MINE STABILITY EVALUATION FROM MICROSEISMIC ACTIVITY

By

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ABSTRACT

Any defect activity resulting from an applied stimulus on a structure will generate a stress wave which travels in the medium under the laws of acoustics, thus the name of acoustic emission (AE). AE techniques can therefore provide information on the deformation of both surface and below ground structures.

Two operating coal mines were monitored from the surface, and both mining activity and post mining microseismic activity were detected. The nature of the detected AE signals demonstrated that there were a range of deformation mechanisms in operation and that some predictive capabilities were possible with the technique.

INTRODUCTION

AE has been used in mines as a structural integrity indication for many years. The use of timber breaker lines which crack and crack as the load condition changes was for many years the only indication of impending roof failure in bord and pillar mines. AE techniques have been developed to a stage where the sophisticated analyses employed can identify defect activity and predict remnant life in civil structures. Encouraging results have also been obtained when these techniques were applied to geological formations. The use of both long and short term Acoustic Emission/Microseismic (AE/HS) monitoring can now be considered as a tool to identify

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the development of failure in intact rock and so provide a possible aid for the prediction of rock falls and roof movement in mines. The fact that AE can detect the activation of a defect under the influence of an external stimulus, means that data about deformation can be obtained prior to the observation of actual failure.

The advent of more sophisticated electronics together with advances in computer technology has greatly extended the boundaries of AE/HS technology. Although the gathering of AE/HS data is not generally difficult if reasonable care is taken, the interpretation of this information is complicated due to the fact that the detected signals are associated with elastic waves that have to travel some distance from the actual source through material which can be both inhomogeneous and anisotropic. Nevertheless patterns of activity can be observed and if some information is available about the propagation path between source and detector then some predictions about the source characteristics can be made. A historical data bank of AE/HS behavior can also be used to predict both stand up time and the onset of possible failure within the rock mass.

AE BASICS

When an object is placed under stress then any defect that is activated by that stress will generate stress waves which propagate under the laws of acoustics. The stress wave initially radiates as a bulk wave with a wavefront determined by the nature of the source and the anisotropy of the medium. On
reaching an interface, some energy will be transmitted into the adjoining medium; some will be reflected back into the material; and some will generate surface waves which propagate along the boundary. These surface waves can be detected by a transducer placed on the boundary. The transducer which generally employs a piezoelectric element, provides an electrical pulse which may then be further analyzed.

A stressed material remembers its previous stress history. In the fact that if a material is stressed then AE is not produced until the previous maximum stress imposed on the material is exceeded. This phenomenon is referred to as the Kaiser Effect. The Kaiser Effect can be violated if there is any recovery in the material or the localized stress distribution is changed. Due to say, crack growth which changes the stress concentration at the crack tip so that it is higher than the general stress in the material.

**AE Signal Analysis**

The most rudimentary analysis of AE events is to simply count the pulses. If every pulse detected increases the count by one irrespective of the nature of the pulse then it is event counting. An alternative is to count the number of times the waveform crosses over a preset threshold which is termed ringdown counting. The higher amplitude pulses will give a higher reading for ringdown counting so this approach gives a crude weighting for pulse amplitude. Event counting together with peak amplitude statistics provides considerably more information (Harris & Wood, 1984).

Source location can be achieved if the relative arrival time and/or amplitudes at an array of transducers is available for each AE source. Much more information is available if the entire pulse can be captured and stored for this allows more extended analyses such as the determination of the power spectral densities. Also the sign of the first excursion of the wave (positive or negative) will indicate whether the source can be associated with an extension or compression although the relationship between the sign and the extension/compression can be difficult without some means of absolute calibration.

**AE/MS Instrumentation**

The basic AE/MS instrumentation consists of transducers, pre-amplifier, filter and a computer for data recording and processing. The transducers used in the mine monitoring programs were combinations of units developed specifically for AE having responses up to hundreds of kilohertz; accelerometers having flat responses up to tens of kilohertz; and some low frequency geophones. The low level signals were initially boosted by a preamplifier placed in close proximity and then the signals were sent along co-axial cable to the main amplifier unit.

The main amplifier provided an extra switchable gain from 10 to 60 dB and also had an envelope detection module so that two outputs were available: an amplified version of the input and a demodulated signal to go to the computer system. The amplified raw signals were passed to digital oscilloscopes linked to computers or a fast ADC card in a PC so that total transient signals could be captured and stored. The demodulated signal passed to a separate computer which allowed peak amplitude statistics to be gathered.

An audible presentation of the received emissions was also provided.

**Waveguides**

The main attributes of waveguides are that they remove a sensor from a hostile environment and also allow information to be gathered from normally inaccessible areas (Wood et al., 1991). Waveguides were used in these investigations and ranged from pipes from the surface to an area
immediately above the coal seam; pipes from the surface to 50-80% of the seam depth; pipes from the surface to 30-40% of the seam depth; and steel pipes driven into the surface soil. and short steel pipes which act as 'natural' waveguides.

MINE MONITORING

A preliminary monitoring program was carried out at Westcliff Colliery near Appin in New South Wales using three transducers attached to methane gas detection pipes. The transducers were placed at different depths. Three other transducers were on nearby rock outcrops. Since there was no direct communication between the mine and the monitoring stations during this preliminary program, the correlation between mine operations and AE activity could only be broadly established after the event. The monitoring was limited to the last three days of extraction of coal from longwall 15.

The AE activity was found to be different as mining conditions and the AE activity were measured. A new borehole was being drilled near the monitoring site and the nature of its operations was reflected in the AE activity. Arrangements were made with the drilling crew to start and stop the drill at specified times and specific data set records were kept for these periods. Analysis of the recorded data indicated that there was a correlation between the AE activity and the frequency of the AE activity. The data recorded during the mining operations were also analysed. A range of waveforms were observed indicating that probably five different active sources were in operation during the mining period. The different waveforms could be identified by the pulse characteristics of rise time, peak amplitude, frequency content and phase (primarily the sign of the first arrival). (Wood and Harris, 1991). Groups of waveforms were detected which indicated that they could have originated from similar sources activated by different stress levels. The indications are that this monitoring program identified activity deep in the mine area which was in excess of 450 metres from the surface, and also activity from areas much closer to the surface.

The detection of events subsequent to some previous minor activity when there was no mining, indicates that the fall of roof areas was being detected.

A way of analysing and plotting the data which can allow simple pattern recognition and differentiate different pulses by observing any clustering, is to plot the average frequency against the ratio of the peak to standard deviation value for each pulse. The average frequency is computed by weighting each value of frequency by the value of the power spectral density at that frequency, and then dividing the sum of these weighted frequencies by the sum of the values of the power spectral densities. Fig. 1 is such a plot for some of the significant data and the variation of waveforms observed is readily apparent as well as the evidence for some clustering. Fig. 1 also has a plot of the peak value against the peak to standard deviation ratio to show the distribution of this parameter.

Fig. 1. Pattern recognition plot for Westcliff Investigations.

Another investigation was carried out at a BHP Colliery over a period of two days. The instrumentation was similar to that employed at the Westcliff Colliery.
where transducers were attached to methane drainage pipes; some stakes driven about a metre into surface soil; and a short waveguide driven into a tree. Some previously installed geophones which were grouted into the coal seam were also monitored. There was only a small amount of mining activity on the first day and the data plotted in the format used in fig. 1 is given in figs 2 and 3. On the second day there was mining activity primarily associated with the cutting of the main gate and the recorded data is displayed in figs 4 and 5. The cutting of the main gate was associated with lower frequency higher amplitude data.

Fig. 2. Pattern recognition plot for BHP for average frequency (day 1).

Fig. 3. Pattern recognition plot for BHP for peak values (day 1).

Fig. 4. Pattern recognition plot for BHP for average frequencies (day 2).

Fig. 5. Pattern recognition plot for peak values (day 2).

In the investigations described above, the relative pulse arrival and rise times indicated that the signal sources were located at a range of levels between the surface and the working area when there was no mining activity. The activity detected during mining generally indicated that the signal sources were at only one level.

The audible representation of the data further substantiated the conclusion that goaf falls were being detected since the sounds heard would at times be likened to ‘marbles rolling down a staircase’ and at other times like ‘emptying a dump truck’.

A puzzling effect observed was the fact that often less emissions
were being detected by sensors placed on waveguides close to the mining area, when sensors on waveguides remote from this area were not. The extent of the activity at the remote locations tended to be higher during active mining. A plausible explanation for this effect was that it is associated with the hydraulic roof supports. If the roof strata is treated as a beam and the support in one area is removed, there will be a tendency for the beam to re-align under the restrictions imposed by the geological material above this beam. Relatively small stress changes in the brittle geological material of this beam will initiate brittle fracture. The hydraulic supports used in the mining operations provide a constraint preventing subsidence and also change the stress distribution in the beam so that the fracture zones are transferred to regions of the beam away from the constrained region and this is why AE activity can be larger at monitoring points away from the actual area being mined. Moving or removing the hydraulic rams will change the stress distribution and relocate the fracture zones which explains why AE is detected from a wide range of levels after the temporary cessation of mining activity.

The hypothesis is supported by an observation of a section of an RTA road construction program at Swansea in NSW where a section of a shallow disused coal mine was excavated for the road. This slice through the coal mine showed essentially vertical brittle fracture cracks in the roof stratum for areas away from the mined region. At the mined region the cracks were seen to be radial and started from the support pillars left after the mining was completed.

Much of the data received via waveguides employing the methane drainage pipes was also detected using the ground level and the 'natural' waveguides, however the signal levels were at least 10 dB lower which meant that only significant events would be detected. The significant amount of information contained within low level activity requires a good mechanical path from source to transducer for its detection, and this was only available for the reported investigation via the pipes going into or close to the coal seam.

DISCUSSION

The AE monitoring of a mine's activities has many aspects, while some forms of monitoring can be expensive and so are restricted in use, consideration should be given to the philosophy regarding mine monitoring. If a mine is monitored for short periods during critical periods such as when mining through a fault zone, it may be possible to provide some advanced warning of rock movement above the mining operations ranging from the onset of microcracking to imminent rock falls. This could be less cost effective than continuous monitoring as equipment has to be provided, installed and a remote monitoring station established for only short periods.

The investigations described previously indicate that a viable monitoring technique is available for mine monitoring. The monitoring can be carried out using transducers located at the surface which are coupled to waveguides extending into or near the coal seam. It may be possible to use waveguides extending only into the shallower rock layers if the strata are composed of competent material. Limited data from short monitoring periods should not be used for long term predictions since the monitoring has only been carried out for a small fraction of the working life of the mine.

If long term monitoring were used, one could consider specific rock strata and outcrops as a beam or unit and consider that the earth as a large testing machine. Geological structures are subjected to stress from naturally occurring loading associated with earth tides as well as the loads produced during mining operations. Locally generated microseismic and/or acoustic emission activity within a structure or formation
will be initially indicative of source or defect activity within the structure. This data can be used to provide a localised structural integrity evaluation and in some instances prediction of damage severity and an estimate of remnant life or pending failure of the structure. Long term monitoring can be used as the basis for a predictive tool in mine operation and maintenance scheduling after the details of local elastic wave propagation have been determined.

CONCLUSIONS

The investigation reported indicates that AE/MS techniques employing transducers attached to pipes which act as waveguides, can be used to successfully monitor geological structures and formations. The nature of the detected waveform is related to the type of source, however unique characterisation will require a more intensive investigation.

The use of acoustic emission techniques to monitor and evaluate structural integrity of civil structures has been used for many years, and by transferring these techniques together with micro-seismic monitoring, it is possible to detect and evaluate activity and so predict any resultant effects on civil structures and the rock mass. This technique can provide a new insight into the response of the rock mass to underground and surface loading, and hence also provide information on possible subsidence.

The initial studies indicate that further development of these techniques will provide some predictive capabilities about mine induced rock movement, provided that adequate information is available on the physical, and geological properties of the material being monitored.

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REFERENCES


