IMPROVED LOCATIONS OF MINE SEISMIC EVENTS

by Matthew Handley

The deep level gold mines of the Witwatersrand Basin in South Africa have long suffered the human and economic costs of mining induced seismicity. A mining induced seismic event is a sudden and violent release of strain energy that has accumulated in the rock as a result of mining. The potentially damaging mining induced seismic event ranges in Richter Magnitude from 1.0 to 4.0, while devastating earthquakes range from 6.0 to 9.0 on the Richter Scale. Therefore a mining event is much smaller (really a mini-earthquake, often called an earth tremor), in energy terms by a factor of a thousand to a million. Because the mining induced seismic events tend to take place within 50 to 100 m of mine workings, they can cause considerable damage and injury, if they occur close by. The damage to a mine excavation is often referred to as a rockburst, because rock is violently ejected into the excavation by the seismic event, causing injury to those in the excavation, damage to the excavation itself, and damage or loss of mining equipment. Thus, all rockbursts are caused by seismic events, but only relatively few seismic events result in rockbursts. Considering that between 2 to 2.5 million seismic events are recorded annually in the Carletonville Goldfield alone, damage to mine workings is almost a daily occurrence.

Research into mining induced seismicity and rockbursts began in earnest in the 1960's, with resulting benefits in the form of reduced seismic activity and rockbursts by improved mining methods, reduced damage by improved mining supports, and better risk assessment and management through improved seismic monitoring systems. Today, mines are deeper, more extensive, and more seismically active than those of yesteryear, yet the losses due to damage and injury have been reduced by about 50%. Despite these achievements, research goes on to reduce the problem to an absolute minimum.

Most gold mines operate seismic monitoring systems to contain and research the problem. Although these systems have improved dramatically in the past decade, they still suffer shortcomings in locating the sources of seismic events. The location of a seismic event is critically important because not only does a good location provide a guide for a rescue effort, but also all other parameters (e.g. moment, and energy) are dependent on it. Location errors scatter the seismic locations, causing them to plot as diffuse clouds, which obscure any seismic patterns that might be emerging. This impacts negatively on seismic hazard assessment, which is often based on spatial-temporal seismicity trends, hence location error has a direct effect on mining safety. In 2002, the Safety in Mines Research Advisory Council (SIMRAC) contracted the University of Pretoria, the Council for Scientific and Industrial Research (CSIR) Division of Mining Technology, and Integrated Seismic Systems International (ISSI) to collaborate in research to improve current seismic location methodologies, without increasing the cost of analysing data obtained from currently installed seismic monitoring systems.

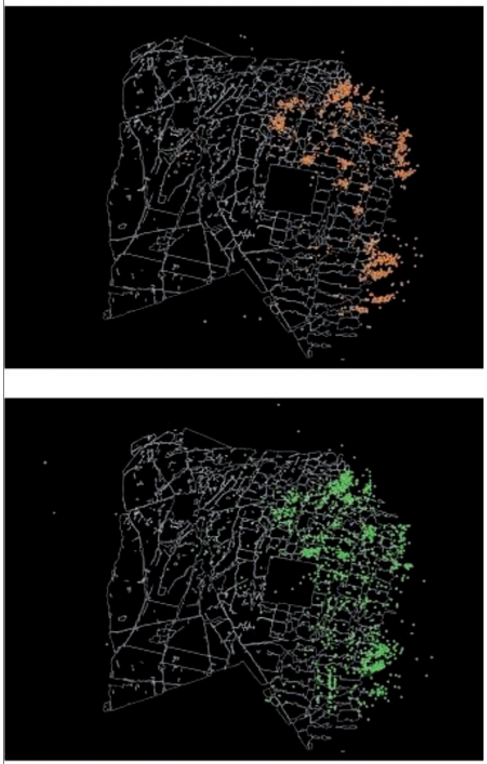
There are two broad groups of event location methodologies, namely absolute location methods, and relative location methods. An absolute location is defined as a once-off location of a single seismic event using some or all the seismograms recorded by the seismic system for the event. A relative location uses some or all of the seismograms from two or more neighbouring seismic events to locate them relative to each other.

The rationale for relative locations originates from the observations of Omori, a Japanese seismologist, who in 1905 noted that horizontal pendulum seismometers produced similar motions for neighbouring earthquakes. Relative locations tend to be more accurate than absolute locations because of the increased utilisation of data from each neighbouring event in the group.

At present both earthquake and mining seismologists use absolute event locations as standard. Absolute location errors in the mining industry range from 30 m to about 100 m, depending on the sensitivity of the system. With errors of this order it is usually possible to pinpoint which working place is closest to the event, and to draw reasonably credible event location – damage distribution correlations. It is also possible to positively identify the most seismically active areas on a mine, and to assess the effectiveness of measures to reduce the seismic hazard.

However, these benefits can only be approximately determined at best, which places mine leadership in the invidious position of having to implement short-term measures to minimise employee exposure to the seismic hazard. Short-term measures consist of deciding whether to evacuate, therefore potentially losing face shifts, to improve stope support temporarily to minimise the probability of a rockburst, or a seismically induced fall of ground, or to continue work as before, thereby exposing employees to a perceived seismic hazard. Since seismic data remains insufficiently reliable for such decision-making, the mining industry has rightly steered clear of any implementation of such short-term measures, excepting in the most exceptional circumstances.

One effective way to improve absolute location accuracy is to install more geophones or accelerometers, that is, to increase the sensitivity of the system so that more data are included in the location. Since the seismic system becomes more sensitive, it records many more events than before, which places a larger load on seismic processing staff. Another rationale for increasing system sensitivity is to improve the reliability of the data on which to base implementation of short-term measures to minimise exposure to the seismic hazard. In a nutshell, increasing system sensitivity improves the potential to reliably predict seismic events, which would have a major



→ Comparison of absolute locations obtained manually (top) and automatically (bottom). The seismic locations are shown as orange and green dots, while the mining excavations are outlined in white. The implication of this work is that automatic locations are becoming good enough to supplant manual location, thereby reducing labour costs, while at the same time speeding up data processing and management. This leaves more time for seismic staff for interpretation, hazard assessment, and risk management.

impact on mine safety. This project explored the potential of an alternative route: get the best out of the seismic system already in place at the lowest possible cost, while at the same time improving safety through more reliable seismic hazard assessment.

This option proposes to leave the seismic system unchanged, and to use relative location techniques to improve location accuracy. All this requires is modifications and additions to existing seismic location software, and will be free from all the other problems associated with more data, and higher processing loads. The relative location techniques can be performed automatically, so they should not add to processing loads on seismic staff. However, biases can creep in, so methods to check this are necessary. The most effective way to ensure the quality of relative locations is to locate the events in relation to a master event of known location. In mining, catalogues of master events could be built up from signals recorded from the daily blast. This may not always be possible, so the mine seismologist could turn to one of the many methods used by earthquake seismologists, who seldom have artificially produced master events of known location to work with.

This study aims to address all these problems and constraints simultaneously, in a way that would be practically implementable in the mining environment. In order for this to be possible the following objectives for a new location algorithm must be met:

1. The relative location algorithm must be able to handle large amounts of data, of the order of 10,000 events per day;

2. It must be able to extract constrained locations from the seismic data obtained from existing seismic systems using one or more of the relative location techniques, with location errors of the order of one magnitude smaller than those currently obtained with absolute location methods;

3. The algorithm must provide clear seismic clustering patterns (i.e. clear images of seismically active features in the rockmass) in the located data, together with a viable means of demonstrating that there are no systematic biases or errors in the images provided;

4. The algorithm must be sufficiently automated in order that it requires minimum operator intervention, thereby minimising location and quality control workloads, while at the same time providing more time for analysis and interpretation;

5. It must provide significantly improved seismic data for management and research purposes;

6. It must be able to relocate seismic events in existing databases retrospectively, thereby creating better quality databases.

The project began on 1 April 2002, continuing for two years to 31 March 2004. The cost of the project totalled R3.2-million with the bulk going to the two outside sub-contractors, namely the CSIR Division of Mining Technology, and ISSI, who were both to develop and integrate relative location algorithms into existing seismic location software for use on the mines. The Department of Mechanical and Aeronautical Engineering at the University of Pretoria also carried out some research on geophone noise, and data distortion because of site effects and geophone misalignment.

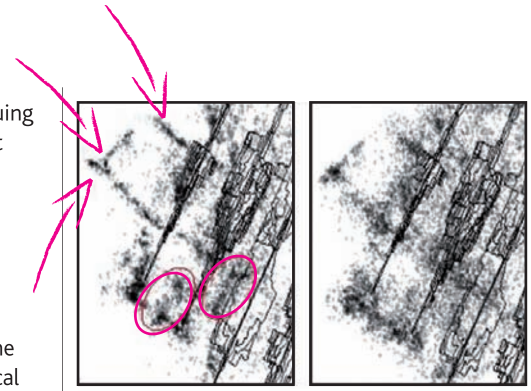
This project has been successful in that it has achieved all the objectives originally set for it. The prime objective, to reduce location error by an order of magnitude (i.e. 10-fold), was considered too ambitious by all the sub-contractors, even though researchers in earthquake seismology had claimed 10-fold error reductions using the double difference method, and a 5-fold reduction in error using the waveform similarity method. These results, obtained from smaller datasets than mining datasets, required meticulous and time-consuming work by the authors, which is impractical in the mining environment because of the manpower cost and the large number of events involved. What this project has achieved is a 2- to 5-fold reduction in location errors when compared with absolute locations, depending on circumstances such as the validity of velocity models, and the accuracy of master event locations.

This achievement has been balanced by another, which is to obtain improved results with minimum operator input and no extra cost, a far more difficult task than had been anticipated in the proposal. As experience with the software grows, and mine-wide velocity models improve with implementation of the software, it is anticipated that the 10-fold reductions in location error will become routine within five years.

Finally, the automatic location algorithm, combined with an automated relative location algorithm and an automatic P-and S-pick inconsistency algorithm, should be able to produce seismic data of a consistently good quality. This will meet another goal, namely to reduce operator workloads, freeing up time for data analysis and interpretation, at no extra cost. This will have significant effects on seismic hazard management, safety, and future research projects, while at the same time making viable seismic prediction a real possibility.

***Professor Matthew Handley**, Department of Mining Engineering, University of Pretoria.*

mhandley@postino.up.ac.za



→ *Absolute locations on the right, and relative locations on the left. The seismic event and blast locations appear as light grey squares, while the mining excavations are outlined in black. The "cloudiness" of the seismic locations in the right diagram is considerably reduced in the left, showing more clearly the spatial relationship between mining and seismic events (magenta ellipses), and improved locations of tunnelling blasts (magenta arrows). Hazard assessments from the diagram on the left are made much easier.*

→ *Testing equipment for investigating the effects of geophone misalignment in the Sasol Laboratories at the University of Pretoria. The geophone is the bright yellow object in the top centre-left of the photograph. The apparatus is used to shake the geophone assembly with vibrational frequencies similar to those measured in the mines, and to determine the fidelity of the geophone record with the machine-input frequency. In this way, the effect of geophone misalignment can be determined and compensation to reduce it implemented.*