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Determination of the *in situ* modulus of the rockmass by the use of backfill measurements*

by R.E GÜRTUNCA and D.J. ADAMS

Written contribution by J.F.Curtis †

The subject matter of the paper is interesting in that, instead of 'numerical modelling based on elastic theory' being used for the prediction of energy release rate (ERR) in relation to various types of stope support, including backfill, use is made of stresses in the backfill in an attempt to correct the numerical modelling.

The concept of ERR was introduced by Cook and Joughin[1] in 1972. It was claimed by More O'Ferrall and Kersten[2] that 'an ERR of up to 41 MJ/ca (MJ per centare) would not cause hardship in stopes'.

ERR as an indicator of seismic event–rockburst potential suffers from two major defects. The initial numerical models assumed that the rockmass surrounding the stope was 'homogeneous, isotropic and linearly elastic'. To any observer underground this was clearly not the case. This defect has been partly remedied by the acknowledgment in the present paper that the following factors affect rockmass behaviour:

'(i) joints in the rockmass,
(ii) different geological layers, and
(iii) inelastic behaviour such as fracture, dilation, bed separation, etc.'

The second defect is more serious.

Cook[3] hypothesized that 'excess potential energy causes the damage noticed as a rockburst'. In the light of Einstein's theory of the equivalence of mass and energy, the concept of 'excess' energy is untenable. Insofar as numerical modelling of ERR is used as a predictor of seismic event–rockburst occurrence and magnitude, it is invalid.

Curtis[4] noted that 'the use of ERR as an index of rockburst activity was dubious'.

Curtis[5] has shown that the magnitude of the largest seismic events–rockburst, which have been experienced on the Witwatersrand as a result of mining operations, is compatible with the strain energy released by the fractured rock associated with the rockburst.

There appears to be little reason to look further for some source of 'excess' energy to explain their occurrence.

Salamon[6] corroborated the first of these two propositions when he noted that 'the enlargement of mining cavities in small steps is a quasi-static, stable process which does not result in the release of kinetic energy into the rock mass, therefore it cannot be the source of seismic energy', and conceded the second when he agreed that 'usually the source of seismic energy is the (strain) energy stored in the rock'.

The 'modelled geometry for a layered rockmass' (Fig. 12) is a considerable advance on former models, but still falls short of a realistic depiction of the factors contributing to seismic events–rockbursts.

Attention must be given to the specific properties of individual layers and the fracture pattern ahead of the stope face.

References

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2. MORE O'FERRALL, R.C. and KERSTEN, R.W. Stress and fracture development around stopes in deep tabular orebodies. *Pap. Discuss. Ass. Mine Mgrs S. Afr.* 1972–1973. p. 16.
3. COOK, N.G.W. The basic mechanics of rockbursts. *Proceedings, Symposium on Rock Mechanics and Strata Control in Mines.* Johannesburg, The South African Institute of Mining and Metallurgy, 1963. pp. 56–66.
4. CURTIS, J.F. Rockburst phenomena in the gold mines of the Witwatersrand. Author's summary. *Trans. Inst. Min. Metall., A,* vol. 90. 1981. pp. 204–206.
5. *Ibid.* pp. 163–176.
6. SALAMON, M.D.G. The alleviation of rockbursts. *Trans. Instn Min. Metall., A,* vol. 9. 1984. p. 84.

Authors' reply to J. F. Curtis

We thank Mr Curtis for his contribution to our paper. First of all, it should be emphasized that the object of the paper is not to address the validity of ERR as a tool for the assessment of seismic events or rockbursts, but to determine an *in situ* modulus for the rockmass with the aid of backfill measurements. It is suggested that this *in situ* modulus should then be used in elastic-stress analysis programs such as MINSIM-D in order that more-realistic convergence rates, and consequently stresses, in backfill can be obtained. Since ERR is determined by the use of elastic convergence and stresses ahead of the face, the magnitude of the *in situ* modulus, as determined from the backfill stresses, will affect these two factors. It is important, therefore, that these factors should be determined as realistically as possible. If the modelled backfill stresses are not similar to those measured

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underground, the reduction of stresses ahead of the face, as well as the increase in convergence, would not be simulated correctly.

We believe that the concept of ERR has been used successfully in the design of mine layouts, and there is no proven fully practical alternative to this concept at present. However, the rock-mechanics practioners should be aware of the implications in the use of the conventional Young's modulus of 70 GPa for the determination of ERR.

Written contribution by T.R. Stacey †

Although the authors of the above-mentioned paper have presented some good and interesting information, the title of the paper, and the recommendation that such an *in situ* modulis should be used for calculations of energy release rate (ERR), are viewed with some concern. The reasons for this concern are as follows.

(1) The modulus determined by the authors is not the *in situ* modulus of the rockmass, but an average elastic modulus that allows the displacements of the stope hangingwalls and footwalls, which are calculated by use of an elastic-stress analysis method, to match the displacements measured *in situ*. It is no more correct than any other modulus value that has been used so far. In practice, the *in situ* modulus is likely to be variable, depending on the distance from the stope, and a single *in situ* modulus for the entire rockmass is not possible.

(2) The real stress distribution surrounding the stope bears little resemblance to that calculated elastically. In the two-dimensional elastic-stress distribution, the immediate hangingwalls and footwalls are in a state of biaxial tension, and this is independent of the value of the modulus used in the calculation. In the real situation, horizontal *compressive* stresses occur in the immediate hangingwalls and footwalls. The mechanism of loading of backfill in the two cases must therefore be significantly different.

(3) The relationship between ERR and rockbursting was developed empirically, elastic analyses being used with the 'standard' modulus of elasticity. The calculation of ERR with a different modulus will naturally have a major effect on the calculated convergence, and effectively negates any value that these past empirical correlations may have had for planning purposes, i.e. new 'benchmark' levels would have to be defined. ERR as used in such correlations is a theoretical concept based on stresses and convergences that are calculated by the use of elastic-stress analyses. The use of a different modulus value will therefore not result in 'more realistic' values of ERR, since there is no absolute definition of a realistic value. Since the real stress distribution and displacements around the stope are significantly different from the elastic values, the 'real ERR' will also be very different, and is perhaps irrelevant.

(4) As pointed out by the authors, there are several explanations for the differences between measured and theoretical behaviour. Non-linear stress analyses reported several years ago[1] demonstrated good agreement between measured and calculated closures and stresses in the backfill, and also predicted the presence of compressive horizontal stresses in the immediate hangingwall. These stress analyses showed that there were great differences between the elastically calculated results and the more-likely values that resulted from the inclusion of joints in the model. It was concluded that the performance and effectiveness of backfill as stope support cannot be determined reliably with the commonly used mining-simulation analyses in which the rockmass is treated as an elastic medium. Consequently, it is considered that the reduced modulus approach suggested by the authors is not an effective solution; it is not any more correct than any other modulus that has been used; and its use would cause confusion in the industry.

It is recommended that the interim solution suggested by the authors should not be used. Also, the development of a new sophisticated computer model will not solve the industry's problems. It is considered that the numerous three- and two-dimensional models that are available are adequate at present. What is required is *greater engineering understanding and interpretation* by the rock-mechanics fraternity, and less blind acceptance of computer output, i.e. more engineering in rock engineering.

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Reference

1. KIRSTEN, H.A.D and STACEY, T.R. Stress-displacement behaviour of the fractured rock around a deep tabular stope of limited span. *J. S. Afr. Inst. Min. Metall.*, vol. 89. Feb. 1989. pp. 47–58.

Authors' reply to T.R. Stacey

Dr Stacey's comments on our paper are appreciated; we should like to address his concerns as follows.

(1) We agree with Dr Stacey that, in a detailed sense, the *in situ* modulus is likely to change according to distance from the stope. However, as discussed in the paper, the closure and resultant stresses in backfill are induced by the entire rockmass. Therefore the *in situ* modulus or effective modulus should be representative of the rockmass between the surface of the earth and the stope.

(2) We agree with Dr Stacey's call for 'greater engineering understanding and interpretation', but cannot accept his absolute rejection of the applicability of elastic modelling to gold-mining problems. Dr Stacey's rejection is based on the results

of his own non-linear computer programs, which, in the modelling of a weak, jointed rockmass, showed at best qualitative agreement with in-stope behaviour[1]. Yet he ignores the careful *quantitative* work of the 1960s in which rockmass movements are shown to agree well with elastic predictions, and in which large inelastic in-stope closures are ascribed to the effects of *localized* face and hangingwall fracturing.

(3) MINSIM-D type elastic-stress analysis programs are usually used for the design of regional support, and these programs are not intended for use in the study of the fractured rock around stopes. It is not our intention to represent the behaviour of this type of fractured rock by the calculated *in situ* modulus.

(4) We accept that, if a reduced modulus is used for the calculation of ERR (in a stope of limited space), the values of ERR become higher. However, it should then also be assumed that the critical magnitude of ERR must be increased in the same proportion. We tried to indicate that the use of the same ERR value as a critical criterion for different gold-mining districts may not be correct because the *in situ* modulus probably differs considerably from district to district.

(5) We believe that currently available two-dimensional non-linear stress-analysis programs cannot be used for the design of regional support such as stabilizing pillars and backfill. Therefore, the use of an *in situ* modulus for the rockmass in MINSIM-D modelling is necessary for more-realistic simulation of stope closure and stresses. By *realistic*, we mean the ability of the model to simulate the observed deformation and stresses encountered *in situ*.

Reference

1. KIRSTEN, H.A.D and STACEY, T.R. Stress-displacement behaviour of the fractured rock around a deep tabular stope of limited span. *J. S.*

Book review

Tunnel Construction 90. London, Institution of Mining and Metallurgy, 1990.

Reviewer: J.A. Cruise

This is the published volume of papers presented at the Tunnel Construction 90 Conference, which was held in London in April 1990 under the auspices of The Institute of Mining and Metallurgy.

Twenty papers are presented and their titles are listed below.

1. Potential problems associated with rising groundwater levels in the deep aquifer beneath London, by R.N. Craig and B. Simpson.
2. Design and construction of a new service tunnel at Edinburgh Castle, by T.H. Douglas and S. Keeble.
3. Grouting Milwaukee's deep tunnel system, by D.F. Driscoll.
4. Specialist tunnelling processes, by C.K. Haswell and D.R. Gutteridge.
5. Premetro tunnel under the River Scheldt, Antwerp—geotechnical site investigation and instrumentation, by E. Hemerijckx and P. de Schrijver.
6. Tunnelling in chalk, by L. Lake.
7. Tunnelling problems in young Himalayas, by M.M. Madan.
8. Ground vibration associated with tunnel construction, by B.M. New.
9. Pipejacking in water-saturated ground, by M. Nussbaumer.
10. Investigation of power-line transmission tunnels to determine their condition and future maintenance needs, by K. Okazaki, Y. Nakanouchi, and Y. Kaneko.
11. Instrumentation and monitoring on two cut-and-cover tunnel projects, by M.P. O'Reilly, I.F. Symons, and D.R. Carder.
12. Construction of the Malabar outfall tunnel, Sydney, Australia, by A.K. Rogmann.
13 Tunnelling under squeezing conditions: A case history—Maneri Bhali stage II project, India, by G.S. Saini and A.K. Dube.
14. Channel Tunnel—Excavation of the Castle Hill section by use of roadheaders, by A.K. Sandtner.
15. New Studley tunnel—Excavation and support by observational method, by J. Scholey, R.A. Jones, and S.J. Irvine.
16. Integrated approach to geotechnical assessment of rock tunnel stability and performance, by M.L. Sutcliffe *et al.*
17. Grouting of rock mass for mining and industrial projects, by J.S. Szczepaniak, W. Serafin, and Z. Gzik.
18. Sealing systems for movement joints in mechanized tunnelling, by J. Washbourne.
19. Evaluation of tunnel stability in relation to rock stress and displacement aspects, by B.N. Whittaker and D.J. Reddish.
20. Fracture development around tunnels, by B.N. Whittaker, S.F. Smith, and H. Chen.

Of particular interest are the papers on

- the Malabar outfall tunnel in Sydney, which describes the excavation and lining of the submarine ocean outfall tunnels under the Pacific Ocean to rid Sydney's famous beaches of pollution; a main tunnel 4 m in diameter and 4 km long was excavated under the sea using a TBM, and effluent will be released through 0,65 m-diameter risers some 2,5 to 4,2 km out to sea;
- the Channel Tunnel, which describes that portion of the work done by road-headers; and
- pipejacking in water-saturated ground; the paper comments that almost 25 per cent of the tunnel kilometres constructed in the Federal Republic of Germany in the past few years are for waste and utility tunnels, and that 75 per cent of these tunnels were constructed predominantly by the use of pipejacking.

The volume should prove to be a useful reference volume on state-of-the-art tunnelling.