Discussion

Comments on paper* by H.A.D. Kirsten†

Contribution by J.S. Kuijpers‡

Kirsten's paper discusses the potential for seismic activity on faults in relation to depth, span, stope support, and discontinuity strength, and puts forward some explicit conclusions. Quoting from the author, the main conclusions are as follows, together with my comments.

(1) 'The occurrence of seismic events on single geological features can therefore be expected to be similar for different depths of mining in both elastic and partly failed rock.' [p. 11 under 'Depth of mining' heading]

This conclusion is based on a comparison between computer simulations in which the mining depth has been changed but the mining span has been maintained constant. Although the contour profile of the 'seismic incidence' lobe with value 1,0 is not affected by the increase in depth, the magnitudes of the contours within this lobe are significantly higher for the increased depth situation. This is also mentioned in the paper ('...the maximum peak values in the contours for seismic-magnitude potential are very sensitive to the depth of mining' [p. 14 under section (e)]), but this finding is not reflected in the conclusion. As the seismic magnitude is related to both the area of the residual strength lobe and the values within that area, the conclusion from this comparison should be: 'the area within the contour, delineated by the shear to normal stress ratio of 1,0, does not change with different depths if the open span remains constant'. In other words, the zone that is disturbed by mining-induced stresses is directly related to the mining span, and not to the mining depth. (This conclusion can also be reached without doing any computer simulations.) However, the seismic moment is a function of the product of the area and the average ride (slip) within this area. With increasing magnitudes of the ratio of shear stress to normal stress within the disturbed area, the average ride and thus the seismic moment will increase with increasing depth and constant span. It should be noted that larger ratios will result in stronger ground motion.

(2) 'The geometrical properties and values of the contours for seismic magnitude potential ... are reduced very substantially in extent and value for increases in mining span for either type of backfill ... This is an unexpected result as indeed reported by Ryder.' [p.14 under section (d)]

This conclusion is not based on any evidence. In fact, the comparison that is referred to (Figures 15 with 18, and Figures 19 with 21) indicates the opposite, namely an increase (approximately 300 per cent) of the seismic potential area with an increase of 500 per cent of the mining span. This effect is obvious since the extent of the disturbed area is directly related to the mining span. The use of backfill reduces the ratio between the open span and the total span with increasing spans as the closure values increase and the backfill becomes more and more effective. What the comparison really shows is that, with the use of backfill, the area of the zone affected by mining-induced stresses does not increase linearly with increasing stope span, but increases nevertheless. This is caused only by the effect of backfill in reducing the open span, which, again, is directly related to the size of the area within the (shear stress/normal stress = 1) lobe.

The unexpected result as reported by Ryder is completely unrelated to the above. Ryder[1] observed that the open zone of a very large stope span is smaller than the open zone for the critical stope span (Figure 1). As the area within the (shear stress/normal, stress = 1) contour is directly related to the size of the open zone, and an increasing span could lead to a decreasing open zone, it is possible that event magnitudes are (slightly) reduced when the stope span is increased beyond the critical span. Obviously, full closure was allowed for in Ryder's analysis.

(3) 'Contrary to general expectations, the rockburst threat will at least not be worse at greater depth, which is ... reassuring for mining at greater depth in future.' [p. 20 under section (v)]

* *Effect of depth, span, stope support, and discontinuity strength on potential seismic activity in the fractured rock around a tabular mining excavation. J. S. Afr. Inst. Min. Metall., vol. 94, no. 1. Jan. 1994. pp. 1–23.*

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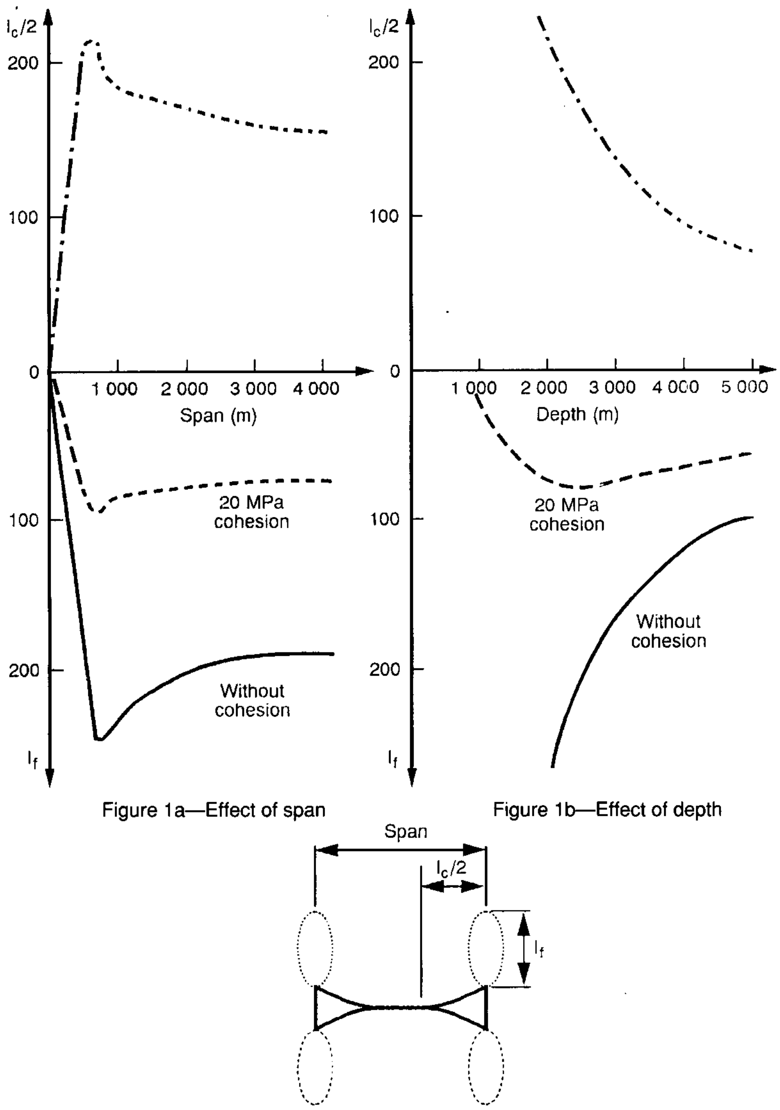

Figure 1—Effect of depth and span on open span ($l_c/2$) and extent of failure zone (l_f)

This conclusion is based on the finding that, with ever-increasing depth and the use of backfill, the values of the contours for seismic incidence potential do not increase, together with the conclusion quoted under paragraph (1) of these comments, where the area of the zone that is influenced by mining-induced stresses is not affected by a change in depth (constant span assumed).

This conclusion is also a highly dangerous generalization because the seismic activity discussed in Kirsten's paper is related only to activity on faults. Ryder[1] also reported that 'an increase in the depth of mining of an isolated stope should in theory be accompanied by a reduction in the magnitude of the associated events', but he did not forget to mention that 'This observation is not well-substantiated by seismic or other data', and it is essential that this conclusion should be considered more carefully; obviously, there is a discrepancy between the results of these analyses and observed behaviour. The following three points will briefly address most of these discrepancies.

(a) Critical strength

A potential fault without inherent strength will slip aseismically and therefore not induce any seismicity. This indicates that a certain threshold stress (depth) has to be reached before any activity can be expected. However, even with this consideration, depths beyond the critical limit will still cause more favourable conditions.

(b) Mining up to a fault at medium and great depth

As can be seen from Figure 2, it is true that less seismic activity can be expected from any single fault at increasing depth for the simple reason that the open span decreases with increasing depth.

(c) Failure of the rock itself

Although explicitly excluded as a source of seismic activity in Kirsten's paper, the failure of the brittle rock itself will occur to a large extent in a violent fashion. Figure 3 shows the geometry of a very simple, but nevertheless representative, analysis in which failure is allowed to occur at every mining step along vertically orientated discontinuities.

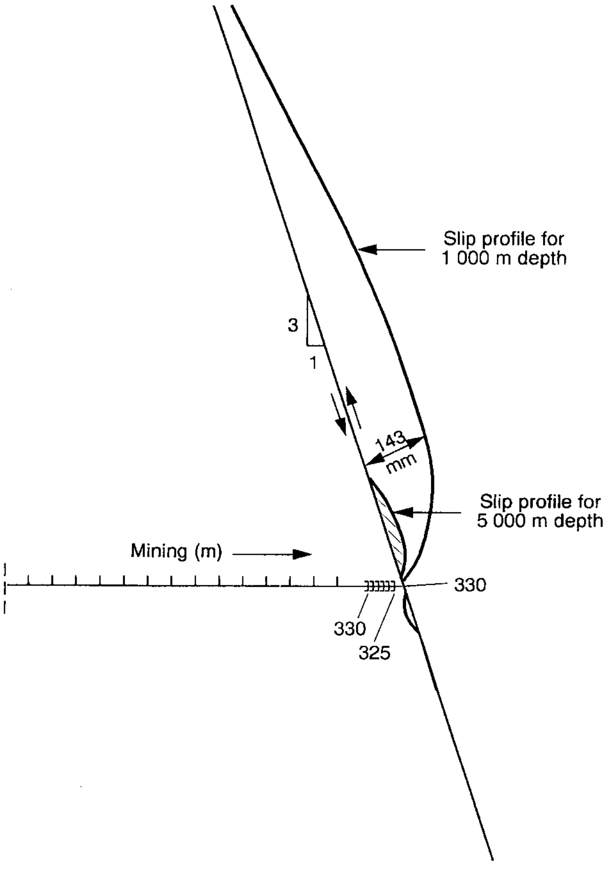

Figure 2—Mining towards a fault: slip profiles for different depths (cohesion = 10 MPa)

From this analysis it is obvious that, at larger depths, much more failure is associated with each mining step than at shallower depths, especially if an inherent strength and consequent stress drop is associated with the slip on the discontinuities. Assuming that failure of the rock around the excavation may occur seismically, the following is proposed: with increasing depth, the seismic activity associated with fracturing around an advancing longwall increases, but the seismic activity associated with slip on individual faults decreases in magnitude.

The findings put forward in my contribution are very basic, but may assist in providing a better and clearer insight into some of the factors that are of relevance to mining at greater depth.

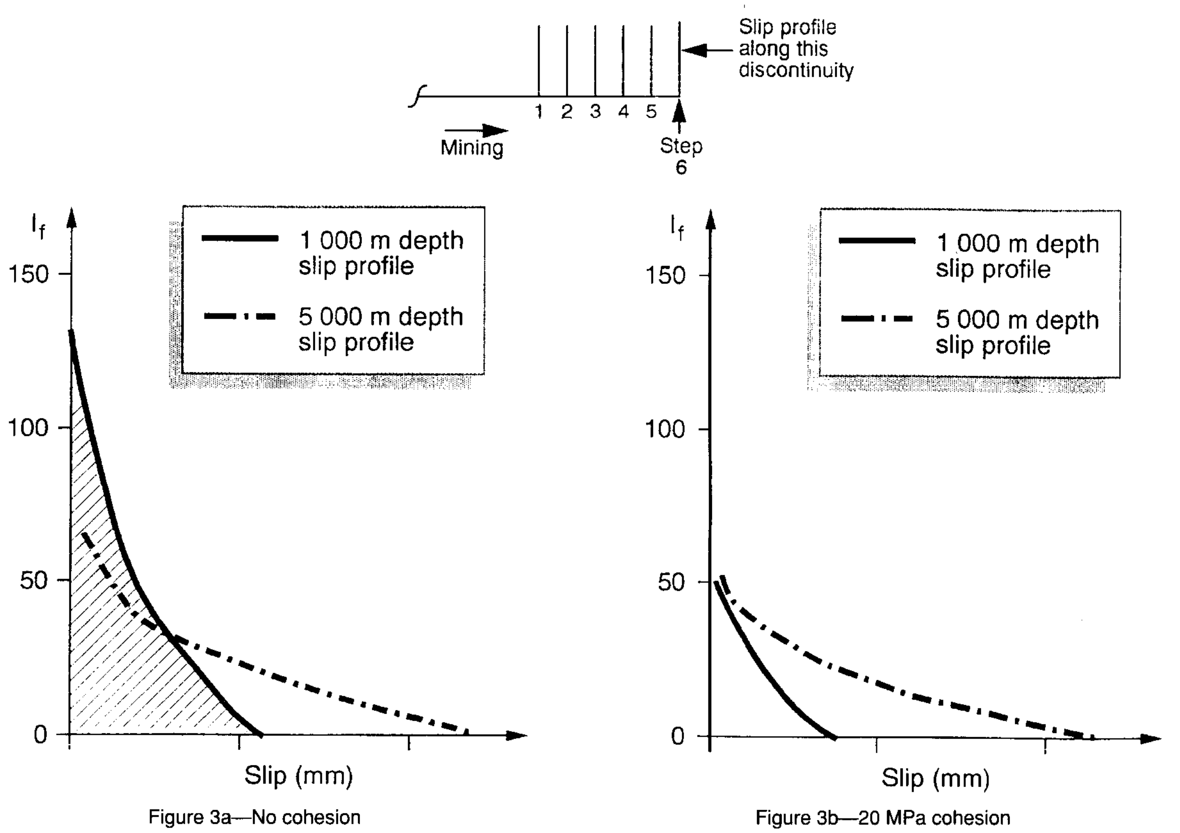

Figure 3—Slip profiles after 6 mining steps for different depths and different peak strengths

Reference

1. Ryder, J.A. Excess shear stress in the assessment of geologically hazardous situations. *J. S. Afr. Inst. Min. Metall.*, vol. 88, no. 1. Jan. 1988, pp. 27–39.

Author's reply

The author gratefully acknowledges the contribution to his paper. It provides further elucidation to the very complex problem of quantifying the effects of mining-induced seismicity. The mechanical behaviour of rock under seismic excitation has been sadly neglected over the past twenty years, during which attention was almost exclusively focused on the study of the spatial location of seismic events. It is to be lamented that, on the eve of South Africa's movement to significantly greater depths of mining, so little quantitive information is known about the mechanical effects of seismicity. It is a challenge at this stage to make up for this lapse in knowledge in the shortest possible time.

An associated problem that will require to be addressed with equal resolve is bridging of the gap between the development and the application of the advanced rock mechanics technology that will be required if mining is to be pursued on an economically viable basis at greater depth. The research organizations are mainly responsible for the development of the technology, and management, with the assistance of the resident rock mechanics personnel, for its application.

A need exists for another function between these two phases. It relates to the translation of the findings of advanced research into practical applications largely as exercises in design and communication. Whereas the rock mechanics personnel on a mine have the capability to fulfil this function, they generally do not have the time to pursue designs with the extensive and intensive attention required. This results in the inefficient exploitation of very expensive research results. Engineering consultancies may well be introduced as an identified approach to provide this function. Discussion across the pages of the *Journal*, of which the above is an example, admirably assists in bridging the gap in terms of communication. ◆