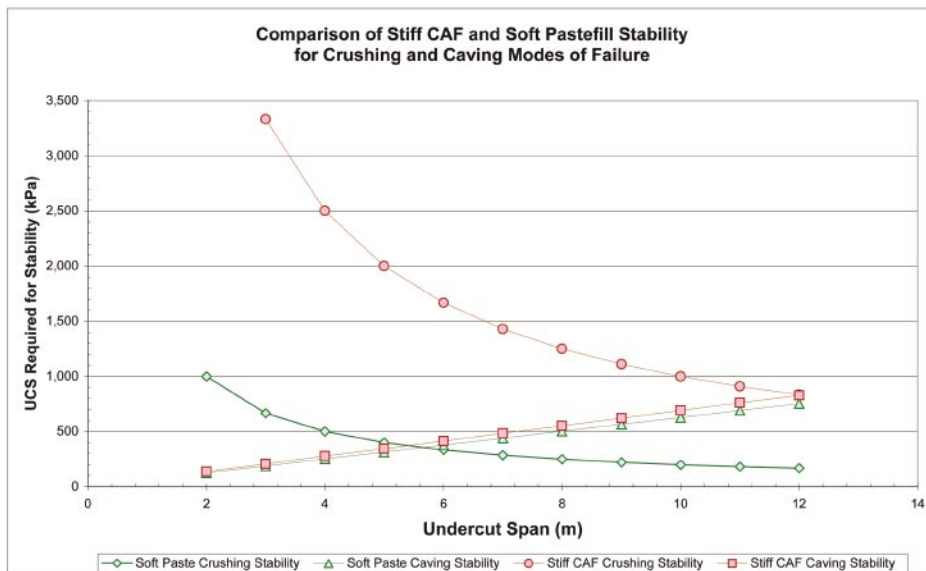
$$UCS = 2\sigma_c$$

This formula shows a direct relationship between the wall closure (strain) and backfill stiffness and the UCS required for stability. The formula is very sensitive to the strain in the fill.

Aubertin et al (2003)ⁱⁱ investigated the effect of stress distribution within backfill in narrow vertical stopes under conditions of high strain. They confirm strong arching effects, with vertical stress distributions due to self weight substantially less than geostatic conditions. However, for strain values of less than 1% they report a doubling of horizontal stress in the fill compared to the expected arching values.

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Figure 1– Comparison of Stiff CAF and Soft Pastefill Stability for Crushing and Caving Modes of Failure



ⁱ Mitchell, RJ & Roettger (1989) Analysis and modelling of sill pillars, Innovations in Mining Backfill Technology, Hassani et al (eds.) Balkema, Rotterdam

ⁱⁱ Aubertin M., Li L., Arnoldi S., Belem T., Bussi re B., Benzaazoua M., Simon R. (2003). Interaction between backfill and rock mass in narrow stopes. SoilRock 2003, MIT, USA

THE CHALLENGE OF NARROW VEIN MINING

Many of the issues involved in narrow vein stoping are similar to any other underground mining method where drill and blast is the primary means of putting ore in the drawpoints. The challenge of narrow vein mining is that many of these issues are exaggerated: that extra 0.3m of overbreak on each wall in the stope adds 60% dilution if the ore is only 1.0m wide, that 2.0m rock that falls off the hanging wall can hang-up valuable broken dirt in the stope or will cause material handling issues with the smaller mining equipment. The list goes on.

Narrow vein orebodies have traditionally been mined using hand-held methods – shrinkage stoping, gallery stoping and leading stopes. The low productivity, high cost and poor safety record of these older mining styles led the mining industry towards longhole stoping. However, all too often the industry adopted this method with little regard to the real costs of dilution. It was generally felt that if the capacity of the mill were increased sufficiently and if sufficient productivity increases were achieved by the introduction of longhole drilling, then lower overall production costs would be achieved.

Whilst the desired results were partly achieved, the drive to increase productivity has often resulted in the use of oversized equipment requiring large-scale development and the use of increased sub-level spacing. Drilling and blasting practices also tended to be neglected. In general, the task of minimising dilution often fell to the bottom of the priority list.

Longhole drilling in narrow vein orebodies is now widely practised in Australia and further significant reductions in total production costs are now most likely to be achieved by reducing dilution.

An example of what can be achieved is shown in the photograph of a stope at Gympie Eldorado Mines (formerly Gympie Eldorado Gold Mines).

Challenged to achieve narrower stopes and less dilution, Gympie placed every part of the mining process under close scrutiny. They have been able to regularly achieve stoping widths of 1.1m with some stopes as narrow as 0.9m.

The following are some suggestions for operators of narrow vein mines wishing to reduce mining widths and dilution:

- Even small changes in design can produce a huge impact on stope performance. Challenge every part of the mine design including stope and development dimensions, mining equipment, drill string configurations, drill patterns, explosives types, firing sequences and firing delays.
- Don't accept the statement "that's how we have always done it" or "if it ain't broke, don't fix it".
- Trials of different stoping parameters are vital to understanding how to optimise narrow vein stopes. Accurate implementation of trials and good recording of results will ensure that the greatest possible knowledge is learnt from every trial. It will also ensure that the correct changes are selected as new standard operating procedures.
- Always pivotal in the trials is the need for strong communication and feedback with all parties involved in the process – geology, design, mark-up/survey, drillers, charge crew, loader operators and supervisors.
- "Buy-in" of trials and implemented changes from all parties is critical, particularly drillers and charge crew.



Narrow vein, longhole stope at Gympie Eldorado Mine, Gympie, Queensland (photograph by permission of Gympie Eldorado Mines). The drive is 2.5m wide and the stope is 0.9m wide.

- Don't measure dilution in terms of a percentage dilution. Measure dilution as minimum mining width and wall overbreak. It will keep everyone focussed on the two main factors affecting dilution in narrow vein stoping.

Are you getting the best out of your narrow stopes?

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Daniel has recently joined AMC Consultants from Gympie Eldorado Mines (formerly Gympie Eldorado Gold Mines).

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From a practical perspective what does this mean? The projects that AMC has worked on have looked at the alternative backfill types of cemented aggregate fill (CAF) or cemented pastefill. CAF is a stiff material with an elastic modulus of between 300 and 500 MPa. By contrast pastefill, due to its higher porosity, tends to have much lower modulus in the range of 50 to 200 MPa. So if we compare

the behaviour of stiff CAF with softer paste as shown in Figure 1, we can see that pastefill requires a much lower UCS compared to CAF. For the example shown, a four metre wide undercut requires a pastefill UCS of 500 kPa, whereas CAF requires 2,000 kPa for stability.

This suggests that mines looking to extract ore with undercut backfill exposures in narrow orebodies under conditions of high strain may find better performance from softer pastefill than from stiffer CAF. AMC has looked at this issue in some detail and concludes that there is a compelling case for softer fill types in narrow orebodies. However, we

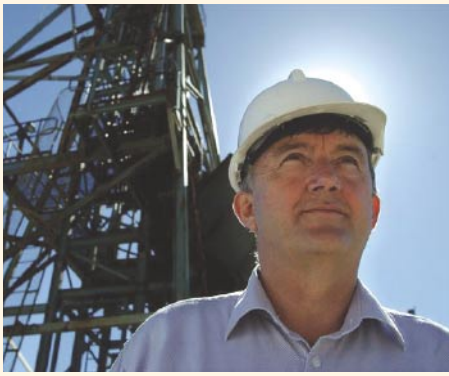
caution that each mining application and each backfill option will be unique for every mine. In particular; the short, medium and long term strain experienced by the fill will strongly influence the performance of the fill and we find that there is only limited field data to carry out effective designs. Time based numerical modelling will be required in most cases to supplement the first pass two dimensional analyses presented here.

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MESSAGE FROM THE MANAGING DIRECTOR

The attraction and retention of employees, particularly of professional staff, has finally emerged as a mission-critical item for new and existing mines. Some good initiatives to address this problem are being developed by the AusIMM and others. I would like to focus here on one topic – the facilities provided in the workplace and town or camp accommodation for professional staff.

The typical mine site office is crowded, even with a 20–30% vacancy rate in the professional ranks.

The standard of construction, office size, fit out and facilities are less than the standard provided by the same company for head office staff, where floor rents are much higher. Why do we accept this or believe it to be appropriate?

The camp accommodation is in low-cost units with little noise insulation. A worn air conditioner drones and rattles through the night. Showers and toilets are the cheap moulded plastic units and even the toilet paper is the cheapest brand available.

These are high-earning employees, who choose to spend their own after-tax income on premium brands and good-quality fixtures. When they travel, they select a good-quality motel and not the cheapest, sleaziest place in town. Why do we send the message that their employer values them less than they value themselves?

By comparison, the Seattle “campus” facilities of Microsoft, and similar facilities operated by many modern out-of-town organisations in Australia and elsewhere, show us how a corporation behaves when it values its staff. The head-office employees of a mining company can enjoy a focaccia and a cappuccino within a few doors of their own office in pleasant surroundings. Is this an unattainable dream for people at a mine site?

Of course not, as the Microsoft campus demonstrates.

The mining company that claims to value its employees must back this up, or the employees will draw their own conclusions. Many of the “baby boomer” generation grew up in fibro cottages (or corrugated iron houses in mining towns) with few appliances and amenities. Generations X and Y have much higher expectations.

The cost of upgrading facilities to the standard required will be paid for out of the reduced cost of recruitment for high turnover, and improved performance by people at work. Smart boards of directors are now realising this. Expect to see a dramatic improvement in conditions at a mine site near you.

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THE VALUE OF MINERAL RESOURCE/ORE RESERVE AUDITS

NINE REASONS WHY YOU SHOULD AUDIT YOUR RESOURCE/RESERVE ESTIMATES...

No. 1 Fundamental Mining Asset

Mineral resources, and their more important derivative ore reserves, are the foundation of every mining project and are fundamental to the success or failure of the operation. Various studies in the last 20 years (contact AMC for details) have shown that failure to achieve predicted head grades remains one of the most serious threats to the economic viability of mining projects. As Agricola observed in 1556: “*The miner ignorant and unskilled in the art digs out the ore without careful discrimination while the learned and experienced miner first assays and proves it ...*”. Perversely, a production grade or contained ounces significantly in excess of prediction can also cause major difficulties, as evidenced by the expensive litigation involving the Kelian gold mine in the mid- to late-90s.

No. 2 Basis for Public Reporting

Regulatory requirements in most major mining countries oblige companies to regularly report material information to the market, including mineral resource and ore reserve estimates. Key stakeholders such as investors, brokers,

company advisors and regulators will rely largely on the company’s public releases to make critical decisions. If such decisions turn out to be founded on unreliable or incorrect estimates, the consequences can be disastrous, as evidenced by the infamous Busang saga.

No. 3 Increasing Scrutiny of Company Directors

Directors of all public companies are coming under increasing personal pressure, through regulatory guidelines such as the ASX corporate governance guidelines in Australia or through government acts such as the Sarbanes-Oxley Act in the USA, to ensure that public disclosures of company information are full, correct and transparent. For mining/exploration companies, mineral resource and ore reserve estimates are one of most important pieces of information for which Directors must take responsibility.

No. 4 Financiers Expect or Require Them

In an article published in 2001 (*The JORC Code – A Banker’s View, The AusIMM Bulletin, November/December 2001*), Quentin Amos and Phil Breaden said: “*In the authors’ experience, ore reserves hold potentially the greatest risk for project finance lenders where there is no recourse to the parent entity beyond the project. Recent history of*

mining finance since the mid 1980s has shown that realisation of grade estimates is rarely achieved and thus banks start their analysis of ore reserves from a position of scepticism in regard to tonnage and grade predictions”. “*...banks will at present continue to insist on Ore Reserve reviews and audits being conducted by parties outside and independent from the mining company*”. Often banks will require the auditor to be appointed by the bank so that the bank can rely on the audit directly.

No. 5 For Valuation Purposes

Arising from point 1 above, resources and reserves are a key basis for the valuation of a mining company. Valuations may be undertaken for various reasons, including (refer VALMIN Code, 1998) preparation of a prospectus or information memorandum or similar document, fairness and reasonableness reports, compensation for compulsory acquisitions, protection of the rights of certain classes of shareholders in transactions between associated companies, valuations involving acquisitions agreed to by shareholders under the Corporations Act, valuation of a vendor’s consideration in a public float, assistance to receivers or managers in the disposal of assets, etc.

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KUGAN KUGANATHAN JOINS AMC

Kugan Kuganathan has joined AMC Consultants at their Melbourne office as a principal backfill engineer. Kugan has been working in the Australian mining industry for the past fifteen years in which the last nine years were spent at Xstrata Mount Isa Mines as senior backfill engineer. He was instrumental in many of the innovative approaches to mine backfilling at Mount Isa Mines during that time and feels that the mine has some of the best backfilling practices in the world. Prior to his Mount Isa involvement, Kugan had specialised in coal mine washery waste disposal by co disposal methods. He wrote his PhD thesis on this topic while at the University of Queensland.

The AMC Backfill Group is now better positioned to increase and improve services to the Australian and international mining industry in this very busy area of specialisation.

Kugan can be contacted on kkuganathan@amcconsultants.com.au

MINING GEOLOGY 2004

AMC will be presenting two consecutive half-day workshops on Friday 22 October at Mining Geology 2004 in Brisbane.

Workshop 1: **How to audit proof your mineral resource document.**

Presented by Pat Stephenson and Peter Stoker.

Workshop 2: **Cut-off grade and optimisation.**

Presented by Brian Hall.

The workshops can be taken separately or together. Contact Warren Peck for details at wpeck@amcconsultants.com.au

THE VALUE OF MINERAL RESOURCE/ORE RESERVE AUDITS

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No. 6 Impact on Accounting Decisions

Resources and reserves impact fundamentally on accounting decisions, and therefore on company profitability. Areas affected include amortisation of exploration, evaluation and development costs, depreciation of plant and equipment, accounting for rehabilitation/restoration expenditure, impairment of assets and any other costs which are brought to account on 'unit-of-production' basis. It is seldom appreciated by accountants and other non-technical users of ore reserve estimates that the amount of ore reserves, and therefore decisions dependent on life-of-mine calculations, depend entirely on a Competent Person's (largely subjective) judgement distinguishing between Inferred Resources and Indicated Resources. Regulators can also become involved in this area (eg the 2002 dispute between Stillwater Mining Company and the USA Securities and Exchange Commission) with costly results.

No. 7 Requirement of Ore Reserve Estimators

In addition to the above, which apply to both mineral resources and ore reserves, it is becoming increasingly common for those preparing ore reserve estimates, particularly consulting groups such as AMC, to undertake or commission a review or audit of the mineral resource estimate. There have been recent instances where the ore reserve estimate prepared by AMC has had to be significantly qualified on the basis of its mineral resource review.

No. 8 Estimations not Calculations

Despite the fundamental importance of resource/reserve estimates as listed above, they remain estimates, subject to uncertainty and susceptible to significant changes as new information comes to light. There is probably no other industry where the asset that underpins its economic health is estimated from a sampling of less than 0.001% of that asset. Given this unique characteristic, there is a greater than usual imperative to ensure that the estimates are undertaken to the highest standards

and subjected to rigorous review.

No. 9 Professional Judgement is Critical

Estimation of mineral resources and ore reserves is arguably as much an art as a science, and depends critically on the skill, experience and judgement of the Competent Person. Inevitably, exercise of judgement is subjective. Both the person exercising the judgement (the Competent Person) and those dependent on the results can benefit from the constructive involvement of appropriately experienced colleagues. The auditing process is one means of providing this input.

...AND ONLY ONE OF THE REASONS WHY YOU SHOULD USE AMC

AMC has the Right People with the Right Experience

On the mineral resource side, Pat Stephenson, Peter Stoker and Dean Carville collectively have over 90 years experience in the industry, Pat and Peter having spent much of their combined 25+ years as consultants in reviewing resource/reserve estimates. With the support of other AMC geologists such as Bob Appleyard (40 years experience) and John Tyrrell (over 15 years), AMC has one of the best qualified resource review teams available nationally or internationally.

On the ore reserve side, AMC has over 40 mining engineers with extensive industry experience in a wide range of metalliferous and coal deposits and in all mining methods. In recent years, AMC has undertaken operational benchmarking exercises on over 40 open pit and underground metalliferous and coal mines, providing it with an unrivalled database of costs and other parameters critical to ore reserve estimation.

In the area of public reporting, Pat and Peter have around 30 years involvement with the Australasian Joint Ore Reserves Committee ("JORC") and, through regular communication with equivalent industry committees overseas, have extensive knowledge of reporting requirements in other countries.

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