Quantitative rockburst hazard assessment at Elandsrand Gold Mine

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Synopsis

A quantitative rockburst hazard assessment procedure was introduced on Elandsrand Gold Mine at the end of 1994. It is currently used to evaluate the seismicity-related risk in production areas on the mine. Six parameters related to seismicity, geology, mining layout, and production are rated and results are used as a planning tool on a regular basis. The applied assessment can be considered successful in that it promotes awareness of the seismic hazard and provides an opportunity to address seismicity-related mining problems.

A comparison between high risk panels and those working areas with rockburst incidents showed that high hazard ratings reliably forecast the occurrence of larger events in the following month but they do not necessarily predict those working places with rockburst-related accidents. From this one may conclude that high levels of seismicity do not coincide with high rockburst rates.

Introduction

South Africa's gold mining at great depth is associated with a degree of seismicity that poses a substantial risk to workers and the mining operation in general. The Carletonville gold field which produced 42% of South Africa's gold in 1995, recorded 41 rockburst fatalities amongst its workers in that year[1]. The financial burden on the mines in terms of direct and consequential losses is considerable. A medium size operation like Elandsrand GM estimated its loss due to seismicity at around R10m in the year 1995.

Elandsrand has developed and applied a rockburst hazard assessment that evaluates several mining- and seismicity-related parameters for each working area on a monthly basis. The procedure described here differs from other rockburst risk assessments that are using a statistical approach[2] based purely on seismic data or on time-dependent changes in seismicity in confined seismogenic areas[3]. Recently, computer-based expert systems for rockburst hazard assessment have emerged which allow evaluation of a large set of parameters[4,5]. Our method is based on six parameters and is suitable for assessing a large number of working places on a monthly basis.

Elandsrand Gold Mine

Elandsrand is situated in the Far West Rand region approximately 80 kilometres southwest of Johannesburg. The Ventersdorp Contact Reef is being mined with Elsburg Quartzites in the foot- and Ventersdorp Lavas in the hangingwall. The sequential grid mining method is applied in the sub-shaft area between 2100 and 2700 metres below surface. Dip stabilising pillars are spaced 200m with a designed pillar width of 30m. Average area mined is 40 000 square metres per month, producing 200 000 tons of ore. Gold production in 1995 was 16.3 tons.

Major geological features in the form of faults and dykes trend north-south and are generally steeply dipping. Faulting is prevalent with largest throws measuring approximately 60 metres. Some discontinuities are seismically active when negotiated, others show little sign of instability. Intrusive materials sometimes show higher competency than the surrounding host rock.

EGM operates a standard ISS seismic system with 23 stations. Tri-axial geophone sites are installed with the majority of stations near the reef horizon. Additional sites on surface and at the shaft bottom provide improved location accuracy in depth. Hypocentre locations are accurate to within ±25 metres inside the network area. This includes all active mining areas and development ends. Minimum magnitude of the network is M_L=0.0, i.e. all events of that magnitude and greater are recorded.

Seismic hazard assessment

In September 1994 a quantitative Seismic Hazard Assessment (SHA) was introduced, based on the 'Mining Alert Level' procedure

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developed by Western Deep Levels South mine for a longwall mining configuration[6]. The assessment procedure was modified to suit Elandsrand's mining conditions.

Evaluated are parameters relating to level of seismicity, geology, mining layout, and face stress[7]. The data is collected from planning officers (planned square metres for the coming month), section geologists (geology rating), and section rock mechanics officers (face configurations and Energy Release Rate, ERR). Two seismic parameters, Average Seismic Index (ASI) and Cumulative Apparent Volume (CAV) are determined from seismic data obtained from the mine's seismic system by using coloured contour plots of the respective parameter. The geology parameter can range between 1 and 8 in order to accommodate the multitude of risk factors and to allow for a greater weight of this parameter while all other parameters range between 1 and 5. A description of the parameters and their scores is given in Table I.

The production parameter differs from all others by not steadily increasing with an increase in total square metres mined. Instead, a moderate production of 800–1200 square metres per month results in the lowest rating of '1' while both very high and very low mining rates are considered a high risk and are rated '5'. In a set of panels with constant face length a drop in area mined results in a lower face advance, possibly giving rise to a deterioration of hangingwall conditions, which in turn increases the probability of falls of ground. On the other hand, excessive production rates tend to increase the level of seismicity and it was therefore decided to increase the score for both very low and very high extraction rates.

All scores are compiled on a spread sheet and a report is added covering the most hazardous working places, the reasons for the high rating, and possible recommendations for improvements. This final evaluation is done by the mine seismologist. The time required for the compilation is approximately two days.

Parameters are evaluated such that a higher score reflects increased risk. Rating is carried out for each set of panels being mined together. On Elandsrand this would include all panels on either the west or east side of a raise between two levels, usually comprising 2 to 7 panels. The total score of all parameters is then translated into a rating for the overall hazard of this working place by assuming the highest ranking of all panels in the set. Therefore, a set of panels is considered as hazardous as the most dangerous of its panels. Totals and SHA levels are related according to Table II.

The assessment yields a number between 1 and 5 for each set of panels mined together, where 1 represents low risk, 3 average, 5 high risk. It is carried out at the end of each mining month and is valid for a four-week period. Sometimes mining conditions and levels of seismicity undergo drastic changes in shorter periods but it was found that one assessment every four-weeks works well in the majority of cases. The assessment in its current form, since it evaluates hazards only, does not constitute a risk assessment in a strict sense. For that to apply, frequency and severity of potential losses would have to be incorporated into the scheme.

Results of the hazard assessment are communicated verbally and in writing to various levels of production management from Mine Overseer to Production Manager. Being a medium-term planning tool, it is usually presented at

Table II

Total	SHA
1..10	1 = low
11..14	2= below average
14..20	3 = average
20..26	4= above average
>26	5= high

Table I

SHA parameters

Parameter	Description	Based on...	Value	Score
Average Seismic Index ASI	reflects the state of stress in the rock mass	previous 4 weeks of seismic data	1..2 2..4 4..6 6..8 >8	**1** **2** **3** **4** **5**
Cumulative Apparent Volume CAV	co-seismic inelastic deformation in km^3	previous 4 weeks of seismic data	1..3 3..6 6..9 9..12 >12	**1** **2** **3** **4** **5**
Energy Release Rate ERR	face stresses in MJ/m^2	layout planned for next month	1..4 4..8 8..12 12..16 >16	**1** **2** **3** **4** **5**
Face Configuration Rating FCR	risk factors: lead/lag, abutment, remnant, overall configuration	layout planned for next month	0.5, 1.0 or 2.0 depending on risk factor (see Appendix)	**1..5**
Geology	risk factors: slope or duplicated reef, approaching/negotiating feature, flat faulting, jointing	layout planned for next month	1.5, 2.0, 2.5 or 3.5 depending on risk factor (see Appendix)	**1..8**
Production	total area mined in a set of panels (m^2)	area planned for next month	0..400 m^2 400..800 800..1200 1200..1600 >1600m^2	**5** **3** **1** **3** **5**

monthly pre-planning meetings where the safety and production performance of working areas is evaluated and where potential rockburst risks are discussed. These meetings also provide a forum for the exchange of recommendations on face configuration, mining rate, sequencing, and support layout. A summary of SHA also forms part of the mine seismologist's monthly report to mine management.

The hazard assessment is generally well received and is considered an additional source of information in the decision-making process, especially its ability to quantify rather than to represent human perception. However, it should be noted that, at times, SHA may be perceived as interfering with a production process that has to satisfy economical requirements. A decision to slow down or stop a panel because of its high rating may not always be an easy one to make.

Case study

The following shall demonstrate the practical application of the SHA procedure to a working place using the example of 88/28 East. Stoping started in November 1994 and was completed in mid-1996; the area is located below a major N-S trending dyke bracketed with a 10m pillar on the downdip and a 5m pillar on the updip side. The ground above the dyke was mined out previously, as was the area to the east of 28 raise line (see Figure 1). A minor intrusion with orientation parallel to the major dyke was expected to intersect at least two of the eight panels planned on 88/28E.

Initially, with only two panels in operation, layout, geology, and stress-related parameters scored low values and the overall SHA rating was 'below average'. Only the production parameter was high accounting for low mining rates as the panels were undercut after ledging. In March 1995 the seismically active Fred dyke was exposed in the E4 panel and ground control problems brought about problems with face configuration and increasing face stresses (Figure 2). The geology score jumped from '1' to '7' and 88/28E received an overall SHA rating of '4' (total score: 24). In the following month this working place experienced three seismic events with M_L>1.0 two of which plotted close to the mining faces and one on the Rubble Dyke above.

During the following months, lead/lags were improved and both seismic parameters scored mostly around 2. Towards the end of 1995 the bottom panels had reached the pillar position, area mined was kept between 500 and 1200m^2 by cycling of the remaining panels, and face stresses were relatively high due to the large strike span and the lack of solid ground surrounding 88/28E (88/28 West had started mining in early 1995). Conditions improved when the total face length and total area mined was reduced. The on-average higher CAV score between September 1995 and March 1996 reflected an increase in seismic source volume as the remaining panels approached the final pillar position.

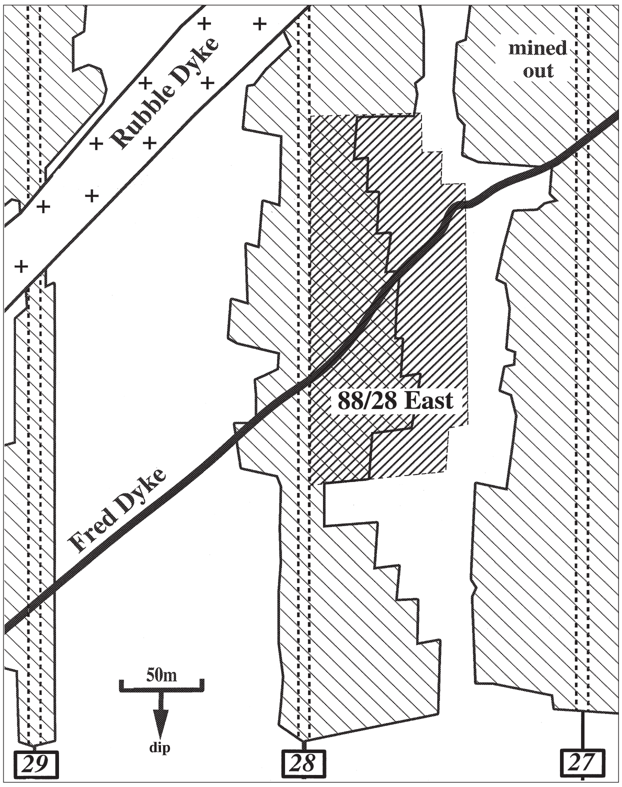

Figure 1—Working place 88/28E (face position: June 1995)

General results

On a mine-wide basis, after the initial implementation of SHA and during a 'settling-in' period of approximately six months, parameters showed some erratic fluctuations in ratings probably caused by incorrect data and lack of experience in the scoring procedure. The monthly ratings began to show trends in early 1995 (Figure 3: average rating of all working places on the mine): It was observed that ERRs remained relatively stable and face configuration ratings improved slightly throughout 1995 as did the stress-related seismic parameter ASI.

At the same time, growing geology ratings showed that the presence of hazardous geological features had not decreased: In 1995, Elandsrand GM mined new ground in the west of the mine which required the extraction of reef in small blocks between major dykes. Due to increased mining

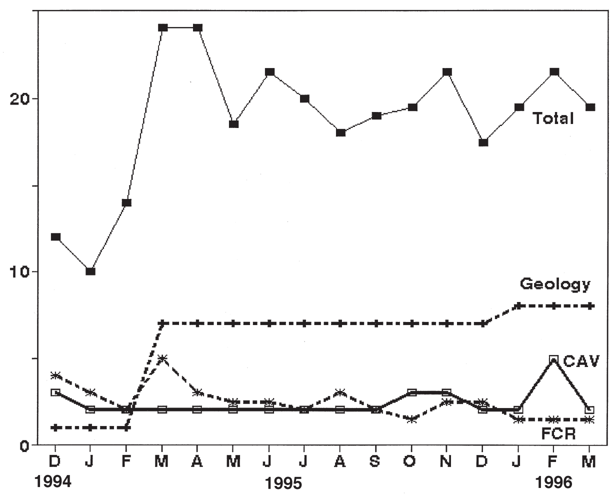

Figure 2—Variation in SHA parameter ratings of the working place 88/28E

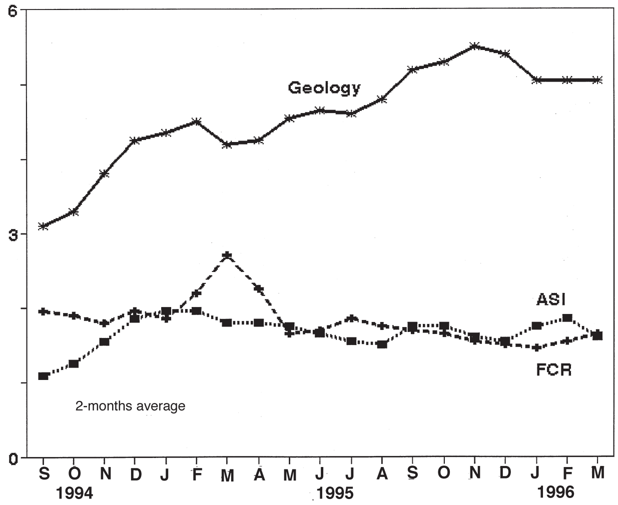

Figure 3—Geology rating increased while face configurations improved (monthly average of all working places)

close to geological features throughout 1995 and the slightly larger event source volumes, the average SHA rating grew during that period.

The Seismic Hazard Assessment is only part of a greater effort by the mine to address the rockburst problem. In recent years, Elandsrand has been engaged in a major training programme in order to raise awareness and general knowledge of rock mechanics principles amongst production personnel. SHA was designed to quantify one of the major threats to a safe working environment in a deep level gold mine and promote discussion of rock mechanics recommendations and their implementation. The continuous drop in large mining-related events observed on Elandsrand is most probably the result of these combined efforts (Figure 4: quarterly events with local magnitude M_L>2.0 associated with mining*). While the number of events associated with the mining faces dropped over the past three years and EGM's production in square metres mined on reef actually increased, the number of large geology- and pillar-related events remained relatively stable.

*In the sequential grid mining environment major structures are usually bracketed with clamping pillars and are not extracted. This allows, in most cases, a clear distinction based on event location between large events associated with an active mining face and events on structures.

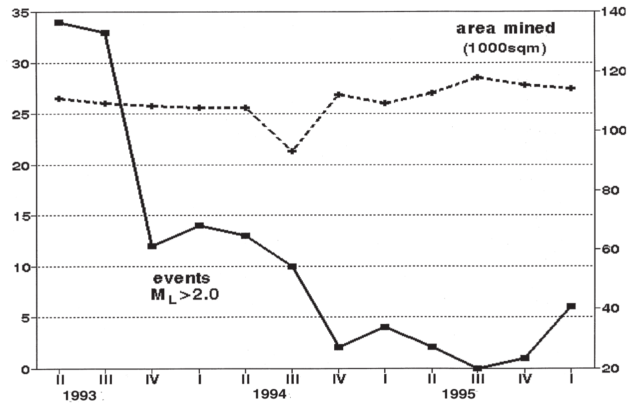

Figure 4—Drop in large mining-related seismic events while quarterly production increased

Such progress in reducing the seismic hazard can only be achieved through a combined effort: Increasing the amount of data available for interpretation, improving the quality of data evaluation, creating a flow of information from the rock engineer/seismologist to production personnel, and finally raising the level of appreciation for this information. SHA should be seen mainly as an instrument to quantify the seismic hazard and to facilitate the flow of information.

Forecasting

However successful in the application of SHA results, the range of parameters covering geology, layout, face stress, and seismicity leaves some uncertainty as to what SHA actually predicts. In order to determine the forecasting capabilities of SHA, correlations between high SHA ratings and three different types of incident were tested: rockbursts, rockburst-related accidents, and level of seismicity. ('Rockburst' is understood as a seismic event that causes damage to an underground excavation with subsequent injury, loss of material/equipment or production shifts.) Over a period of 19 months, from September 1994 to March 1996, the working places with the highest 30 per cent score were selected in each month, thus identifying the areas with the highest hazard potential. These selected areas—approximately five to ten out of a total of 40 to 50 areas assessed in each month—were then correlated with those which had experienced rockbursts, rockburst-related accidents, or had experienced seismicity in the range M_L>1.0.

In April 1995, the 88/28E working place described above received an SHA rating 'above average' with a total parameter score of 24, the highest on the mine. In order to find a possible correlation between high SHA rating and seismic events M_L>1.0, rockbursts, and rockburst injuries, all working places within the highest 30 per cent score (total score of 17 and higher) were selected in April yielding 10 out of 41 areas assessed in that month. For the purpose of this test let 88/28E be area A_1 and the other top-score areas be $A_{2\text{-}10}$.

In the month of April three working places experienced events M_L>1.0, namely $A_{1,2,6}$ and two additional areas whose total score was *below* 17 (i.e. 3 hits and 2 misses). Incidents of the second type (rockburst accidents) were recorded in A_9 and one other low-score area (1 hit, 1 miss); and finally rockbursts were recorded in $A_{7,9}$ and two low-score areas (2 hits, 2 misses). A simple success rate could then be calculated from the ratio hits/(hits+misses) expressed in per cent. The results are described in Table III.

Table III

Correlation between high SHA rating and seismicity or seismicity-related damage in April 1995

April 1995	Rockburst	Rockburst accident	Seismic activity M_L>1.0
Hit	2	1	3
Miss	2	1	2
Total	4	2	5
% success	**50**	**50**	**60**

Table IV

Forecasting capability of the SHA procedure in per cent Hits/Total (779 working place ratings between September 1994 and March 1996)

September 1994–April 1996	Rockburst	Rockburst accident	Seismic activity M_L>1.0
Hit	49	31	88
Total	87	50	125
% success	**56**	**62**	**70**

The same evaluation was then carried out for the period September 1994 to April 1996, the results of which are presented in Table IV. It was found that 70 per cent of the top rated panels experienced increased seismicity (events with M_L>1.0), i.e. that SHA correctly predicts the majority of high seismicity panels. The same working places had 62 per cent of all rockbursts and 56 per cent of all rockburst-related accidents recorded on the mine. Thus, SHA predicts increased levels of potentially damaging events, but it is less accurate in identifying potential sites of rockbursts and related accidents. The reason for this probably lies with the rather large number of factors influencing falls of ground and accident occurrence, ranging from general safety awareness, effectiveness of barring procedures to the quality of stope support systems and to hanging wall conditions in a particular working place.

The fact that high levels of seismicity and accident occurrence are not closely correlated, perhaps indicates that once a panel has been identified as hazardous a successful effort was made to alleviate the negative effects of this seismicity. It would be an encouraging sign, if an early warning resulted in special attention being paid and precautionary measures being taken.

Conclusions

By implementing the Seismic Hazard Assessment procedure on Elandsrand as a planning tool, a contribution was made to the reduction of large seismic events on the mine. While the assessment reliably forecasted the majority of working areas with increased seismicity levels, it was less successful in predicting rockburst accident areas. Further efforts will be made to improve the rating system, to eliminate the less significant parameters and to find new ones that may contribute more to a successful assessment. Following points should be noted:

- The production rating, currently based on planned square metres, is under review. It is felt that this parameter should be based on a scientific evaluation of the production/seismicity-relationship rather than on perception.
- It was noted that average ratings vary with time (Figure 3): after a period of dropping SHA ratings and lower levels of seismicity, no area was higher than 'average'. The absolute scale was consequently abandoned in favour of a relative scale which is based on the average total score of all areas in that particular month. The classification into low or high hazard is effected through the total score being below or above the mine's average by a certain margin.
- SHA does not take account of the quality and type of support measures or the possible presence of backfill. Certain working places on the mine have received high hazard ratings and experienced events with high damage potential over several months without suffering severe losses from rockbursts. In such a situation, production personnel tended to lose confidence in the rating system because of the discrepancy between score and seismic damage. It must be understood that SHA is a pure hazard rating as opposed to a risk assessment that would consider historical and future losses.
- There is a mutual dependence between some of the parameters: seismic energy release and event source size are related to the volume of rock extracted in a non-linear and not well-understood way. A large abutment or otherwise problematic layout would increase the FCR parameter and could at the same time be the location of high stress drop events which would influence the Average Seismic Index rating. The purpose of the seismic parameters in the rating is to allow the seismic history of a particular working place to enter into the assessment, thereby acknowledging that under the same mining conditions higher or lower levels of seismicity can be observed.

In general, SHA should be seen as one step towards a full-scale rockburst risk assessment. Since it evaluates a number of different factors it readily draws attention to the parameter that contributes most to a high rating and allows corrective action to be directed at critical issues.

Appendix

Face configuration rating

Starting score: 1.0
-lead/lag <5m or >10m: 0.5
-abutment of >20m: 1.0
-remnant/special area: distance to holing <30m, history of high seismicity, direct vicinity of hazardous geological discontinuity, ERR: 2.0.

Geology

Starting score normal terrace reef: 1.5
-negotiating/mining away from seismically active feature: 3.5
-approaching seismically active feature 20–40m: 1.5
-slope or duplicated reef: 2.5
-multiple hanging wall jointing: 2.0.

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Top Wits engineering students coin it*

Students in physical metallurgy from the University of the Witwatersrand's School of Process and Materials Engineering won first and second prizes in the annual Powder Metallurgy Association Student Competition in the face of stiff competition.

Ghita Erling, a MSc (Eng) student, took top honours when she won the Parsons Memorial Award of a Kruger Rand for her paper entitled 'Fatigue in Tungsten-Carbide Cobalt'.

Ghita expects to complete her MSc (Eng) degree next year (1998). Her paper forms part of the research for her degree, including experimental and theoretical work.

Andrew Masongwa, a fourth-year physical metallurgy student, was judged second by the narrow margin of a single point and won a half Kruger Rand for his paper 'Effects of VC Additions to WC-Co alloys'.

The Parsons Award forms part of the Powder Metallurgy Association (PMA)'s annual conference and the competition is open to all undergraduate and MSc students in physical metallurgy researching powder metallurgy-related topics at South African universities. Marking for work by MScstudents is more rigorous. Presentations are judged by the PMA committee and invited overseas keynote speakers.

Presenting the prizes was Ian Northrop, Chairman of the PMA, who said the standard of competition was very good. 'This year saw the largest number of contestants ever, and the competition was characterized by the closeness of the marks awarded to the students.' ◆

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Ingwe's Rick Mohring heads up SAIMM

Ingwe Executive Director and Senior Manager—Operations, Rick Mohring, has been inaugurated as the 101st President of the South African Institute of Mining & Metallurgy (SAIMM). Mr Mohring will be President for the 1997/8 year. In his Presidential address entitled 'The South African Coal Industry: Current Position and Future Challenges' he outlined the rapid growth of the South African coal industry post-1970 and the significant contribution it makes to the country's economy and the international energy scene. He stated however, that the industry faced many challenges in a very competitive environment including the need to remain cost -ompetitive despite pressures on the environmental and safety and health fronts and a deteriorating resource base. ◆