Bringing seismological information to Rock Engineers and Production Personnel

By F. Essrich, SiM Mining Consultants (Pty) Ltd.

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Introduction

The loss of resident mine seismologists on SA gold mines over the past years has created new motivation for the discipline to find means to bring seismological information to its main customer base: Mine management, production personnel, and rock engineers. Increasing mining depth and the greater role of remnant extraction in ore reserves has ensured that the rockburst risk is still amongst the main threats to safe operations in the South African gold mining industry: During the period 1990-98, the Carbon Leader and Ventersdorp Contact reef horizons experienced 2-3 times as many rockburst fatalities as rock fall fatalities per million square metres mined (Roberts et al, 2001). At the same time, the advances in monitoring technology have shifted the boundaries of location accuracy and sensitivity that existed a decade ago. Network technology now enables us to pre-record and store several hundred events simultaneously underground, perform automatic processing, and then selectively send only that data to surface that is of required quality and that is likely to contribute relevant information to subsequent data evaluation.

As the hardware became more sophisticated thanks to development done by network suppliers, the theory of rock mass failure was enhanced with new concepts: Seismic deformation of the rock mass as a process of flow in a 'viscous' medium (Mendecki, 1997), characterisation of geotechnical regions as stiff or soft in terms of their seismic response to mining (van Aswegen et al, 1999), or a possible explanation for non-linear frequency magnitude distributions often observed in seismic event populations. Multi-modal behaviour in event populations was discussed by Ebrahim-Trollope [1997] and by Finnie (1999), possible reasons were suggested by Richardson & Jordan (2000). These concepts have enriched the palette of 'images' that we use to picture the processes behind seismic failure. Important parts of the seismological research were funded by the industry through SIMRAC, some drawing criticism for not being understandable by users and for not being implemented on the mines.

While the SIMRAC research earned a reputation for being costly and sometimes lacking the desired impact, mine-based seismologists have made efforts to develop tools and practices that are applied and integrated. This paper is mainly about tools, the application of mine seismology to provide answers to relevant questions, the integration of seismology with other disciplines present on the mine, and ways and means to cooperate in order to reduce the severity and frequency of hazardous incidents related to mining induced seismicity. The principals of successful interaction are neither complex nor difficult to understand, unlike some of the theory referred to above. The author is convinced that, in many cases, the questions facing mine seismology are straightforward, and the answers and solutions do not need to be complex.

Environment

In the mining environment the seismologist regularly interacts with mine management, production management, and specialists from other disciplines, mainly rock engineers. Apart from technical tasks like network design and seismic system management, main aim of the interaction is to either exchange information or to collaborate in problem solving. In general, the objectives of the combined efforts can be...
grouped into measures of risk reduction and efforts to reduce losses resulting from seismic failures. Examples for either group are:

*Risk reduction:* Identify sources of seismic energy emission and their relative hazard level; optimise mining layouts to lessen seismic energy release; identify seismically active geological features; identify trends and patterns in seismicity; devise regional support strategy; train in order to raise appreciation for seismic hazard; establish channels of communication and assign responsibility to take action when necessary; assess seismic hazard of part or whole of the operation; evaluate risks of selected or entire mining processes;

*Loss reduction:* Advise in ground support strategy; identify rockburst and injury scenarios; devise effective safety pillars; evaluate rockbursts; design procedures, assist in their implementation; raise awareness of seismic risk; quantify seismicity related losses; help to manage emergencies; assist in contingency planning; estimate seismic hazard level of future mining projects;

These are fields of activity for seismologists grouped around the central themes of risk management and loss control (Figure 1). They present an opportunity to assist the mining process in managing the seismic risk by reducing either frequency or severity of hazardous incidents. From above list one may conclude that not only the seismic hazard but seismicity as such can be managed. If we succeed in reducing levels of seismicity and not only its negative effects we have actively controlled this hazard.

The risk management process is commonly defined through four components: Risk Quantification, Evaluation, Control, and Financing. Mine seismology can assist in all four of these steps by identifying sources of seismicity, quantifying their relative importance, recommending steps to treat and/or terminate risks, and quantifying the financial losses resulting from seismicity.

The following chapters illustrate a number of methods used to transfer knowledge gained from the interpretation of seismic data on mines. The emphasis is, in this case, not on the results obtained but on the methodology used to convey appropriate answers to the pending questions. In each case, the results of seismological evaluation are shared with the relevant customer base in a way that is comprehensible and easy to relate to through a combination of appropriate terminology, graphic formats, or the means of communication. Often, the chosen format was the result of negotiation between seismic specialist and customer in order to ensure that seismological information is appreciated and utilised.

![Figure 1: Factors contributing to seismic risk levels (left); factors determining the severity of seismicity related losses (right).](image-url)
Examples

Fields where seismology can contribute to and interact with other disciplines and help solve problems are numerous. To demonstrate the nature of questions raised by production personnel and rock engineers and to show the method used to find answers, the examples will be presented anonymously, without reference to the environment where they originated from. The following examples stem from mining operations in either South Africa or Australia. The author gives his assurance that all cases are genuine.

1. Layout and Mining

Frequently, in the context of mine design, rock engineers and production personnel face the question of critical dimensions: Are stabilising pillars wide enough and is their spacing sufficient? Do bracket pillars reliably prevent slip on a structure as designed? Does backfill reduce regional stress levels sufficiently to impact on seismic energy emission? At what length does an abutment fail at given depth? Is there an upper limit to the total face length that should be mined contiguously? When extracting remnants, at which width:height ratio does the core of the pillar fail?

Answers to these questions can be attempted where sufficient seismic data is available to build a case. As an example, the question of critical pillar width will be discussed as it was presented on Mine A in the Klerksdorp region that employs a scattered mining layout. Access to the reef blocks is via raise lines at approximately 180m spacing. Panels from neighbouring raises mine towards each other creating an elongated remnant that decreases in width as faces advance (Figure 2).

As pillar width decreases, the width:height ratio decreases leading to potential instability when the load exceeds strength and failure occurs. At a W:H ratio of approximately 5 controlled deformation occurs without complete failure of the core. When the size is further reduced complete failure occurs. This can take place slowly over days or weeks, or suddenly in the form of a seismic event, depending on the loading stiffness of the system.

Six previous pillar extractions were evaluated in terms of monthly mining rate, remaining pillar width, and seismic deformation (cumulative Apparent Volume of events recorded). To summarise the observations from these six cases, median values of all three variables were plotted in Figure 3. Seismic deformation was evaluated by giving the (arbitrary) value of 15 to the month with highest deformation, 10 to the second, and 5 to the third highest. These values merely provide a ranking and help to plot seismic deformation with the other variables, they have no physical meaning. The purpose of combining the three variables into the chart was to emphasise the strong relationship between the three processes.

![Figure 2: Elongated remnant in the shape of a dip-pillar formed between approaching panel sets](image-url)
and to express the results in terms of parameters readily understood by production personnel and rock engineers.

The variable 'seismic deformation' can be related to more readily by production personnel and rock mechanics and is more descriptive than 'volume of co-seismic inelastic deformation' or 'cumulative Apparent Volume'. It refers to the sometimes visible changes in shape and volume that rock undergoes in the process of seismic failure.

The results can be used to raise awareness amongst production personnel when nearing the critical phase when large seismic events are likely to occur, to adjust support requirements, and to generally prepare the crews for increased rockburst hazard. The evaluation of seismic records thus helps to focus on critical items and to be prepared for the possible rockburst damage.

In similar cases, recommendations were made regarding the critical length of abutments, the minimum length of strike stabilising pillars that seems to induce seismic failure, and the maximum number of panels that should be mined together to avoid excessive seismic energy release on the mining faces. In each instance the recommendation assisted the respective mine in the optimisation of layouts and at the same time contributed to reducing potential losses in the future. The latter also applies to recommendations referring to the minimal length of re-entry periods after production blasts in order to minimise the rockburst risk in an Australian gold mine.

### Critical Pillar Width

**Initiator of Investigation:** Seismologist  
**Recipients of results:** Rock Engineers, production management  
**Distribution Medium:** Written report, personal communication, planning meetings

2. **Hazard Estimation**

The Mine Health and Safety Act (Act 29 of 1996) requires a mine to perform risk assessments on all tasks and processes that mine employees are exposed to during the execution of their duties. This legal requirement and the need to prepare for likely

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4 The results indicate that remnant size decreases sharply up to three months before holing. Then one side stops mining and the rate of extraction decreases. This drop is also clearly visible in 'area-mined' which falls below 300 square metres per month. The distance to holing at this point is about 25 metres and the rate of seismic deformation is stable. It is only in the second last month, when pillar width is down to 15 metres, that seismic source size suddenly increases. This can be considered the failure phase of the pillar: A number of larger seismic events occur despite the low production rate. This is probably also the most hazardous phase during the mining of the panel set.
future scenarios through proper planning, is the motivation for hazard assessments when new reef blocks are negotiated. Knowledge of the seismic hazard level associated with the extraction of new mining areas can assist in reducing the losses by adapting support strategy and worker's exposure. It also facilitates proper contingency planning.

Where completely new ground is negotiated, other areas with similar characteristics could be evaluated in order to draw conclusions regarding event frequency, maximum event magnitude expected, or likely severity of damage. When the remnant extractions are planned in an area that was mined previously, the seismic history of the area can deliver useful clues about the hazard level and the likely location of large events.

A statistical hazard estimation based on a truncated Gutenberg-Richter Fit is an example for such a hazard estimate\(^5\). The following example refers to remnant extraction along several major geological features. The type of information provided by seismological analysis allows the rock engineer to adjust support standards, the production management team to decide not only how, but if at all to extract the ground, and, if decided in favour of extraction, how to best negotiate the reef block.

\(^5\) The Gutenberg-Richter graph of a seismic event population describes the frequency distribution of events in varying magnitude ranges. While a cumulative frequency graph is not easily interpreted by non-scientists, parameters such as maximum magnitude and event probability are readily understood. The parameter \(M_{\text{max}}\) represents the unknown area-specific upper magnitude limit, the maximum expected seismic event magnitude. The distribution is model-fitted using either a parametric approach (approximately linear distribution) or a non-parametric approach. Note that in this model \(M_{\text{max}}\) is time dependant.
On Mine B four remnants were planned for extraction along major faults and a dyke in a mining area that was essentially depleted during the previous ten-year period. The remaining ground was located either alongside structures or, as small blocks, in between faults (Blocks B1 to B4 in Figure 4).

Rock engineers responsible for the section requested an estimate of the seismic hazard level in frequency and severity for the area. In general, where sufficient seismic data is available, the following parameters can be estimated:

- **Probable maximum magnitude of events** $M_{\text{max}}$
- **Probable locations of severe seismic failures**
- **Probability of occurrence of large events within 3 or 6 months**
- **Possible relationship between production rate and seismicity**
- **Diurnal distribution of potentially damaging events**
- **Extent of rockburst damage**

In case of the faulted area on Mine B, an analysis of the previous ten years of production under seismic monitoring from a regional seismic network was performed. Most but not all of the above were quantified:

1) The expected $M_{\text{max}}$ for the fault system is $3.6 \pm 0.2$
2) The probable location for such regional failure can be anywhere on Fault System B or on Dyke A, with an increased probability for it to be on the intersection of these structures.
3) The ratio of smaller to large failures, i.e. directly mining related as opposed to regional, is low with more than expected regional events taking place.
4) The frequency of events $M>2.0$ is less than two per year.
5) Most of the medium magnitude events occurred in the morning shift, for large events $M>2.0$ the distribution is more even throughout the day:

- $M_L > 1.0$: Morning 40% Afternoon 34% Night 26%
- $M_L > 2.0$: Morning 39% Afternoon 28% Night 33%

The last point could become relevant when a major rock mass instability is expected and temporary suspension of one of the shifts is being considered. For the area in question, this would be the day shift because of the higher likelihood of large events in the morning$^6$.

With the above, the level of seismic hazard associated with reef extraction within the Central Fault System and alongside Dyke A can be quantified. In addition, the historic clustering of large events on Dyke A suggests that the reef block B1 earmarked for extraction is likely to be subjected to a particularly high seismic hazard level and that its extraction should be reconsidered.

### Statistical Hazard Estimation

**Initiator of Investigation:** Rock Engineer  
**Recipients of results:** Rock Engineers, production management, mine planner  
**Distribution Medium:** Written report, personal communication

A further example for a seismic hazard estimation is an event frequency map for different mining areas (Figure 5). It consists of a mine plan overlain with probability contours to visually assign estimated event probabilities to working areas.

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$^6$ Compared to other areas on the mine this distribution is unusual. On average, the majority of large events occurs during the afternoon blasting shift.
Event probabilities describe one of the aspects of seismic risk - the frequency with which the hazardous situation is present in a working place. This method of communicating hazard information, i.e. colored contours in combination with mine plans, is well suited for production personnel who can easily determine whether their area of responsibility has a low or high hazard level. When plots are provided on a weekly or monthly basis, current and previous ratings can be compared.

Where the location accuracy of the seismic system is sufficient and where the levels of seismicity are such that the contouring algorithm has sufficient data for analysis, the grid size of the hazard map can be reduced to give more detail. Under favorable conditions, each panel can receive a separate rating and the hazard information could be shared directly with panel crews.

**Figure 5: Contour map of seismic hazard (probability of events M>1.5 within 3 months).**

Seismic Hazard Contour Map
Initiator of Investigation: Seismologist
Recipients of results: Production personnel
Distribution Medium: Monthly report, web site

3. Risk Assessment

The obvious shortcoming of the seismic hazard assessment is that it does not consider the potential losses that can result from exposure to the seismic hazard. A situation in which two reef blocks are exposed to the same seismic hazard, but one block has significantly higher grades than the other, calls for a more detailed evaluation. The next step in the development beyond hazard assessments are therefore seismic risk assessments. These are particularly relevant when people are exposed to hazards since injuries must be considered amongst the most severe losses to a mining operation.

The following example describes one form of seismic risk assessment, the quantification of rockburst risk to service excavations in a shaft pillar. Damage to shaft barrels and winder chambers are potentially life-threatening incidents to a mining operation as they have the capacity to injure or kill workers and interrupt operations for extended periods. To have knowledge of risk levels and the type of damage that may be
incurred by seismic events enables an engineering manager to provide for extra protection or to treat the risk by lowering the exposure.

For Mine C, the seismic hazard was calculated separately for each major service excavation in the shaft pillar. Since the potential for damage increases with event magnitude and the likelihood for occurrence decreases as fewer large events occur than small events, the hazard calculation was performed for a number of magnitude ranges. Following a methodology outlined by Handley (1999), each excavation was assigned a probability of rockburst damage based on its volume and the probability of damaging events occurring close enough to result in damage. The likelihood for damage was then combined with the likelihood of people present in the excavation resulting in a risk rating for each excavation. The results for Mine C are listed in Table 1.

<table>
<thead>
<tr>
<th>Mag</th>
<th>M/M Shaft</th>
<th>V. Shaft</th>
<th>Lift Shaft</th>
<th>Winder A</th>
<th>Winder B</th>
<th>Winder C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.05557</td>
<td>0.05557</td>
<td>0.00006</td>
<td>0.00002</td>
<td>0.00002</td>
<td>0.00002</td>
</tr>
<tr>
<td>2</td>
<td>0.17776</td>
<td>0.17776</td>
<td>0.00032</td>
<td>0.00011</td>
<td>0.00011</td>
<td>0.00011</td>
</tr>
<tr>
<td>3</td>
<td>0.21818</td>
<td>0.21818</td>
<td>0.00048</td>
<td>0.00019</td>
<td>0.00019</td>
<td>0.00019</td>
</tr>
<tr>
<td>4</td>
<td>0.00505</td>
<td>0.00505</td>
<td>0.00001</td>
<td>0.00001</td>
<td>0.00001</td>
<td>0.00001</td>
</tr>
</tbody>
</table>

Table 1: Results of seismic risk assessment for major service excavations in the shaft pillar of Mine C

From the results it is evident that the two shaft barrels are exposed to the highest risks and that this risk does not necessarily emanate from the largest magnitude event. The risk for all other excavations is lower by approximately three orders of magnitude which emphasises the importance of all actions aimed at preserving the integrity of the shaft barrels. With above information, the relevant Engineering Manager is in a position to quantify the risk levels relative to other excavations and to initiate relevant actions to reduce the probability of damage. Among these could be a thorough investigation into all possible sources of seismic events in the magnitude range M=2…3 in the vicinity of the shaft pillar trying to reduce their frequency as much as possible.

This method of seismic risk assessment allows a quantification of risk levels of objects, in this case excavations, relative to other objects included in the same study. The results are relevant only in relative terms and cannot easily be compared to the results of risk assessments on other shafts. Yet, there is an obvious need for practitioners to compare risk levels absolute, for instance where remnant mining or shaft pillar extraction is concerned. It would be beneficial to develop methods that not only allow to assess relative risk levels but also risk levels calibrated according to an internationally accepted standard. This would allow management to judge whether the risks associated with certain tasks are at all tolerable and what their execution would be comparable with in terms of other civil engineering tasks, for example. Some efforts have already been made to fill this gap, but future work is needed to continue testing and implementation by bringing together engineers, earth science practitioners, and risk management experts.

7 The intensity of ground motion required to damage intact rock or, in the case of shaft barrels, concrete linings, generally depends on the strength of the seismic source, hypocentral distance, and local rock conditions. Data from the West Rand suggest that a peak ground velocity (PGV) of 0.7m/s is a reasonable approximation (Handley, 1999). Additional rockburst data was evaluated by Kruth (1998) who reported "severe" and "catastrophic" damage from rockbursts in Vaal River Mines at PGVs ranging from 0.006m/s to 0.09m/s (outliers excluded). Other considerations suggest that the differential strain in the free surface during the passage of seismic waves may be more relevant than the maximum amplitude of the ground velocity.

8 Methodology has been developed and applied in 10-15 case studies, e.g. Makinen et al. (2001); details on request.
4. Rockburst Evaluation

The notion that much of seismological analysis relies on the existence of quality data bases is especially true when it comes to the analysis of rockbursts. A mine experiencing rockburst related losses frequently seeks answers to questions like: What are the sources of seismic energy emission? Which types of seismic events cause damage? What are the costs of seismicity related losses and how can they be reduced? Can we characterise damage mechanisms as opposed to failure mechanisms? Are strategies designed and implemented to reduce seismic hazard levels successful, and what developments and trends are evident? A rock engineer may be interested to know if support strategies for seismically active panels are efficient, what ground velocities the support system has to cater for, and which energy absorption criteria must be satisfied.

![Figure 5](image_url) 

**Figure 5:** Evaluation of a combination of rockburst and seismic data reveals the extent of seismic FOG area (a), percentage of rockbursts affecting more than one panel (b), magnitude of damaging events (c), and shifts lost per rockburst (d). N is the number of cases per bin.

These and similar questions can be answered where a combination of seismic and rockburst data has been collected. The following example from Mine D illustrates the variety of information that can be gained from a rockburst analysis. In this case the mine made available over 350 rockburst reports, in addition to the seismic data base for the equivalent period. From the results of the study it was evident that the mine suffered comparatively severe losses from relatively small events\(^9\), that FOG thickness was in most cases within the performance criteria of support types, and that the mine typically lost two production shifts per rockburst incident, roughly equivalent to one panel blast.

\(^9\) The average magnitude of rockbursts was M=1.0, rockburst related falls of ground measured approximately 15m\(^2\) with a thickness of 1m (both medians). The median 2D-distance between seismic source and site of damage was 84m and the damaging ground velocities ranged from 0.1mm/s to 0.73m/s . The correlation between event magnitude (or energy) and FOG area was poor with correlation coefficients R<0.1.
The data also allowed an estimation of the distance between seismic source and damage site and of the ejection velocities. The diurnal distribution of damaging events showed to which extent underground personnel were directly exposed to the hazard and which trends had developed over a five-year period in terms of rockburst frequency and rockburst related injuries. In several ways, the analysis was a benchmarking exercise providing the basis for future comparisons.

**Rockburst Evaluation**

<table>
<thead>
<tr>
<th>Initiator of Investigation:</th>
<th>Mine manager</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recipients of results:</td>
<td>Mine Manager, production management, rock engineer, S&amp;H Department</td>
</tr>
<tr>
<td>Distribution Medium:</td>
<td>Written report, presentations</td>
</tr>
</tbody>
</table>

5. Planning

A rockburst analysis such as the one quoted in Example 4. can also reveal the direct and indirect costs of losses associated with seismicity. On the mine in question costs amounted to between R6m and R8m per year over the period covered in the analysis which has implications not only for contingency planning but can also serve as a guideline for the amount of resources to be made available to reduce the losses and manage the seismic risk. Included in the costs are those for injuries\(^{10}\), equipment damaged or lost in FOGs, lost production shifts, and abandoned panels that became inaccessible after rockbursts or whose continued operation was perceived as being too hazardous.

<table>
<thead>
<tr>
<th>M(_L) RANGE</th>
<th>2.0 – 2.5</th>
<th>2.5 – 3.0</th>
<th>3.0 – 3.5</th>
<th>&gt; 3.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total No. of Events</td>
<td>91</td>
<td>67</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>No Damage (%)</td>
<td>58%</td>
<td>36%</td>
<td>7%</td>
<td>-</td>
</tr>
<tr>
<td>Minor Damage (%)</td>
<td>10%</td>
<td>4%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Moderate Damage (%)</td>
<td>24%</td>
<td>23%</td>
<td>36%</td>
<td>-</td>
</tr>
<tr>
<td>Severe Damage (%)</td>
<td>2%</td>
<td>28%</td>
<td>29%</td>
<td>67%</td>
</tr>
<tr>
<td>Very Severe Damage (%)</td>
<td>-</td>
<td>-</td>
<td>7%</td>
<td>33%</td>
</tr>
<tr>
<td>Too far ‘Back Area’ (%)</td>
<td>6%</td>
<td>9%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Percentage that are Rockbursts</td>
<td>36%</td>
<td>55%</td>
<td>72%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 2: Percentage of damaging seismic events and severity of damage in various magnitude ranges

Where records of rockburst damage have been kept, the mine is in a position to estimate future losses in advance, for example by determining the percentage of damaging events and the likely extent of losses associated with future seismicity. On Mine E this data was available, which led to the information in Table 2. The benefit of such information is evident: It enables the planning manager to cater for lost shifts, damaged equipment, and expected costs of re-supporting certain excavations, and facilitates the setting up of a contingency plan. It helps pro-active management of the seismic hazard by preparing for the likely consequences of seismicity and taking control of the situation.

\(^{10}\) The mine’s ESH department used following estimated cost factors when approximating the financial losses due to injuries (1998 figures): Dressing Case R400, Serious Injury R5 800, Lost Time Injury R55 000, Fatal Injury R700 000. This includes medical treatment, productivity loss, administrative costs, and compensation to the injured employee or family.
6. Procedures

Few mines choose the route of written procedures to implement and support the process of seismic hazard management. This is probably due to the unwillingness to make the necessary resources available, or it may be a reluctance to commit to certain actions following pre-defined incidents. However, those mines that have a dedicated written procedure, probably find that it facilitates the flow of information and removes any doubt who needs to act in which manner following an incident involving seismicity.

Although written procedures can be limited to simple issues like who has to inform the Mine Manager in case of a large seismic event over weekends, they can be elaborate and detailed attempting to cover all types of incidents and emergencies that may occur. The following list details issues that could be subject to regulation by internal procedure on a seismically active mine:

1. **Monitoring Strategy**
   Which mining areas are to be monitored, specify network performance (accuracy, sensitivity), detail frequency and extent of data analysis, describe seismic emission sources;

2. **Quick location**
   Who informs who in case of large, potentially damaging events; specify means (phone/e-mail/fax) and the type of information to be disseminated;

3. **Seismic System Management**
   Nominate person(s) in charge of system management, system administration, and maintenance; list duties; define resources available to the system; select substitutes in case of absence of responsible person;

4. **Daily/Weekly/Monthly summary**
   Who performs various periodic analyses; what methods are to be applied; who receives results of interpretation;

5. **Unusual occurrence**
   What constitutes an 'unusual occurrence', who is to be informed, and by whom;

6. **Seismic Alert**
   Define parameters to be evaluated, methods applied, quantify Alert criteria; who to be informed of Alerts, who to take action, which action;

7. **Rockburst**
   Person(s) in charge of rockburst investigation; aspects to be investigated; who receives results of investigation;

8. **Periodic Hazard Assessment**
   Methods employed, conducted by whom, information distributed to whom;

9. **Communication**
   Select means of communication for various parts of information flow; define boundaries between sensitive and public information, choose suitable platform for communication (e-mail, web-site, newsletters, meetings, written reports, presentations, personal communication).

Each mine may select the relevant topics to be included in its set of procedures. Special applications must be catered for where appropriate, for example where the prime purpose of seismic monitoring is to monitor the caving process in a cut-and-fill operation and not the inherent rockburst risk. The above is a list that should cover most of the deep-level, tabular ore bodies that are mined for gold or platinum in SA.

Implementing detailed written procedures is a step towards successful management of seismicity. It is a form of acknowledgement that seismicity is induced by mining and that certain parameters influencing the level of seismicity are under our control, mining layout being one of them. Rather than portraying seismicity as a 'natural disaster' beyond our influence, it opens the door to a pro-active approach. To adhere to written procedures reflects positively on the management approach and should be encouraged on all levels of the operation.

Several South African gold mines have implemented a set of procedures for the management of seismic risk. An excerpt from Mine E, the 'Seismic Alert Procedure', is...
reproduced here. The initial paragraph states the purpose of 'Seismic Alert', which is 'to define a set of precautionary measures related to different levels of seismic hazard'. The following section assigns the responsibility for data evaluation and describes the way in which results are communicated, including a written document from the Rock Engineering Department to the relevant Section Manager and an e-mail to the planning department for inclusion in the planning minutes of the section.

The following describes the action to be taken when Alert I has been raised:

<table>
<thead>
<tr>
<th>Action: Following steps must be taken when a working place receives ALERT I status:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- continuous monitoring of seismic events with reporting every 24 hours</td>
</tr>
<tr>
<td>- daily evaluation of seismic parameters for possible instability</td>
</tr>
<tr>
<td>- a document to be generated by Rock Engineering to inform the relevant Section manager of the Alert status (refer to Panel rating document)</td>
</tr>
<tr>
<td>- SREO to visit at least three working areas under ALERT I per month in their area of responsibility.</td>
</tr>
</tbody>
</table>

| Procedure: A three-level ALERT system is proposed to manage the seismic hazard in an underground working place. The system provides for different precautions to be taken with each level of ALERT. The level of seismic hazard determines the type of precautions implemented. |

The assessment of seismic parameters is being carried out by the seismologist or by a Rock Engineering Officer who has received the relevant training, preferably by both. It is the responsibility of the mine seismologist to ensure the quality of seismic data evaluated for Alert purposes.

Results of the Alert assessment are documented in form of a checklist (see Appendix). Changes in parameters and possible Alerts are communicated to relevant personnel as stipulated below. In addition, an e-mail message is dispatched to the Planning Department for documentation in planning minutes.

For each level certain criteria must be satisfied before the Alert can be raised. In case of level III, these are:

<table>
<thead>
<tr>
<th>ALERT III</th>
</tr>
</thead>
<tbody>
<tr>
<td>If continuous monitoring of an area indicates fluctuations in seismic parameters that are significant and that exceed following limits, the alert level is raised to III:</td>
</tr>
<tr>
<td>- Change in log_{10} of Energy Index by more than 0.25</td>
</tr>
<tr>
<td>- Decrease in log_{10} of Schmidt Number by more than 1.0</td>
</tr>
<tr>
<td>- Significant drop in Seismic Softening</td>
</tr>
<tr>
<td>- Abnormal temporal and spatial changes in seismicity</td>
</tr>
</tbody>
</table>

These trends in seismic source parameters must be supported by more than one event in order to be significant.

Level III calls for decisive action: The use of shorter drill steel, reduction in the total face length blasted, installation of yielding temporary support, a delayed begin of night shift until midnight, and special instructions to be issued by the Section Manager for the working place. It also demands a visit by the relevant Safety Officer to the respective working area to assess safety standards and working conditions.

The reduction in production rate can be seen as a compromise between complete suspension of blasting which leaves the rock mass without an opportunity to shed energy, and 'mining as normal' which may continue to contribute to the energy build-up anticipated in the Alert. The optimum response to Alert situations is likely to vary from area to area and should be investigated separately. Once detailed data are available,
procedures could be extended by a schedule specifying means of response for different mining areas.

**Procedures for Management of Seismicity**

**Initiator:** Mine manager  
**Recipients of information:** Production management, rock engineer, S&H Department, planning officer  
**Distribution Medium:** Policy and Procedures

Whatever measures are being prescribed, it is important to inform all concerned parties of the special status of a working place. On Mine E, this information is made available on the shaft's intranet web site whose structure is described below. This is one possible tool for effective communication allowing knowledge transfer to take place. The traditional methods of communication (meetings and presentations, written reports, personal communication) have thus been expanded to include a new means of information sharing.

7. **Communication**

Web sites are well suited for the distribution of graphical information, but they require the active participation of the recipient: Knowledge is only made available, it is not directly brought to the user. Usually, there is a lack of time and opportunity to address production personnel in meetings and the web site offers a convenient alternative: Information can be accessed at the user's convenience. The web site is viewable with internet browsers and is located on the network server of the respective mine (Figure 6). All mine personnel with a PC have access to the web site, although this can be limited by the system administrator. The web site contains results of seismic data interpretation for production personnel, hazard ratings and rockburst reports for rock engineers and the Loss Control Department, status of problems and system faults for the Engineering Department in charge of system maintenance, and budgetary information for the Financial department.

In general, information posted on the web site can be grouped into 'current' and 'reference', the former ranging from rockburst reports to the latest seismic Alerts, events statistics and network maintenance, the latter covering a glossary of terms and various procedures pertaining to the management of seismicity on the mine. Thus, the site serves as a provider of the latest seismic trends as well as a source of reference for those interested in mine seismology or in the technical aspects of system operation.

When making seismological information available to the wider work force, one simultaneously needs to address the issue of training. Surely, just to disseminate information is not necessarily enhancing our ability to better manage a hazard. Information, if misunderstood or even abused, can be detrimental. Therefore, the goal should be to facilitate the use of information to the benefit of the operation, i.e. to equip the recipients with the means to appreciate and utilise rather than to be intimidated or misinformed (as opposed to uninformed). It is therefore essential to combine any efforts to distribute information with efforts to train in the correct interpretation.
Figure 6: Layout of the Intranet Web site of Mine E

Main Page

Procedures

Large Events

Seismic Alerts

Glossary of Terms

Rockbursts

Event Statistics

System Installation


**Seismic System Web Site**  
**Initiator:** Seismologist  
**Recipients of results:** Mine Manager, production personnel, rock engineers, S&H Department, technicians  
**Distribution Medium:** Intranet web site

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### Conclusions

Above examples reflect successful attempts of mine seismologists to disseminate seismological information and to share applied solutions to relevant questions raised by rock engineers and production management. They are based partly on new software tools, partly on efforts to bring together and integrate information from several disciplines. They constitute a sample of what the discipline has contributed over the past years to the successful and effective operation of deep level mines with stress-induced rock mass failure.

The author suggests that mine seismology can continue to provide solutions and shed the image of a pseudo-science that generates incomprehensible results that cost millions in research money to produce. We, as a group of specialised geo-scientists, and the industry as a whole need to address and improve on the following:

- STANDARDISE AND SIMPLIFY TERMINOLOGY for basic mine seismology  
- ENSURE RELEVANCE of research initiatives  
- IMPLEMENT research results where appropriate  
- UTILISE the existing seismic data bases  
- FURTHER CO-OPERATION between neighbouring mines  
- STANDARDISE data formats  
- INTEGRATE the knowledge and experience of disciplines

Similarly, the agencies awarding research projects should place emphasis on the applicability of the results and use funding to rather test and implement research findings than to finance the writing of unwieldy project reports that remain mostly unread by the industry. This money-for-paper approach has proven wasteful in the past and needs to be replaced by a strong peer-review component that should be integrated into the project work. Why not utilise part of the funding to compensate mines for employee time that is hen used to test and implement research findings? Research work should be reviewed by practitioners in the industry and their opinion should be crucial for the acceptance and the successful completion of a project.

But there will be no research without quality data. The mines should continue their efforts to operate seismic networks and to maintain quality data bases which are vital for future work of mine seismologists. This applies not only to raw seismic data but to various data from related disciplines: Rock mechanics, geology, loss control etc. Too often a certain practice is only maintained until the next manager takes responsibility. Procedures and standards are changed and one subjective method is replaced by another. In addition, suppliers change data formats and algorithms in their software and historic data is not being converted to the new standard. This practice has a detrimental effect on the quality of raw data, in particular its consistency.

Fortunately, all of the above issues can be addressed. There are no principal boundaries limiting our continued contribution to the safe and profitable operation of deep level mines in South Africa.
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