Microseismic monitoring of roof reaction to highwall mining

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Abstract: A microseismic monitoring study was carried out at a highwall mining site at the Oaky Creek Mine, Queensland, in order to assess highwall mining span stability. 320 events were recorded during the monitoring period of which 224 events were mining noise and 96 events were microseismic events. The results show that any fracturing in the roof associated with highwall mining at this location was very minor and the associated microseismic signals are at frequencies greater than 2,000 Hz. The fracturing occurred 6-10 m behind the mining face and appeared to be less intense close to coal seam in the immediate roof. The results suggest that there was little rock failure in the immediate roof at this site.

Key Words: Microseismic monitoring, highwall mining, rock fracture, immediate roof, Oaky Creek Mine

Introduction

Highwall mining is a relatively new mining method in the Bowen Basin of Central Queensland, Australia. It is a method used in surface coal mines which extracts coal by cutting drives into seams exposed at the base of highwall. It is reliant upon the self supporting capacities of the rock mass for success. Consequently, the stability of the unsupported span is one of the major concerns for highwall mining.

Following a successful application of microseismic monitoring in mapping of overburden caving and fracturing associated with longwall mining at Gordonstone Mine (Hatherly et al. 1995) this technique was proposed as a supplementary tool for monitoring the response of the immediate coal seam roof to a highwall mining operation (Duncan Fama et al. 1996). From July 15 to 19, 1996 a microseismic system was set up at the Oaky Creek Mine for the purpose of highwall mining span stability assessment.

The Oaky Creek Mine mines the German Creek Seam of about 2 m in thickness using a highwall continuous miner some 45 m below the ground surface. The immediate roof rocks are dominantly sandstones with numerous interbeded siltstone partings throughout. Laboratory tests show that the sandstone rock at the monitoring site is very soft and weak with its UCS=5-10 MPa. The highwall mining operation at the mine has had varied success and experienced ongoing difficulties in some pits with unsupported span stability (Duncan Fama et al. 1996).
Field monitoring

The part of the highwall mining layout where the monitoring took place is shown in Figure 1. It consists of four consecutive highwall mining entries (Entries 2, 3, 4 and 5) and three pillars. The width of each entry is about 3.6 m. Three boreholes of 100 mm diameter were drilled from the ground surface downward to the top of the coal seam and above pillars. The distance of the boreholes to the edge of the highwall face is about 50 m. In each of the boreholes 2 triaxial geophones were installed at different depth as shown in Figure 2. The interval between the two geophones was 4 m in boreholes 1 and 3. Two geophones with different sensitivity were installed at nearly the same depth in borehole 2. In all holes, the bottom geophone was about 0.5 m above the coal seam. This survey configuration was thought to be sufficient to capture any microseismic event which might occur in the vicinity of the boreholes.

![Highwall Face Diagram](image)

**Figure 1** Highwall mining layout at Oaky Creek Mine showing entries, pillars and locations of geophone boreholes 1, 2 and 3 (H1, H2 and H3). Mining activity is illustrated in Entry 5.

![Vertical Cross Section Diagram](image)

**Figure 2** A vertical cross section showing geophone installations in the three boreholes, looking along the entries from the highwall face. Geophone 3 (G3) is a Sensor-SM6. Its sensitivity is 10 times higher than G1, G2, G4, G5 and G6 which are OYO-GS-14-L3 geophones.

As microseismic monitoring in a highwall mining environment was new to us we had three concerns in planning the monitoring. One was whether there would be sufficient roof fracturing occurring from the 3.6 m wide entries to generate microseismic events big enough to be recorded. The second was the effect of the noise generated by the mining. The microseismic monitoring would have to contend with this and detect the microseismic events against what could be quite significant background noise. The last concern was that as the monitoring was over a very small area the microseismic signals generated from local fracturing were expected to have very high frequencies.
The recording system and the geophones therefore need to have high sensitivity and the capacity to accommodate high frequency signals.

The recording system we used for this monitoring was a BMX Blast monitor produced by Blastronics Ltd of Australia. The high sensitivity range specified for the instrument is within the microseismic window. The system is operated by a computer with preinstalled software. The sampling rate, recording range, sensitivity to small events, trigger threshold value can be adjusted through the software. The system can be run continuously until the storage space of the hard disk is full. The analogue inputs can be sampled at up to 200 kHz and digitised as 8 bit signals. The power supply of the system was a truck battery of 12 volts.

Five triaxial geophones were made using fifteen OYO-GS-14-L3, 28 Hz velocity transducers by putting three transducers together in three orthogonal directions. The sensitivity of the transducer is 0.00289 V/mm/s. The other triaxial geophone used was a Sensor-SM6 with 4.5 Hz geophone elements. Its sensitivity is 0.027 V/mm/s, 10 times higher than that of the OYO-GS-14-L3, 28 Hz transducer. We used this geophone to increase the recording sensitivity. The flat frequency response of these two types of geophones are up to 1,000 Hz. A test conducted by Blastronics Ltd showed that a good response can be achieved up to 2,000 Hz for the two geophones.

All geophones were initially installed in the boreholes below the standing water level but without rigid coupling. The sampling rate for the waveforms was 0.1 ms. A separate trigger level was set for each of the geophones. Once any geophone was triggered the whole system was triggered. However, the system failed to get any triggers during mining of Entry 1. To test for a coupling effect we further coupled the geophones in borehole 1 using gravel. This experiment showed that there was no improvement in the detection of signals in borehole 1. In fact during the whole survey period no events were detected in this holec.

We had expected that system to be sensitive enough to detect very small events through the use of small threshold values. However it was found that the noise level of the instrument was higher than the smallest threshold values specified in the manual. As a result the threshold value had to be kept above the instrument noise level thus restricting the sensitivity of instrument to small events. Another problem was that the instrumental noise level appeared to vary with temperature and changes in battery voltage. Several times the hard disk filled with mistriggers.

As a result the system could not be left unattended over several hours. Constant supervision of the instrument was required during monitoring. We therefore concentrated on monitoring in particular time windows. The recording system was switched on one hour ahead of the start of each entry and kept monitoring for about 3 hours over which time the continuous miner went from 0 to approximately 100 m depth from the highwall face. Within this time frame we did not see a significant change in the instrument noise level. Beyond 100 m depth few triggers were recorded.

320 events associated with the mining activity were recorded during the monitoring period. Of these 224 events are mining noise and 96 events are microseismic events. On July 17 when Entry 2 and Entry 3 were cut past the boreholes, the system was
interrupted many times to allow resetting of the recording parameters. The data for these entries is not usable. The recording was improved for Entry 4 with only a few short interruptions. The best results were obtained on 19 July for Entry 5 by which time a good understanding of the recording system and the behaviour of microfracturing was achieved. The recording was uninterrupted for about three hours. As expected the survey recorded most of the events at geophone 3 (G3) which is 10 times more sensitive than the other geophones, G1, G2, G4, G5 and G6.

Discussion

Basically the system was triggered by two different signals, mining noise of low frequency (200-350 Hz) and microseismic events of high frequency (greater than 2,000 Hz). In all cases the signal to noise ratio was poor.

The number of events plotted against the mining time and the miner distance from the highwall face for Entry 5 is shown in Figure 3. The length of the miner and the first car is 14.2 m and the length of the rest of the cars is 12.4 m. We assume that a car change took 3 minutes and that the car was pushed in at a steady rate.

![Figure 3](image.png)

Figure 3 Number of events against mining time and the miner distance from the highwall face for Entry 5. Events in group A are correlated with mining noise and events in group B are microseismic events.

There are two groups of events shown in the figure. The first one is named group A and occurred from the start of the second car and continued to the end of car 4 which is the position of the boreholes. The signals in this group are characterised by relatively low frequency mining noise. It is evident that the number of events increased as the mining face approached the geophone with maximum occurring about
5 m ahead of the geophone location. It does not show a symmetric pattern with respect to the geophone location and decreases sharply when the mining face moves close to and beyond the geophone. After a quiet period of about 8 minutes there is another strong triggering period which we named group B.

Events in group B are all within the high frequency range. We believe that they are related to microfracturing in the strata. The activity in group B declines sharply. It lasted only for about 6 minutes. The roof fracture appears to commence approximately 6-10 metres behind the working face.

A similar pattern of events was observed for Entry 4 as shown in Figure 4. Mining related events were observed from car 3, peaking during car 4 and declining through car 5. Again there was a quiet period of about 10 minutes before microseismic events of group B type occurred.

Why the mining related events of group A should peak ahead of the boreholes is unclear to us. A decline in activity might be expected once the continuous miner is past because of the effects of the directionality of the wave propagation and possible shielding by the mined entry.

![Figure 4: Number of events against mining time and the miner distance from the highwall face for Entry 4. Events in group A are correlated with mining noise and events in group B are microseismic events.](image)

As evidenced by the fact that the microseismic events were weak and none of them was recorded by more than one geophone, it is clear that the fracturing was small and occurred only in very close proximity to the geophones. No locations of the events
could be obtained. The results agree well with the mining record in this pit in that the highwall mining operation proceeded without major roof falls. It was observed that geophone 5 (G5) located 4.5 m above the seam, recorded more microseismic events than geophone 6 (G6), 0.5 m above the seam. This may imply that more fracturing occurred in the vicinity of geophone 5 than geophone 6. Figure 7 illustrates a model for the microfracturing associated with highwall mining.

Figure 5 A model for the microfracturing associated with highwall mining, interpreted based on Figure 3, Figure 4 and the number of microseismic events recorded at G5 and G6.

Conclusions

An understanding of the characteristics of the microseismic signals and mining noise associated with highwall mining has been obtained from monitoring at Oaky Creek Mine. The seismic frequencies due to mining noise is from 200-400 Hz while the microseismic signals associated with roof fracturing are at frequencies greater than 2,000 Hz. The mining noise is much stronger than the microseismic signals in this monitoring.

Minor rock failure in the roof occurred 6-10 m behind the mining face and appeared to be less intense close in the immediate roof to coal seam.

The recorded events were all very weak and none of the microseismic events triggered more than one geophone at any time. It is evident that the fracturing induced by highwall mining process at Oaky Creek was very minor.

More detailed microseismic monitoring is warranted. However more sensitive instrumentation and sensors better suited to the very high frequencies and low energy levels of the microseismic activity are needed. It is also highly desirable that the locations of the microseismic events be identified. On the basis of our current results, microseismic monitoring using sensors remote (>20 m) from the mining face does not appear feasible.
Microseismic monitoring from this exercise has been shown to be potentially useful for monitoring highwall mining roof failure.

References
