Application of a Microseismic System in Monitoring E26 Block Cave at Northparkes Mines, Australia

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Abstract: Northparkes Mines is a joint venture between North Limited and Sumitomo Group and is developing a 130mt copper-gold resource located about 30km north of Parkes, NSW. Annual production is scheduled to be 5.0 mt using both open cut (1.0 mt) and underground (4.0 mt) mining. One of the most important features is the use of block caving at the E26 orebody. This rock mass is relatively competent, compared to other block cave mines, and the cavability, fragmentation and risk of an air blast were of major concern in the early stage of mine design and planning. It is only through the use of monitoring technologies that the risk associated with selecting this mining method can be reduced.

To understand the rock mass behaviour due to caving, a comprehensive monitoring program has been undertaken. This includes conventional monitoring systems and an advanced microseismic monitoring system. After a long period of investigation it was decided that the Integrated Seismic System (ISS) from South Africa should be used at the E26 block cave mine. The system was then commissioned in October 1996. A test period of two months was required to calibrate the system. The monitoring results show a good agreement with the conventional monitoring. They also show that the microseismic system is a better tool in monitoring cave advancement rather than accurately defining the cave back. Various microseismic periods associated with the identified caving activities are discussed.

Key Words: seismic, monitoring, block caving, ISS, mining

1. Introduction

Understanding the initiation and propagation of a cave is always critical for a virgin caving block. It becomes particularly important in a mine without previous block cave experience like Northparkes Mines. It is desirable that the cave starts up quickly to get the payback for the large capital investment and it must be accomplished safely. During the mine design stage of the E26 block cave project at Northparkes Mines, the timing of caving, cave rate and cave propagation direction were major concerns. In order to provide timely and accurate information on caving a comprehensive monitoring system has been implemented at the E26 block cave. These instruments installed for cave monitoring are time domain reflectometer (TDR), extensometers and open hole monitoring devices.

A microseismic system was considered as part of the monitoring system when planning of the monitoring program began in 1994. However due to the high capital and high ongoing maintenance costs this system was not favoured. In addition, this technology was not proven in monitoring cave propagation even though some applications were reported on gold mining in rock burst condition (Mendecki et
al. 1994 and Aswegan & Butler 1993) and the coal mining environment (Hatherly et al 1995 and Minney et al 1997). It was only after a visit to El Teniente, a panel caving mine in Chile, in May 1996, that the decision was made to install a seismic system. Although the seismic monitoring in El Teniente mine was mainly for the management of rock bursts in a high stress environment, the results indicated that the mine seismicity can be used for interpretation of caving (Dunlop 1996 and Dunlop & Gacete 1997). This was enough to encourage Northparkes Mines to implement a microseismic system for the E26 block cave.

The major objectives of the seismic monitoring included the following:

1) Confirmation of cave initiation and the critical hydraulic radius (CHR) which indicates continuous caving;
2) Determination of cave back profile and cave progression;
3) Determination of the limits of the cave boundary and the projected subsidence zone;
4) Monitoring stress changes and unstable ground conditions in the extraction level.

2. The Mine

Northparkes Mines is located 30 km north of Parkes. The planned production is 5.0 Mt annually to produce 65,000 t of copper and 70,000 oz of gold in concentrate. The E26 orebody is designed to be mined using the block cave technique and to produce 4.0 Mt/year. A section, shown in Figure 1, shows the mine design. The production level is

![Figure 1. Schematic section of the E26 block cave mine](image-url)
set at 9800RL (480 m below surface) with two undercut levels at 9818RL and 9830RL. Caved ore is loaded by electric LHDs from 150 drawpoints and dumped into two crushers on either side of the orebody. The crushed ore is transported to three ore bins through a conveyor system and then hoisted to surface for processing.

3. The Microseismic System

The Integrated Seismic System (ISS) developed in South Africa was chosen because of the following advantages:

1) Advanced data display and processing software (4di);
2) Sophisticated theoretical assessment; and
3) Convenient technical support and maintenance.

The system was commissioned on 3 October 1996 with 10 accelerometers and 10 processing seismometers (PS) units. Two more accelerometers and one multi-seismometer (MS) unit were installed later to increase the coverage for the eastern side of the extraction level. The whole system is controlled by a multiplexer in the Crusher No. 2 chamber from where the data is transferred to surface for processing. The location of these instruments is shown in Figure 2.

![Figure 2. Seismic sensor location diagram](image)

4. System Calibration

Average velocities of a compressional wave (P) and a shear wave (S) are calculated from P and S arrival times from calibration shots. As the velocity model is assumed to be homogenous, the velocity is calculated by:
\[ V = \frac{1}{n} \sum_{i=1}^{n} \frac{D_i - D_r}{T_i - T_r} \]

Where \( V \) is the wave velocity; \( n \) is the number of stations; \( D_i \) is the distance between station \( i \) and the calibration shot; \( D_r \) is the distance from a reference station to the shot; \( T_i \) and \( T_r \) are \( P \) or \( S \) arrival times at station \( i \) and the reference station respectively.

To find the transmission velocities of seismic waves in the rock mass two calibration shots were fired. The first shot was in a geological exploration hole near PS No. 7 at 10030RL with only 4 stations being triggered. Processing of the calibration shot indicated an average \( P \) wave velocity of 3930 m/s, however no clear shear wave was identified for calculation. The second shot was arranged near PS No. 4 and the identified \( P \) and \( S \) velocities were calculated as: \( V_P = 3900 \text{ m/s} \) and \( V_S = 2575 \text{ m/s} \).

A seismic event can be measured by a number of parameters. These parameters include magnitude, moment, energy, apparent volume and energy index etc. It has been found that energy index and apparent volume are the two relevant measurements at the E26 block cave. The energy index, \( EI \), of an event is the ratio of the observed radiated seismic energy of that event, \( E \), to the average energy radiated by events of the same seismic moment \( \bar{E} \) (M) taken from the logE versus logM relation for the area of interest (Mendecki, 1997):

\[ EI = \frac{E}{\bar{E}(m)} \]

\[ \bar{E}(m) = 10^{c_3 \log(M+c_4)} \]

Where \( c_3 \) and \( c_4 \) are constants for a given area.

The apparent volume \( V_a \) for a given seismic event measures the volume of rock with coseismic inelastic strain with an accuracy in the order of magnitude of apparent stress, \( \sigma_a \), divided by rigidity, \( \mu \):

\[ V_a = \frac{M}{2\sigma_a} = \frac{M^2}{2\mu E} \]

According to these definitions a consistently higher value of energy index in a given area may indicate a higher rock strength. A consistently higher value of apparent volume may indicate a weakness such as a fault zone.

5. Characterisation of Data

The data is processed on site, however help can be obtained through a modern connected with the ISS Pacific office in Melbourne. Data processing is carried out on each working day by a mine technician and a geotechnical engineer. In a normal production day 200-300 events are recorded and approximately two hours is required to process these data. Four types of events have been identified at Northparkes Mines (Figure 3). They are:
1) caving events - events in the cave back or near the boundary;
2) crushing/mechanical events - events generated by crushing;
3) blast event - events generated by blasts; and
4) production events - events within or under the broken ore due to production activities such as mucking and also due to the formation and collapse of bridges and arches.

![Graph showing seismic waves](image)

Figure 3. Wave forms at E26 block cave

Most events recorded are mechanical events from the two crushers. These events are without clear P and S arrivals and are easily identified and rejected. Events from blasting are also marked. The remaining events are caving events and production events on the extraction level, which are of most interest for analysis and interpretation.

6. Seismicity Related to Caving

After the bottom part of a block is removed by drill and blast the created room allows the rock mass to fracture under gravity. Seismic events are produced through rock mass fracturing. It then continues when production from the extraction level is carried out. Therefore a seismic event corresponds to a rock mass fracture and induced seismicity is always associated with a caving process (Dunlop and Gaete 1997).

6.1 Cave initiation

The E26 block cave had a unique double undercut to improve fragmentation in the early stage of production. The upper undercut at 9830RL commenced in January 1996 with a slot along the western side of the orebody. After the slot was formed the charged rings were fired into the slot. Two rings were fired in each single blast. To ensure no pillar left within the undercut area, a cavity monitoring system (CMS) was used to survey the undercut area through the opened drawpoints. The undercut area
reached 4450 m², hydraulic radius of 10.5m, in April 1996 and it remained stable. Small failures from the back were monitored in the period from May to June 1996 along the western boundary of the orebody. Some of the failures have a volume of more than 5000 m³. As the undercut continued the failure volume increased. By early September the undercut area was 15500 m² with a hydraulic radius of 25.0 m, large scale caving was reached. The maximum caved height was then 30.0 m. However the seismic system was not commissioned until early October 1996 and no seismic information was available for interpretation before then. Since then the cave has been active and the change of the cave back profile is shown in Figure 4.

![Figure 4. Cave advancing of E26 block cave mine](image)

6.2 Surge caving

From the analysis of all the monitoring data it can be concluded that the E26 block cave involves a surge caving process, i.e. a sudden caving up to 20 - 30 m can be achieved. This surge caving is controlled by continuous joints/shears and is considered to be typical stress caving. During mid March 1997 TDR hole No. 2 indicated 25.0 m of fractured rock in the cave back, as shown in Figure 5. During the same period the energy index changed greatly, and a rapidly increased apparent volume of approximately 20000 m³ was monitored. This caving activity was also picked up by the open hole monitoring, a simple probe lowered down an open diamond-drilled hole.

6.3 Cave advancing

As mentioned previously one of the objectives for the seismic system is to monitor the cave back profile. Analysis of the data indicated that an accurate cave back profile cannot be currently obtained from interpretation of the seismic data at the E26 block
Figure 5. Monitoring results from TDR No.2 (lower diagram) & seismic system (upper diagram)

cave. The seismically-active zone is usually within a band of approximately 50 m width, as shown in Figure 6. It is difficult to determine the cave profile with this big band. However when the undercut advances, the seismically-active zone advances with the undercutting.

From Figure 6 two zones, a higher energy zone and a lower energy zone, can be seen above the cave back. It has been found that these zones do not have any implication of different fracturing stages, as was found in the El Teniente mine before the rock falls from the back. They are probably the results of cave back geometry, mining sequence and stress condition at the time. The maximum principal stress is oriented NW-SE
with a dip angle of 5° and the undercut advance was from the west to the east of orebody. The eastern side is therefore in the stress shadow and this possibly contributed to the generation of lower energy events.

![Diagram](image)

Figure 6. East-west section (looking north). Seismic monitoring results from 01/02/97 to 31/03/97

A destressed zone has also been defined. Within this zone the rock has entirely failed and is ready to fall from the cave back. It can be seen that very few events were recorded within this zone. Possibly this zone together with seismically-active zone above can be used for cave prediction.

6.4 Seismicity at the extraction level

During the development of the extraction level in the north west quadrant, seismic noise was reported. Some rock movement caused rock falls. Figure 7 shows a plan view of the seismicity in the area concerned. A concentrated crusher event zone in the west and a truck dumping event zone in the north-west corner can be clearly seen. Seismic events were also concentrated in the north west quadrant of the extraction level. This seismicity was closely analysed and a daily seismic report system was implemented in March 1997 to give advice for the development management.

Figure 8 shows a time history of Energy Index and Apparent Volume. The value of the EI varied greatly between February and mid April. A changing stress condition has been interpreted. This changing stress was due to the unfavourable orientation of the
Figure 7. Seismic activity in the NW corner of the extraction level

Figure 8. Time history of energy index and apparent volume in the NW corner of the extraction level
maximum principal stress and the mining development. This NW-SE oriented maximum principal stress dips slightly to the SE. When approximately 50% of the pillar area at the extraction level was excavated, a local stress concentration resulted. The seismicity was a rock mass response to the stress redistribution.

7. Discussion of Seismicity Related to Caving

Figure 3A shows a typical wave form of a cave event with clear P and S arrivals. These events have a higher frequency compared to the mechanical events and the typical frequency is approximately 1200 Hz, ranging roughly from 1000 - 1500 Hz. The number and magnitude of the events have been used for the evaluation of the seismicity and the interpretation of the caving process.

Figure 9 presents the number of seismic events related to caving on a weekly basis. It is interesting to find that caving was active when the stress was changing at the extraction level from February to April 1997. After mid April 1997 seismic events in both the cave back and the extraction level have decreased greatly.

![Caving Related Seismic Events - Weekly](image)

**Figure 9. Number of caving events triggered weekly**

As mentioned previously most of the cave events are located approximately in a 50 m band above the cave back. This is similar to the figure of 50 - 70 m obtained ahead of a face in longwall coal mining (Hatherly et. al. 1995). However very few events were triggered at the cave front due to a coverage problem for the eastern side of the orebody. It was expected that many more events should be located in the cave front where the stress is concentrated.

A study has been carried out to investigate the caving mechanism. The preliminary results indicate that the seismicity at the E26 block cave is due to shear failure along the joints. The stress level in the cave back is not high enough to cause any fracturing in the intact rock. More studies will be necessary to provide further understanding of the seismicity related to the caving process and the caving mechanism.
Mechanical events from crushers were categorised after a couple of months application of the system. The wave form of a typical mechanical event shown in Figure 3B shows no clear P or S arrivals. Therefore no reliable event location can be obtained.

8. Experience in Using the System

Due to the limited reliability of the automatic processing the data needs to be reprocessed manually. By simply locating the P and S arrivals correctly the location of an event can then be obtained. This location should be checked for consistency against the sensor array’s location. A further adjustment of P and S arrival and a change of the location model may produce a better result. Knowledge on caving progression, production rate, some seismological theory and basic rock mechanics is also useful in gaining reliable information. If there is any doubt the data must be checked/reprocessed. As the energy level and other seismic parameters are calculated from the source location a great difference in these parameters can result if the location is incorrect.

It should be noted that there are several factors influencing event locations. These are associated with:

1) Incorrect P and S pickup;
2) Too much mathematical location error;
3) The triggering sensors being only in a horizontal level;
4) The triggering sensors in a vertical plan;
5) Insufficient sensors to define the location; and
6) Inappropriate location model.

An experienced technician with reasonable knowledge in caving and production progress is able to recognise the problem caused by these causes and correct them.

It is important that the person who does the interpretation should have knowledge in both seismology and rock mechanics. It is also worthwhile to note that the correctly located event is the corner stone for a good interpretation. Incorrectly located events would result in an inappropriate interpretation and therefore would mislead mine decision making.

9. Conclusions

After 14 months use of the ISS system, some preliminary conclusions can be drawn:

1) The ISS system is a useful tool in interpretation of rock mass behaviour under block caving condition;
2) Although an accurate cave back profile cannot be given, the monitoring results can indicate a trend of cave advancement;
3) The mine seismicity indicated changes in the stress condition due to the quick undercut and development rate at the extraction level during the development period;
4) An active seismic period always indicated an active caving period;
5) The system missed the cave initiation and early cave stage due to late commissioning;
6) Sensors would be better located around the orebody and on more than two levels; and
7) A mirror effect on an event location has been identified and it causes uncertainty for an event location.

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References


