Coal Operators' Conference

Faculty of Engineering and Information Sciences

2013

Monitoring longwall weighting at Austar Mine using microseismic systems and stressmeters

Baotang Shen
CSIRO Earth Science and Resource Engineering

Xun Luo
CSIRO Earth Science and Resource Engineering

Adrian Moodie
Austar Coal Mine Pty Ltd

Gregory McKay
Austar Coal Mine Pty Ltd

Recommended Citation

Baotang Shen, Xun Luo, Adrian Moodie, and Gregory McKay, Monitoring longwall weighting at Austar Mine using microseismic systems and stressmeters, in Naj Aziz and Bob Kininmonth (eds.), Proceedings of the 2013 Coal Operators' Conference, Mining Engineering, University of Wollongong, 18-20 February 2019
https://ro.uow.edu.au/coal/437

MONITORING LONGWALL WEIGHTING AT AUSTAR MINE USING MICROSEISMIC SYSTEMS AND STRESSMETERS

Baotang Shen[1], Xun Luo[1], Adrian Moodie[2] and Gregory McKay[2]

ABSTRACT: Cyclic weighting is a major hazard for longwall operations in many deep mines with strong roof strata. Significant cyclic weighting events had been experienced at Austar Mine, resulting in production delays. Early warning of imminent weighting events by means of geotechnical monitoring will help to minimise the risk associated and to develop preventative solutions.

This paper describes a study undertaken by CSIRO and Austar Mine in which an integrated stress and microseismic monitoring system was trialled to detect strata responses to the mining processes. The main objectives of this study were to understand the caving mechanics and develop an effective early warning system for roof weighting management.

The field monitoring results clearly demonstrated the effectiveness of using both stress and seismic signatures to infer longwall caving and weighting events. Stress changes recorded by stressmeters in shallow surface strata and underground roadway roofs showed a strong correlation with the chock pressure increase at the longwall face. The same phenomenon had also been observed from the recorded microseismic events.

In order to develop an automated early warning system for longwall weighting, a trigger index method, which integrates the warning signs from different sensors, was developed and tested against the mine weighting observations and chock pressure data. A remarkably good agreement was achieved. For a limited number of cases examined, the warning signs from the monitoring system mostly occurred at least several hours before the roof weighting events and the major increase in chock pressure. This has demonstrated that the integrated stress and microseismic monitoring system, together with the analysis method developed, is capable of providing sufficient early warning for imminent underground weighting events.

INTRODUCTION

Cyclic weighting is a phenomenon of roof strata break-up, causing dynamic loading on the longwall support system. It is a major hazard for longwall mining operations as it can damage longwall chocks and cause production losses. This phenomenon is more pronounced in deep mines with strong roof strata. Early warning of imminent weighting events by means of geotechnical monitoring will help to minimise the associated risk and lead to development of preventative solutions.

Austar Mine is the first mine in Australia to successfully implement the Longwall Top Coal Caving (LTCC) mining method. The mine is extracting the Greta Seam of 6 m thickness at a depth of approximately 520 m. The main overburden unit is the Branxton Formation which is massive and strong (fine to medium sandstone/silty sandstone/pebbly bands). Significant cyclic weighting had been experienced when Panels A3 and A4 were mined, resulting in significant production delays. It had been observed that, where the top coal (2 m) was not extracted in the central part of the panel, the severity of cyclic weighting appeared to have been reduced. However, the reason for this weighting reduction is not yet understood. To better manage and prevent the damaging cyclic weightings, it is essential to understand which strata units contribute to the loading cycles. It is also necessary to investigate the impact on the weighting frequency and severity of leaving top coal unextracted. Microseismic monitoring and stressmeter monitoring are considered to be feasible methods for characterising and forecasting longwall weighting events.

Microseismic monitoring is an efficient technology for locating rock fracturing events inside a rock mass which is being stressed. The event occurrence and locations can be used to infer the location of high stress regimes and rock fracturing characteristics in the overburden strata associated with longwall mining. Rock fracturing events may be considered as the precursors of a weighting event because the

---

[1] *CSIRO Earth Science and Resource Engineering, PO Box 883, Kenmore, QLD 4069, Australia, +61 73327 4560*
[2] *Austar Coal Mine Pty Ltd, Locked Bag 806, Cessnock, NSW 2325 Australia*

rock fracturing could break up roof beams that may later create excessive load on the longwall support system. In a CSIRO study at Southern Colliery in Queensland, 60% of roof weighting events had microseismic precursors (Guo, *et al.*, 2000).

Stress sensors installed in overburden strata have demonstrated in previous studies the ability to detect caving events occurring behind the longwall face at a distance of at least 800 m from the sensors (Shen, *et al.*, 2008). Using sensitive stressmeters (such as the vibrating wire stressmeter), a small stress change in the roof strata, caused by beam breakage and caving, can be detected at a distant location.

This paper describes a study undertaken by CSIRO and Austar Mine in late 2011 and early 2012 in which an integrated stress and microseismic monitoring system was trialled to detect strata responses to the mining processes at Longwall Panel A5, Austar Mine. The main objectives of this study were to:

- Obtain the key microseismic and stress signatures associated with longwall weighting events;
- Understand the mechanisms of cyclic weighting at Austar Mine through the microseismic and stress measurement data sets;
- Investigate the feasibility of using microseismic and stress monitoring techniques for weighting event forecast; and
- Investigate the ability of partial or no-cave-zones to assist in the management of the cyclic weighting event.

MONITORING DESIGN AND SYSTEM INSTALLATION

An integrated monitoring system was used for monitoring Longwall Panel A5 at Austar Mine. The system is composed of four independent sub-systems, including a surface and an underground stressmeter system and a surface and an underground microseismic system (Figure 1). Each system has its own data logging unit which records stress and microseimic data continuously. Their results, however, can be correlated during data analysis.

Microseismic network

The microseismic monitoring network includes a ground surface array and an underground array. The ground surface array consists of four triaxial geophones which were grouted (using non-shrinking grout) in four 15 m deep boreholes. The lateral spacing of the geophones is about 180-250 m. Seismic signals monitored by the geophones were transmitted through cables to the monitoring station located in the middle of the array.

The underground array consists of three triaxial geophones installed at three cut-throughs near the travel road. Two of the geophones were installed in 5 m long vertical roof holes and the other geophone was installed in a coal pillar right below a ground surface geophone. The underground geophones were connected through cables to a 12 channel microseismic data acquisition unit that was located near the Mains.

The ground surface and underground geophone arrays form an ideal configuration for event detection and location. Manual data downloading was conducted for both of the units once every 4-7 d (depending on battery charged level).

Stress monitoring systems

The surface stressmeter system consists of one biaxial stressmeter and two uniaxial stressmeters which were installed in three shallow boreholes (15 m deep), together with a data logging system. The three holes are approximately 100 m apart along the centreline of Longwall Panel A5. The logging system was located next to the seismic logging station. It was powered by a battery and a solar panel.

The underground stress monitoring system consisted of six uniaxial stressmeters which were installed in the roof at three locations next to the geophones (Figure 1). At each location, two roof boreholes (depth = 5 m and 8 m) were drilled at a spacing of approximately 1 m, and the stressmeters were installed at the ends of the roof holes. All the underground stressmeters were connected through cables to safety barriers before a data logger that was located in the underground monitoring station near the Mains. The stress data were recorded every five minutes.

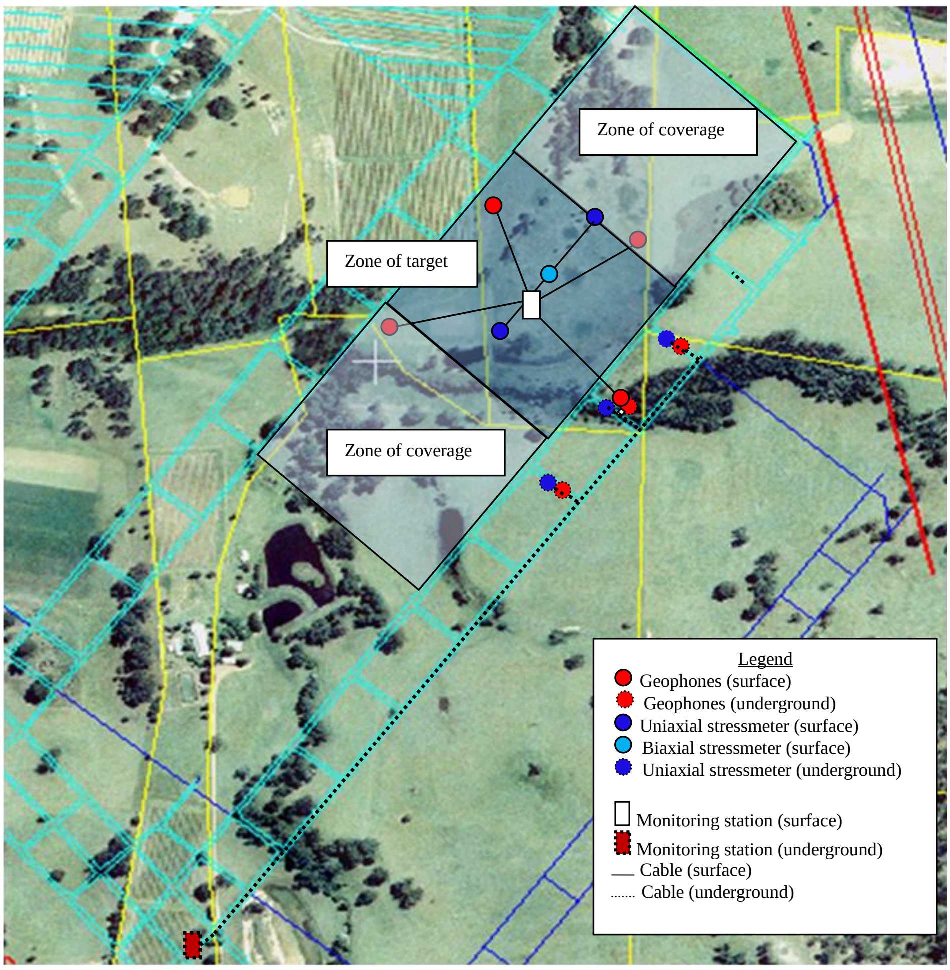

Figure 1 - Locations for geophones and stressmeters in a monitoring trial at Panel A5, Austar Mine

Field installation

All surface stressmeters and geophones were installed during the 12th -13th July 2011 (Figure 2). All stressmeters were orientated in the direction along the centreline of the panel. The two uniaxial stressmeters measures the horizontal stress changes in the mining direction whereas the biaxial stressmeter measures the stress changes in both mining and face directions.

The underground stressmeters and geophones were installed during the 13th -17th June 2011. At each of the three cut-throughs (9CT, 8CT and 7CT), two stressmeters were installed with one oriented parallel to the cut-throughs and the other at a 45° angle pointing at the longwall start-up.

The geophones were installed at the top end of 5 m vertical boreholes in the roof. They were grouted in the boreholes in order to achieve good coupling between the geophones and the rock. Judging from the monitoring results, however, it is suspected that the grout might not have fully covered the geophones at the borehole top ends, possibly due to leakage of the grout. This poor coupling led to data quality below expectation.

Mining of Longwall Panel A5 commenced on the 11th July 2011 and it advanced at an average speed of about 40 m per week.

(a) Surface stressmeter system **(b) Surface microseismic system**
Figure 2 - Installation of surface stressmeter and microseismic systems

MONITORING RESULTS

The monitoring program lasted for approximately six months until the longwall face had advanced to outside the targeted zone. During mining, the top coal of 2 m thickness was left in the goaf for the first 320 m longwall to control weighting. The operation reverted to a full face caving afterward.

Stress monitoring results

The horizontal stress changes in shallow strata at the three monitoring locations are shown in Figure 3. It is noted that the horizontal stress in the shallow strata was generally reducing as the longwall face approached and passed the monitoring locations.

Figure 4 shows the monitored horizontal stress changes in the immediate roof strata at the three underground locations. The underground stressmeters were installed in the immediate roof in the three cut-throughs, 7CT, 8CT and 9CT. Stressmeters 7CTA, 8CTA and 9CTA were installed to measure the horizontal stress change orientated at 45 degree toward the longwall start-up, whereas 7CTB, 8CTB and 9CTB were measuring the stress change in the direction parallel to the cut-through (or longwall face direction). The distance between the three cut-throughs and the longwall start-up was approximately 360 m, 260 m and 160 m respectively.

It was observed that the horizontal stresses in the 45 degree direction to the longwall face (8CTA and 7CTA) increased as the longwall face passed the monitoring locations. Stresses parallel to cut-throughs (8CTB and 7CTB) decreased after the longwall face passed. Horizontal stresses at 9CT (A and B) showed a different trend, both decreasing as the longwall face passed, possibly due to the complex effect of initial caving and 3D geometry as 9 CT is close to the longwall start-up and full caving might not have been developed as the face passed this location.

The results shown in Figures 3 and 4 do not show clear signs of longwall caving events. The surface monitoring results give apparently smooth stress change with time. The underground results showed a few steep changes as the sensors are closer to the face locations and might have been affected by the localised pillar/roof fracturing. However, if the monitored stress changes are plotted in the form of "stress rate", clear signs of sharp changes can be seen from the monitoring results, see Figure 5. The stress rate used in this analysis is calculated over a 15 min duration (three data readings with an interval of five minutes) using the equation below

$$S_{rate}(MPa/day) = \frac{S(t_0+15min)-S(t_0)}{0.0105} \quad (1)$$

where S_{rate} is the stress rate (MPa/d); S (t_0) and S (t_0+15min) are the monitored stress changes at time t_0 and t_0+15min, respectively.

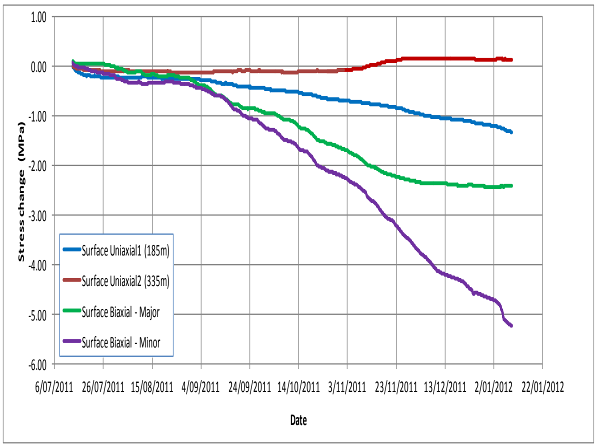

Figure 3 - Horizontal stress changes in shallow strata and monitored by two uniaxial stressmeters (red and blue curves) and one biaxial stressmeter

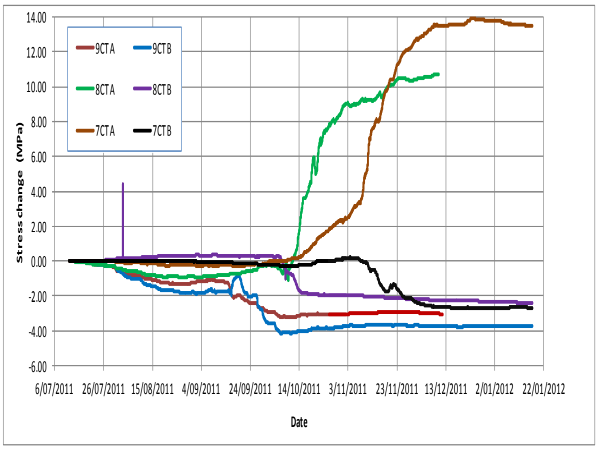

Figure 4 - Horizontal stress changes in the immediate roof strata in three cut-throughs at a respective distance of 160 m, 260 m and 360 m from the longwall start-up

Figure 5 shows an example of the correspondent stress change curve and stress rate plot for the surface biaxial stressmeter. There are numerous clear spike-like changes in the stress rate plot which reflect sudden stress changes although their magnitudes are still very small (e.g. 0.2 MPa/d). Also noted from the stress rate plot is that periodic stress changes occurred with a seven days cycle. A detailed examination showed that the stable period corresponds to the weekends when the longwall mining operation was stopped for maintenance. The monitoring results appear to reflect the mining activities very well.

Microseismic monitoring results

The advantages of using microseismic monitoring at Austar Mine are that this technology can reliably detect seismic events generated by rock fracturing near the longwall face and provide accurate locations of the rock fractures for ground stability analysis. In addition, the techniques can also provide the occurrence time and magnitude of an individual seismic event. The event counts and magnitude levels can be used as indicators for impending roof weighting analysis.

More than 15 000 seismic events were recorded during this monitoring period. Most of the events were weak and only recorded by one or some geophones. It was expected that significant roof weighting events should not be controlled by small events but strong ones. Therefore, only strong events that triggered most of the geophones and have the maximum waveform amplitude (ground vibration velocity) greater than 10^{-1} mm/s were analysed and located.

The seismicity (number of microseismic events against a specified time period) of the strong events is plotted in Figure 6 for the surface systems. Similar results were obtained from the underground system. The strongest event occurred on 26/09/2011 with the waveform amplitude of 90 mm/s. There is a general trend that the seismic event magnitude increased gradually until 26/09/2011 when the largest event occurred. This is followed by a relative quiet period of about 25 d before the seismic activities increased again.

The locations of the strong events in plan view are shown in Figure 7. The majority of the events are located within the longwall panel being mined and with a concentration towards the tailgate side. A number of events occurred in the adjacent panel that had already been mined. Few events were located in the adjacent panel that had not been mined.

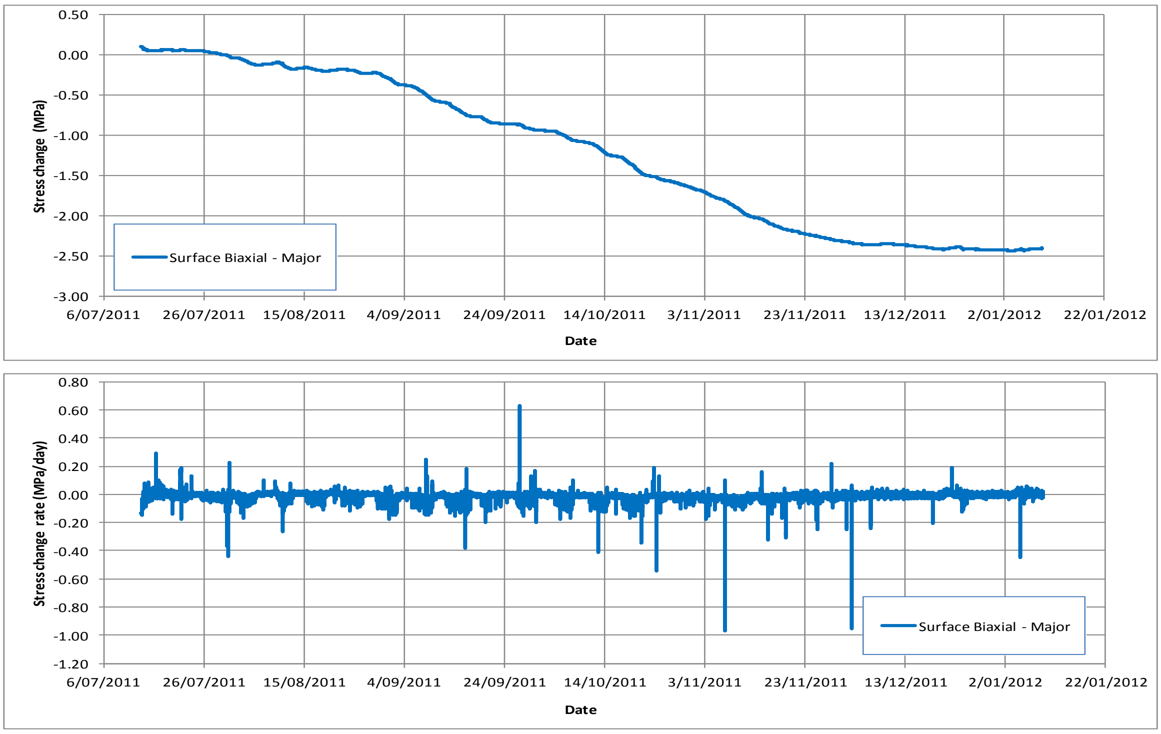

Figure 5 - Comparison of monitored stress change and stress rate, major stress from surface biaxial stressmeter

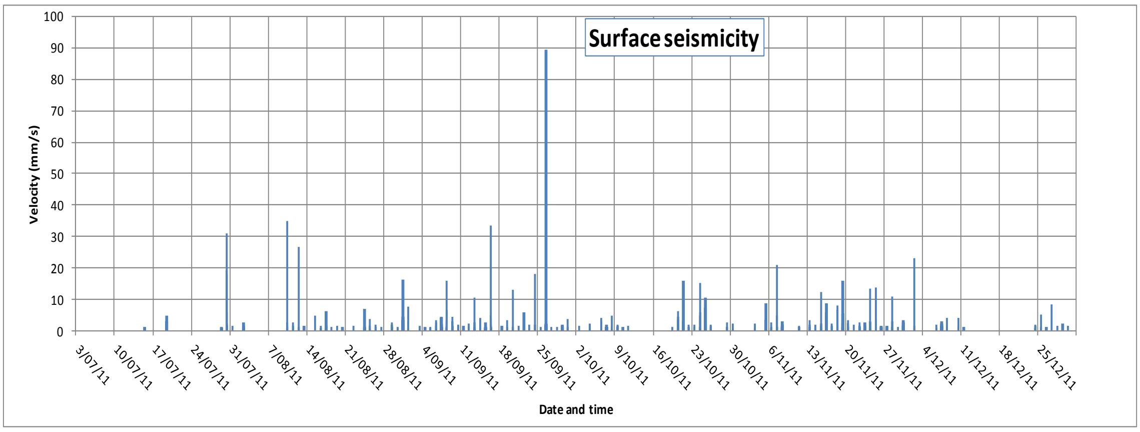

Figure 6 - The amplitude and occurrence of strong seismic events recorded by the surface microseismic monitoring system

A summary of located event distribution vs. depth is shown in Figure 8. It is evident that more than 90% of the events are located in the roof. A concentration of seismic events occurred about 30-150 m above the coal seam, in sandstone/siltshale, or the Branxton Formation which is massive and strong.

DETERMINATION OF CAVING PRECURSORS

Visual examinations of the stress rate plots (e.g. Figure 5) and seismic plots (e.g. Figure 6) can identify events that could be associated with major caving. If the stress rate or seismicity is consistently low for a period of time and then followed by a sudden change like a spike, it often indicates a fracturing event. However, it is important that the level of the background noise due to the instrument itself and normal mining operations is filtered out during this process. Otherwise too many false alarms could result.

One simple way to do so is setting a uniform threshold level above the background noise, and when the spike in stress rate and/or the seismicity energy is over the threshold level, a trigger is considered. This simple method however has a major shortcoming particularly for the underground monitoring systems. When the longwall face is far away from the monitoring location, the recorded stress rate or seismicity is relatively low, and the threshold level is unlikely to be triggered. In contrast, when the longwall face is getting closer to the monitoring location, the stress rate and seismicity can be much higher and even the background noise may trigger the threshold level. It is important to recognise that the real telltale sign for a major fracturing event is not the absolute value of the stress rate or seismicity recorded by the monitoring instruments. Rather, it is the sudden out-of-trend spike that reflects rock fracturing and failure events.

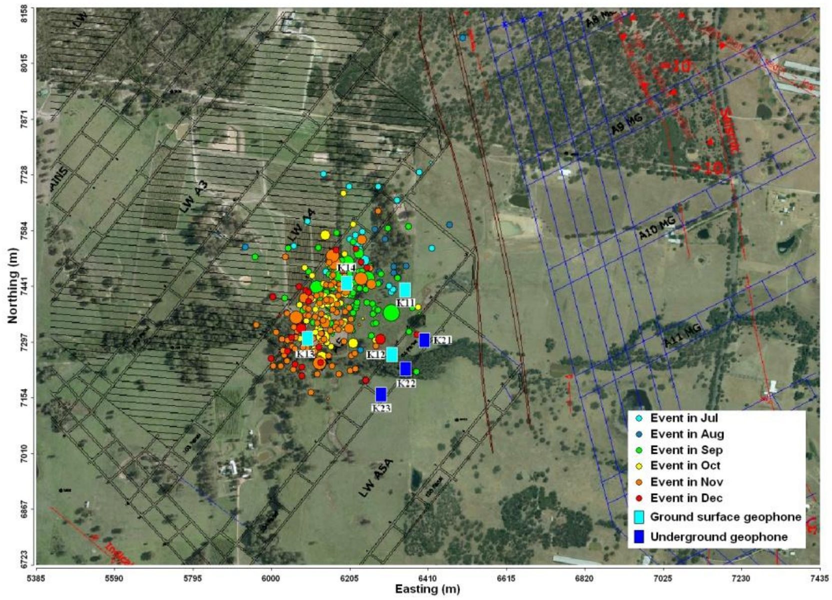

Figure 7 - Plan view of the strong events recorded by the ground surface stations, from July to December 2011

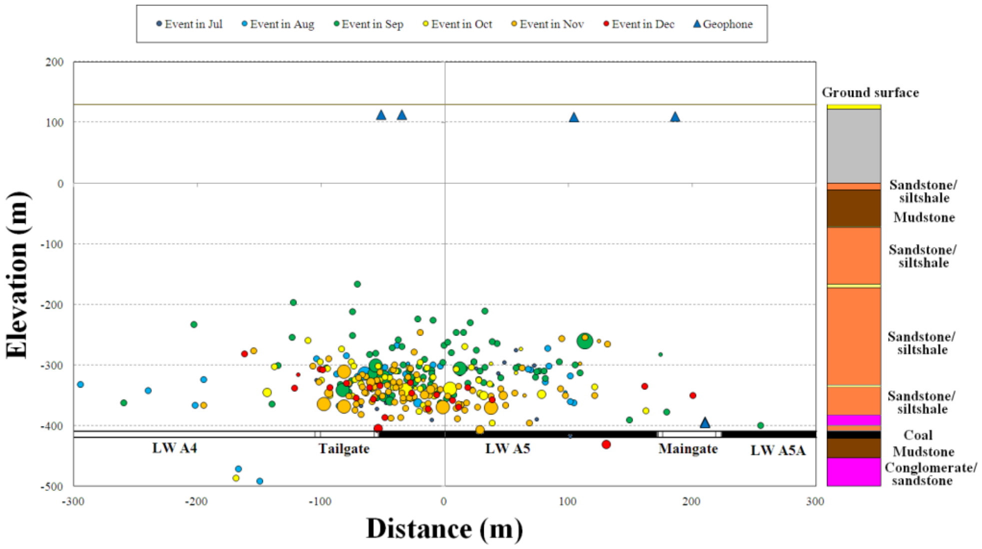

Figure 8 - Vertical cross-section of the strong events recorded from July to December 2011

Based on the above consideration, an intelligent method for detecting precursors of longwall caving events has been developed. This method uses the mean value and standard deviation of the signals (including noises) within a given period as the baseline. If the stress rate or seismicity is low, the standard deviation will be low. When they change suddenly, the immediate stress rate or seismicity will be high but the standard deviation remains low because it uses the data over a past period. In this case, the stress rate or seismicity becomes greater than the standard deviation multiplied by a factor, a caving precursor is then detected.

This method using standard deviation as a measure will minimise false alarms, in particular, immediately after a major caving event. It is also effective to minimise the effect from the varying distance between the longwall face and the sensors. A stronger signal is often detected when the longwall face is closer to the sensor. However, this does not mean that the caving is more likely to occur. Details of this method can be found in Shen *et al.*, (2012).

Four monitoring systems were installed at Panel A5, including two for surface and underground stressmeters, and two for surface and underground microseismicity. The stressmeter systems have a number of stressmeters whose results are analysed independently. The microseismic systems also have several sensors but each of the two surface and underground systems are analysed as a system, and only those events triggering all the surface or underground geophones are considered.

A caving event may or may not trigger all the four systems and its sensors depending on its strength and magnitude. A method to quantify the strength of a precursor is developed based on the number of systems and sensors being successfully triggered by the event. This method uses a "Combined Trigger Index" for the four systems with triggering value ($T_{trigger}$) defined as:

$$T_{trigger} = T_{stress\_su} + T_{stress\_ug} + T_{seis\_su} + T_{seis\_ug} \qquad (2)$$

where T_{stress_su} and T_{stress_ug} are the trigger index of the surface and underground stress monitoring system, respectively, whose value is in the range of (0 - 1.0) and is determined by the number of stressmeters triggered. T_{seis_su} and T_{seis_ug} are trigger index for the correspondent surface and underground seismic monitoring system.

The Combined Trigger Index method was tested against the monitoring data in Panel A5. Figure 9 shows the resultant Combined Trigger Index ($T_{trigger}$) over a period from July 2011 to January 2012. Also shown in the figure are the chock pressure data and the longwall chainage data. The red clusters in the chock pressure plot indicate high chock pressure, and possibly longwall weighting events. Some red clusters that have a constant value for a few days may not be real weighting events as they mostly occurred when the chainage stopped and longwall face was not advancing.

The figure demonstrates a good correlation between the high trigger index event ($T_{trigger}$≥1.0) and high chock pressure (red clusters). Notably, the index showed the first major trigger ($T_{trigger}$=2.0) on 30/07/2011 1:55 p.m. while a major chock pressure increase occurred between 30/07/2011 and 2/08/2011. This event could be the initial caving after the longwall face had advanced by 70 m.

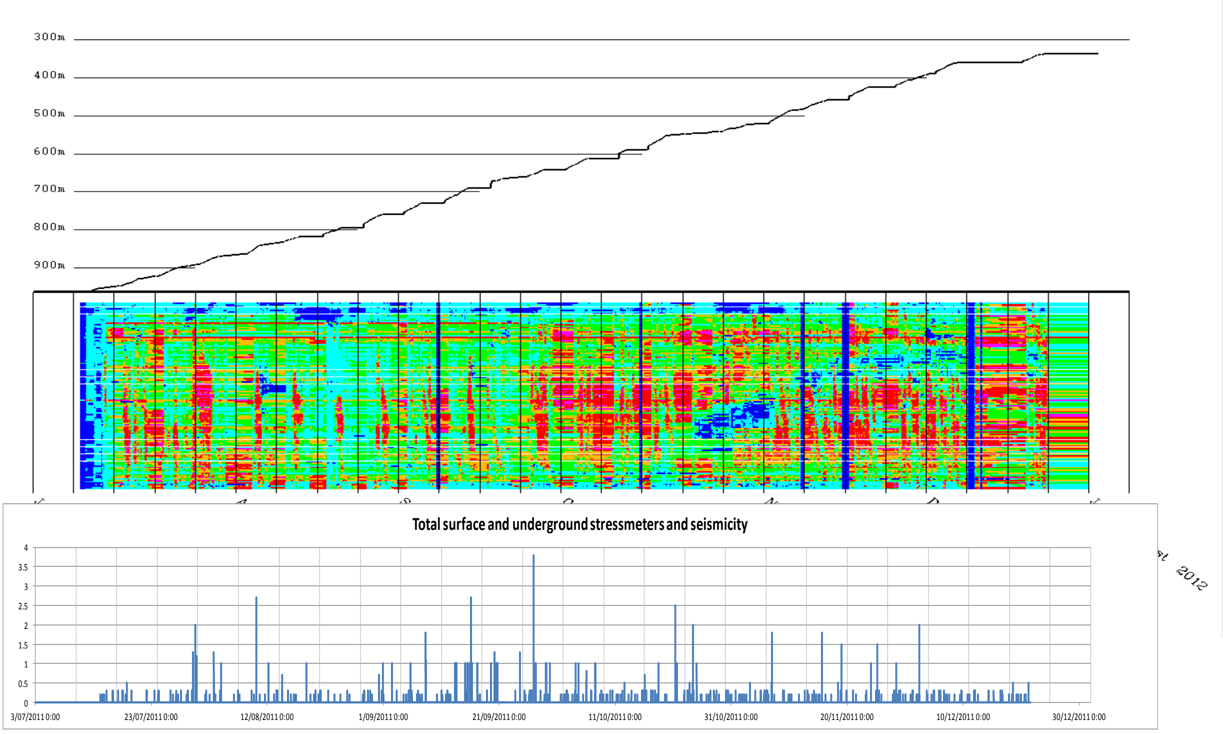

Figure 9 - Trigger index compared with chock pressure and longwall chainage at Panel A5, Austar Mine

Also detected by the trigger index are a major caving event on 16/09/2011 ($T_{trigger}$=2.4) and the strongest caving event on 26/09/2011 (Ttrigger=3.8).

An attempt has been made to correlate the mining observation records and the chock pressure (LVA) data with the triggers derived from the monitoring data. The two most severe weighting events occurred on 10/08/2011 8:00 am. and 16/09/2011 5:25 am. based on the mining records. The monitoring system was triggered at 10/08/2011 1:00 am. (trigger level = 2.7 out of 4.0) and 16/09/2011 2:40 am. (trigger level = 2.7 out of 4.0). These represent a successful early warning for the two major events by about 7 hours and 2.75 hours respectively prior to the actual events.

Comparing the monitoring triggers with all the major and minor weighting events recorded during mining operations, a rate for successful early warning of 8 out of 13 (i.e. 62%) is obtained. The rate of missed warning is 5 out of 13 (38%), and the rate of false alarm is 3 out of 13 real events (23%). The above results are based on both the surface and underground stressmeter and microseismic results, using a pre-set trigger level of 1.0 out of maximum 4.0.

The underground stressmeter and microseismic systems were effective until 7 November 2011 when some sensors and cables were damaged by pillar failures and roof falls. If we only consider the effective monitoring duration before this date and use the results from underground systems only, the resultant rate for successful early warning is 10 out of 12 (i.e. 83%). The rate of missed warning is 2 out of 12 (17%), and the rate of false alarm is 3 out of 12 real events (25%). A pre-set trigger level of 0.5 out of maximum 2.0 is used.

The successful warning triggers occurred mostly hours or days before the increase in chock pressure. It is therefore possible to use this monitoring technique and the trigger index method to forecast an imminent longwall loading event.

CONCLUSIONS

An integrated stress and seismicity monitoring system was trialed at Panel A5 at Austar Mine to detect and forecast longwall weighting events. The integrated monitoring system is composed of four independent sub-systems, including a surface and an underground stressmeter system; and a surface and an underground microseismic system.

The monitoring results have demonstrated that this experiment had been successful in detecting both stress and seismic signatures associated with caving and longwall weighting events. Both the stress changes recorded by stressmeters installed in shallow surface strata and underground roadway roofs showed a strong correlation with the chock pressure increases at the longwall face. The same phenomenon had been observed from the recorded microseismic events.

In order to develop an automated early warning method for longwall weighting, a trigger index method, which integrates the warning signs from all the four systems, was developed and tested against the mine weighting observations and chock pressure data. A good agreement had been observed. For all the weighting events observed, a rate of successful warning of up to 83% was achieved at Panel A5 using this trigger index method. The warning signs from the monitoring system mostly occurred at least several hours before the underground weighting events and the major increase in chock pressure. This demonstrates that the integrated stress and microseismic monitoring system, together with the analysis method developed, is capable of providing sufficient early warning for imminent underground weighting events.

No clear difference in the monitoring results was observed when the longwall operation changed from partial top coal caving to full face top coal caving.

Future development will focus on updating the integrated monitoring system to a wireless and fully automated system which can be easily used for early warning of longwall weighting.

ACKNOWLEDGEMENTS

The work presented in this paper was sponsored by Austar and CSIRO. The stressmeters were installed by Gavin Langerak of GEL Instrumentations Pty Ltd. We would also like to thank our CSIRO colleague

Shivakumar Karekal, Joey Duan, Brett Poulsen, Qingdong Qu, Zak Jecny for their help in instrumentation, data processing and numerical modelling.

REFERENCES

Guo, H, Luo, X, Zhou, B, Poulsen, B, Kelly, M, Craig, S, Adhikary, D, LeBlanc, S G, Caris, C, Yago, J, King, A, Ross, J and Coulthard, M, 2000. *Southern Colliery LW704 geotechnical study, CSIRO Report 759*, p200.

Shen, B, King, A and Guo, H, 2008. Displacement, stress and seismicity in roadway roofs during mining induced failure. *International Journal of Rock Mechanics and Mining Sciences.* 45:672-688.

Shen, B, Luo, X, Karekal, S and Duan, J, 2012. Monitoring longwall weighting at Austar mine using microseismic systems and stressmeters. *CSIRO Earth Science and Resource Engineering Report EP123936*.