

## STABILITY OF RAISEBORED SHAFTS

### The Limitations of the McCracken & Stacey Raisebore Risk Assessment Method

#### Introduction

Although the McCracken and Stacey method of assessing geotechnical risk for large-diameter raisebored shafts has been widely used in Australia, shortcuts are often taken and the resulting analyses are not in accordance with the method. Some professionals claiming to have done a McCracken and Stacey analysis have, in fact, incorrectly calculated  $Q_r$  and only done part of the analysis. Others have deduced stand-up times despite the fact that the method does not consider time-dependant behaviour.

McCracken and Stacey published the method in 1989 and it was successfully applied to the planned Airshaft No.5 at Broken Hill that same year. The method predicted severe instability if raiseboring was attempted at the planned 6m diameter. It indicated that some overbreak would occur even if raisebored at 1.8m diameter, a conclusion supported by an analysis using the Q-System. The McCracken and Stacey method gained significant credibility when the predicted overbreak occurred during reaming at 1.8m diameter, prior to enlargement to 6.7m diameter by V-mole (Bennet & de Bruin, 1993).

#### Fundamentals

McCracken & Stacey (1989) applied the principles of the Q-System (Barton et al, 1974) to the problem of assessing raisebore stability following the collapse of a number of large-diameter shafts during raiseboring. The Q-System had developed a relationship between  $Q$  and the Maximum Stable Unsupported Span (MSUS). Additionally, the Q-System had

established a factor called the Excavation Support Ratio (ESR) to account for different degrees of allowable instability based on excavation service life and usage. McCracken and Stacey used these concepts to develop the relationship between Raise Rock Quality ( $Q_r$ ) and the maximum stable raise diameter presented as Figure 1.  $Q_r$  is based on the  $Q$  value obtained from using Kirsten's approach to determine the Stress Reduction Factor (SRF), with further corrections to accommodate adversely oriented sets of discontinuities, weathering and alteration.

Kirsten developed a relationship between SRF and the extent to which the rock is overstressed. His approach is to calculate a SRF value for the ground stress condition and another value for rock mass loosening and to use whichever SRF value is numerically greater. Peck (2000) published similar SRF equations for Australian conditions.

Figure 1 demonstrates that the required  $Q_r$  value for stability significantly increases with increasing raise diameter. Whilst a 2m raise is likely to be stable in poor quality rock ( $Q_r = 1$  to 4), a 5m raise requires fair quality rock and a 6m raise requires fair to good quality rock ( $Q_r > 8$ ). McCracken and Stacey also defined raisebore rock quality in terms of block size ( $RQD/J_n$ ) and low interblock shear strength ( $J_r/J_a$ ). Their paper drew attention to the fact that problems may be expected in large diameter raises if the critical parameter values for  $RQD/J_n$  and  $J_r/J_a$  are poor or worse.



Figure 1 Relationship between Raise Diameter &  $Q_r$  (after Figure 4, McCracken & Stacey, 1989)

**Stand-up Time**

Unstable rock excavations without support will collapse in time, ranging from less than an hour to more than a year. The time-dependant behaviour of unstable rock masses is complex and poorly understood. The Q-System does not include any correlation between Q values and stand-up times. Bieniawski (1993) published a correlation between the span of an opening, maximum stand-up time and RMR value, based on a study of a large number of mine openings and tunnels. Unfortunately, RMR values are not easily related to Q values, as not all the same parameters are used to assess rock quality. For example, only Q gives a rating for the ground stress condition, whilst only RMR rates the persistence or continuity of the individual rock defects such as joints. Bieniawski's chart suggests that to stand unsupported for 6 months, a 3 metre span needs an RMR of at least 58 and a 6 metre span needs an RMR of at least 64 out of a possible maximum of 100. The RMR system rates good rock as having RMR values between 61 and 80. Hence, fair to good rock is required for 3 metre to 6 metre spans to stand unsupported for 6 months.

As the McCracken and Stacey method relies on the Q-System, it cannot predict stand-up times. Predictions of stand-up times of any unstable rock identified by a McCracken and Stacey analysis would need to be based on RMR ratings.

**Assessment of Raisebore Stability**

McCracken and Stacey state that the preliminary geotechnical assessment should be aimed at determining the average and lower bound geotechnical conditions: "The range and distribution of the raisebore rock quality  $Q_r$ ; and the most important RQD/ $J_n$  and  $J_r/J_a$  parameters must be compared to the required minima for stability at the proposed shaft diameter." It is insufficient to simply look at the variation of MSUS with depth.

"At the preliminary evaluation stage the risk should only be deemed 'acceptable' if the tunnelling quality is consistently indicated to significantly exceed (i.e. be in the next class up from), the required quality throughout its length." The paper goes on to state that marginal cases occur where the indicated quality  $Q_r$  either straddles the required value for stability, or is not confidently known.

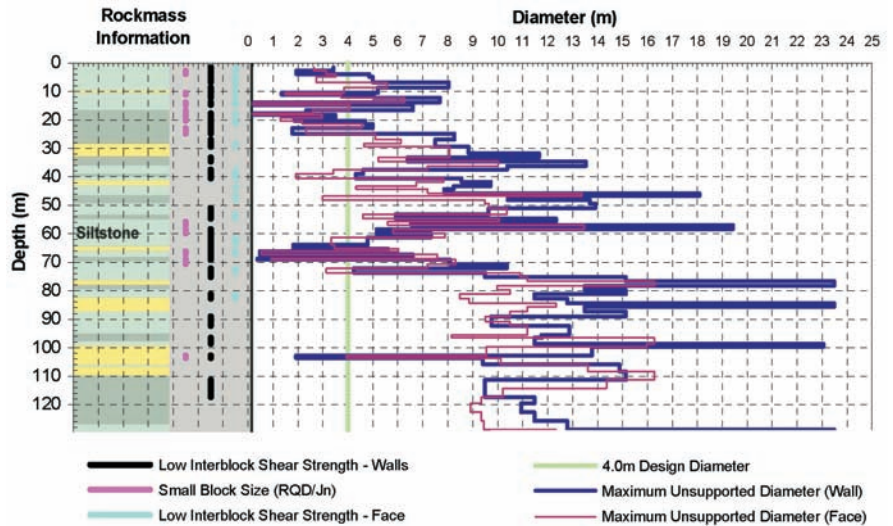


Figure 2 Typical Plot of Diameter and Critical Rock Quality Parameters versus Depth

McCracken and Stacey also state "In addition to simply assessing the range of predicted  $Q_r$  values against those required, the rockmass properties and discontinuity orientations would be used as input to detailed stability analysis."

Figure 2 presents typical results showing the variation of MSUS (expressed as diameter) with depth and identifying those areas with small block size and low interblock shear strength. It clearly identifies two potentially unstable areas; the first at the shaft collar (0 – 25m) and the second between 60m and 70m. Both were reinforced prior to raiseboring. A one metre thick zone with an indicated MSUS of only 2m occurs at about 103m depth. The  $Q_r$  value in this zone is only 0.5, but the  $Q_r$  values above and below it are of the order of 100 times greater and were assessed as capable of providing support for this thin weak layer. This raise has been successfully raisebored at 4m diameter as planned.

**Validation of the McCracken and Stacey Method**

The method has not been formally validated by McCracken and Stacey publishing a database of case histories, similar to those supporting the RMR and Q Systems. Therefore the method currently relies on the prior experience of the geotechnical engineer undertaking the investigation. AMC's Warren Peck, working through the Eastern Australia Ground Control Group (EAGCG), is currently compiling a McCracken and Stacey database planned for publication in 2007.

**Limitations and Problems**

- Shortcuts are often taken, so that the full McCracken and Stacey analysis is not done and only MSUS is calculated.
- The method requires the SRF factor in  $Q_r$  be calculated using Kirsten's approach, but some practitioners do not do this.
- The method cannot predict stand-up times. Hence it contains no basis for making assessments as to what period of time can safely elapse between reaming and the installation of support in a raisebored shaft.
- Mine operators are being encouraged to take large risks, such as accepting a one-in-three chance of the raise collapsing during reaming, on the dubious premise that the risk would be much less if reaming and lining are completed in a period of only a few months.
- There is no published database of McCracken and Stacey case histories and hence the method currently relies on the prior experience of the geotechnical engineer undertaking the investigation.

**References**

Barton, N., Lien, R., and Lunde, J. 1974. Engineering classification of rock masses for the design of tunnel support. *Rock Mechanics*, Vol 6, No.4, May 1974, pp 189 – 236

Bieniawski, Z.T., 1993. Classification of rock masses for engineering: The RMR system and future trends. *Comprehensive Rock Engineering*, (ed. Hudson), Oxford: Pergamon, Vol 3, pp 553 - 573

## MESSAGE FROM THE MANAGING DIRECTOR

### 100 Years Ago

Given the current debate about nuclear power in Australia, it is interesting to note that our first uranium deposit was discovered 100 years ago at Radium Hill (near Broken Hill) by prospector A J Smith, who at first thought the heavy dark rock to be an ore of tin. The Radium Hill Company had produced six hundred tonnes of ore by 1911, with radium being sent to the Curies in France. Also in 1906 Auguste De Bavay patented his 'skin' or 'film' flotation process and opened what was to become a successful plant at Broken Hill. The process was the basis of Amalgamated Zinc and the Zinc Corporation, a grandparent of today's Rio Tinto. Zebina Lane died in 1906 after a successful mining engineering career in California and Victoria. He was particularly known for his work in reviving the Lord Nelson mine at St Arnaud. His son Zebina B Lane became better known through his mining engineering achievements in Broken Hill and Coolgardie, and was a member of the Legislative Council in Perth at the time of his father's death. Broken Hill has a Zebina

Street and a Lane Street, and because each east-west street has a parallel lane of the same name (for the night carts) there is a Zebina Lane and a Lane Lane.

1906 also marked the start of phosphate mining in Nauru and the beginning of the copper rush in Queensland, with the railway extended from Richmond to Cloncurry. Worldwide, the most newsworthy event was the Courrières mine disaster in France, where 1,099 miners lost their lives in a coal dust explosion.

George Lansell, who died in 1906, was known as 'Australia's Quartz-King' and was director of thirty-eight mines in Bendigo, some being the deepest mines in the world by the turn of the 20th Century. He pioneered the use of diamond drilling in Australia and had made his fortune by the age of fifty, but continued to support the industry into his eighties.

1906 saw the introduction of Diplomas in Mining and Metallurgy for mine managers at Melbourne University. Which brings me to the



point. In my previous editorial I said that Victoria no longer graduates students in Mining and Metallurgy, but Dr Michael Tuck assures me that the University of Ballarat offers a three year Bachelor of Engineering Science degree in Mining Engineering with a follow up 1.5 year Master of Engineering Technology program in Mining Engineering. Ballarat graduated its 100th Graduate Diploma of Mining student early this year and will reach 200 quickly with the way enrolments are going.

**Peter McCarthy**  
Managing Director  
[pmccarthy@amcconsultants.com.au](mailto:pmccarthy@amcconsultants.com.au)

Bennet, A.G. and de Bruin, N.J.H., 1993. Investigation and Development of Pasmenco No.5 Ventilation Shaft, Broken Hill. *Proceedings VIII Australian Tunnelling Conference*, AuslMM, pp 55 – 63

Kirsten, H.A.D., 1983. The Combined Q – NATM System – the design and specification of primary tunnel support. *South African Tunnelling Vol 6*, No.1

McCracken, A and Stacey, T.R., 1989. Geotechnical Risk Assessment of Large Diameter Raisebored Shafts. *Shaft Engineering*, Inst Min Met, pp 309 – 316

Peck, W.A., 2000. Determining the Stress Reduction Factor in Highly Stressed Jointed Rock. *Australian Geomechanics Vol 35*, No.2

**Warren Peck**  
Principal Geotechnical Engineer  
[wpeck@amcconsultants.com.au](mailto:wpeck@amcconsultants.com.au)

## LIFE OF A MINING CONSULTANT

The mining industry continues to grow, and mining companies are struggling to attract and retain personnel. This is also a concern for mining consultancy groups, but as the attraction of FIFO wears off, more and more engineers are looking to work with mining consultancy groups.

Twenty years ago whenever a consultant walked into a workplace they had been briefed prior to the visit and were fully prepared for the undertaking that was in front of them. A second briefing of the project was undertaken on site and copies of all and any relevant information available was handed over.

Some time later a response detailing what had to be undertaken was produced and seldom, if ever, was there detail on how to go about it, but that was fine because site did not like being told how to do things, that was their domain. How things have changed.

Today any person contemplating the life of a mining consultant must be fully prepared to:

- travel to mine sites at a moment's notice
- use their own measuring instruments and undertake all appropriate measurements

- work with the most junior engineer on site who generally needs training, mentoring and encouragement
- search through mine records for any information that may be available
- coerce information from any number of sources
- undertake all of the necessary calculations
- provide a solution that doesn't require capital expenditure because there is no money in the budget
- be prepared to undertake pre-feasibility studies with detail normally expected in a 5 year plan
- run at least two, possibly three, studies at one time
- answer of-the-cuff questions from clients, even though you finished their study a couple of years ago.

Anyone for golf?

**Paul Gardner**  
Mine Ventilation Consultant  
[pgardner@amcconsultants.com.au](mailto:pgardner@amcconsultants.com.au)

# OPTIMISATION OF OPEN COAL RESOURCES

AMC's Coal Group capabilities have continued to steadily grow in the past year and now include optimisation for open cut coal mines. Pit optimisation is the most established application of its kind in the minerals industry, but it primarily has been driven by metal, not coal. Coal has the same financial drivers for resource optimisation as does the metalliferous industry, yet pit optimisation for coal operations have not been similarly emphasised.

Earlier this year, AMC's Coal Group was engaged to develop a custom pit optimiser for the Kogan Creek Power coal mine in western Queensland. The mine deposit consists of numerous coal plies that were thinly bedded in a synclinal formation. The geologic model of the deposit was presented in a stratified form, which is common to most coal operations.

Off-the-shelf optimisation packages such as Whittle require the geologic data to be in a block model form. This presented us with a problem due to the thinly bedded, multiple seam and synclinal nature of the coal deposit. To overcome the need to convert the stratified geologic model into a block model, AMC developed a customised pit optimiser that evaluated the geologic data in its stratified form.

In practice, it is difficult to separate out thin coal plies with large excavation equipment. But, as far as a first step, compositing the thin coal plies into mineable bands allowed us to model and monitor the quality of the final coal product. With a composited model, AMC developed an optimiser based on the constraints of the deposit.

The biggest challenge for AMC was to develop an optimiser which maintained the crop orientation of the coal while applying advancing mining slopes to highwalls. Overcoming this was a huge achievement for the optimisation process and led to the ability to include quality constraints and objectives for the optimiser. The result

was an optimised multi-period pit that satisfied the quality targets of the operation while addressing the constraints and complexities of the deposit. The picture below shows the result of the optimisation process for the Kogan Creek deposit.

AMC's work at Kogan Creek has led to many interests for optimising coal operations in central Queensland and Indonesia. With the fluctuations in coal prices and diesel prices, more and more coal mine operators are forced to constantly review pit economic limits. The ability to do this rapidly has become an increasing demand. By drawing on in-house expertise in optimisation and coal, AMC is confident that it will be able to stay at the forefront of optimisation for the coal industry.

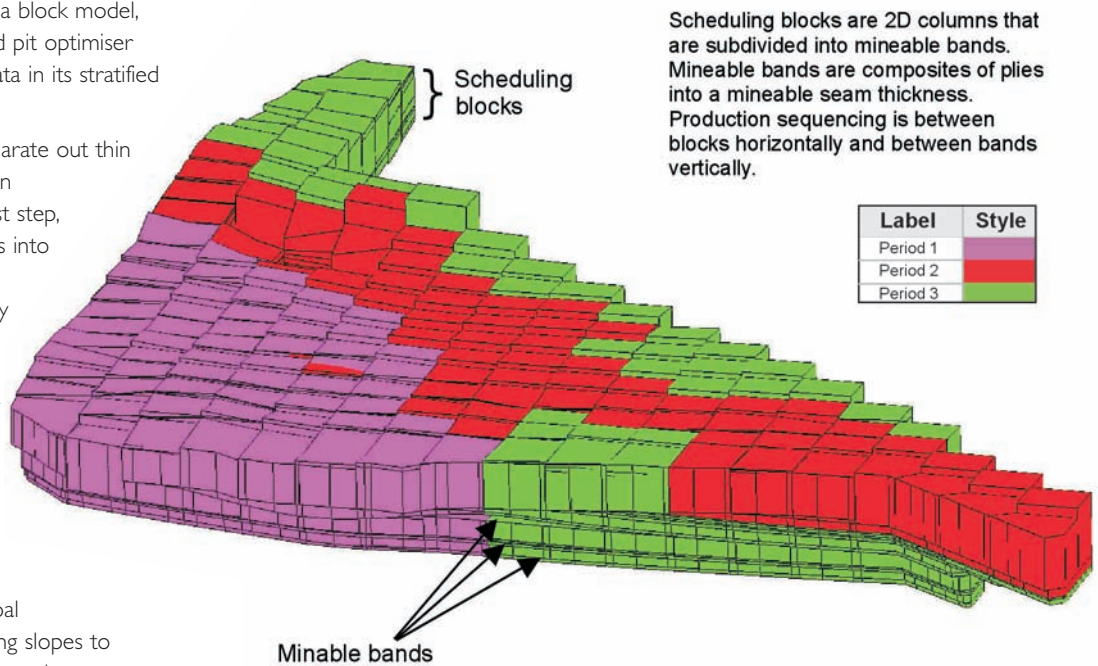
Over recent years, AMC has built a strong portfolio of quality consulting advice to the coal industry. AMC has been committed in maintaining support to our Australian clientele

while expanding our services into India and Indonesia in both open cut and underground coal operations. The ability of AMC's Coal Group to provide both operations and evaluative support combined with its ongoing commitment of staff and resources to a client's project allows an integrated analysis of underground and open cut coal mining projects.

*Isaac Denny*  
Mining Engineer  
[idenry@amcconsultants.com.au](mailto:idenry@amcconsultants.com.au)

and

*Karen Goh*  
Senior Mining Engineer  
[kgoh@amcconsultants.com.au](mailto:kgoh@amcconsultants.com.au)



Scheduling blocks are 2D columns that are subdivided into mineable bands. Mineable bands are composites of plies into a mineable seam thickness. Production sequencing is between blocks horizontally and between bands vertically.

Label	Style
Period 1	
Period 2	
Period 3	

AMC Consultants Pty Ltd ABN 58 008 129 164  
Website: [www.amcconsultants.com.au](http://www.amcconsultants.com.au)

## AMC – The Business of Mining

### MELBOURNE

Level 19  
114 William Street  
Melbourne 3000  
Telephone +61 3 8601 3300  
Facsimile +61 3 8601 3399  
[amcmelb@amcconsultants.com.au](mailto:amcmelb@amcconsultants.com.au)

### PERTH

Ground level  
9 Havelock Street  
West Perth 6005  
Telephone +61 8 9481 6611  
Facsimile +61 8 9481 6622  
[amcperth@amcconsultants.com.au](mailto:amcperth@amcconsultants.com.au)

### BRISBANE

Level 8  
135 Wickham Terrace  
Brisbane 4000  
Telephone +61 7 3839 0099  
Facsimile +61 7 3839 0077  
[amcbris@amcconsultants.com.au](mailto:amcbris@amcconsultants.com.au)

### UNITED KINGDOM

7 Bridge Avenue,  
Maidenhead  
Berkshire, SL6 1RR, UK  
Telephone +44 1628 778 256  
Facsimile +44 1628 638 956  
[amcuk@amc-consultants.co.uk](mailto:amcuk@amc-consultants.co.uk)