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COALBURST CONTROL METHODS

Justine Calleja[1] and Ian Porter[2]

ABSTRACT: Coalburst (also known as coal bump) is a well known phenomenon in underground coal mines internationally, however, it was not recognised as a risk for Australian coal mines until the recent double fatality at Austar Coal Mine in the Hunter Valley in 2014. This paper reviews the international knowledge base from research and practice to provide Australian mining professionals with an understanding of the basics of coalburst control methods in order to allow mine operators to address the risk of coalburst in mining safety management plans. This is the second of two companion papers to be read with the first paper, "Coalburst causes and mechanisms" (Calleja and Nemcik 2016).

INTRODUCTION

There are many different methods available to manage coalburst risk. The approaches can be broadly categorised into predictive, preventative, mitigating and protective control measures. Control measures range from very simple rules of thumb to highly sophisticated technology and engineering. The most effective coalburst management systems are likely to include a mix of both approaches.

PREDICTIVE CONTROL METHODS

Predictive control methods can be used to identify coalburst risk prior to mining in order to allow mine planning and design changes to be implemented in order to reduce or eliminate the risk (planning prediction or strategic controls). Predictive measures can also be used during mining where coalburst risk has not been eliminated, in order to minimise the hazard through the implementation of mitigating and protective control measures (operational or real time prediction).

Planning Prediction

The first and most important predictive control measure, which will determine the need for other control measures is risk assessment. Site specific empirical risk assessment has been used successfully at the Lynch No. 37 Mine in Kentucky where the key risk indicators were found to be depth greater than 460 m, sandstone thickness greater than 10 m and sandstone in contact with the top of the coalbed (Iannacchione and Tadolini 2015). However, these risk factors and values may not be appropriate for use at other mines as they are a function of the specific geotechnical and mining environment present at this particular site.

Mark and Gauna (2015) recognised that a universal quantitative risk rating scale has not been developed, but suggested rating the individual factors which are known to be important, based on existing cases, on a site by site basis with regard to existing experience at the site. The risk analysis factors suggested for pillar recovery which would be considered high risk include depth of cover greater than 450 m, multiple seam workings with remnants surrounded by goaf, strong thick and massive strata (e.g. a Coal Mine Roof Rating Unit Rating > 50 (Calleja 2006, 2008) within 15 m of the seam, presence of geological features (such as sandstone channels, faults, fracture zones, seam dips or rapid topographic changes), panel width larger than 150 m, full extraction and a burst history at the mine.

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As there are currently no risk assessment guidelines applicable for use in Australia, empirical risk assessment can be conducted based on the risk factors described by Calleja and Nemcik (2016). The most important risk indicator is a history of coalbursts in the seam and at the mine, as many of the other factors associated with coalburst can be present at mine sites which do not ever experience coalbursts (e.g. seismicity, high depth of cover, presence of thick massive strata in proximity to the seam). Mark and Gauna (2015) provided evidence from eleven mines that a past history of bursts is an important indicator of burst risk, "Major bursts have often been preceded by a pattern of increasing coalburst activity." The development of Australian coalburst risk assessment guidelines is currently of critical importance. Until such guidelines are developed, it is recommended that the principal indicator to use to determine the presence of coalburst risk should be a past history of coalbursts, and the Mine Safety and Health Administration (MSHA) (2012) guidelines for reporting coalbursts are a reasonable criteria to use.

In the Czech Republic, risk assessment is based on both regional risk and local risk factors (Ptacek, 2015). Regional risk factors include tectonic features, seismic and microseismic monitoring, stratigraphic sequence, mechanical properties of the coal and rock, depth, seam thickness and dip. Local risk factors are used to determine specific areas within a mine which may be at risk and include depth, seam thickness and mine layout (mining next to goaf or under remnant pillars).

Dou and Gong (2014) described the zoning and levelling forecasting method of predictive control (see Figure 1) which is used in Chinese coal mines. It is an integrated approach which involves early regional risk assessment combined with real time local and point forecasting of coalburst. This predictive system uses the comprehensive index method, the multi-factor coupling method, microseismic monitoring, the electromagnetic radiation method and the drilling cuttings method.

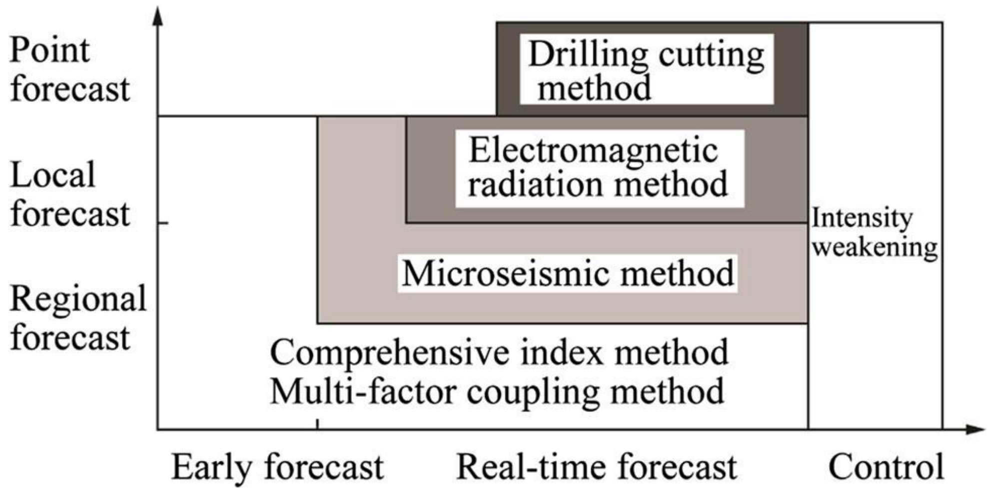

Figure 1: Zoning Spatio-Temporal forecast method of prediction (Dou and Gong 2014)

Operational Real-Time Prediction

A great deal of research effort has been focused on developing methods to predict the location and timing of coalburst. Traditional methods of prediction have involved the use of test drilling and incident history recording. More technologically advanced systems under current investigation include the use of seismic monitoring, seismic tomography, electromagnetic radiation (EMR), stress and strain monitoring and numerical modelling.

Tan *et al.*, (2014) described a method of coalburst risk monitoring which was used at Yangcheng Mine in China. Three different monitoring strategies were employed concurrently and indicated that a silence period in the microseismic monitoring, combined with increasing electromagnetic radiation could be used to predict a coalburst. Once the risk was identified, face drilling with fines monitoring could be conducted to identify the location of high burst risk in the face and allow targeted de-stressing measures to be implemented.

Traditional Methods – Observation, Rock Noise Reporting and Test Drilling

Traditional techniques are often inherently simple and inexpensive. The value of these approaches, such as rock noise reporting and event histories, should not be overlooked as useful methods of assessing coalburst risk.

The use of qualitative (observational) seismic monitoring is still an important component of seismic management systems. Mt Isa Mines initially relied on "Rock Noise Reporting" by underground operators to monitor seismicity in their Deep Lead orebody (Thin *et al*., 2005). Similarly, seismic rock fall reporting and rock noise reporting (a tick and flick form) were introduced for seismic management when Beaconsfield first encountered mining seismicity in 2003 (Hills 2013). In both cases the level of seismicity increased and required an instrumented seismic monitoring system to be installed. In the Czech Republic, Ptacek (2015), recommends that the data necessary for continuous coalburst prediction includes personal monitoring, by miners, of rock strata and coal seam behaviour.

High static stress conditions have been proven to be capable of causing coalbursts even without external seismic events (Brauner 1994). As such, being able to identify high *in-situ* stress areas and the development of high stress in the coal close to the excavation boundary is a key tool for identifying areas of coalburst risk. Regular stress mapping by trained geotechnical personnel can be conducted to identify and predict high stress areas. It is very difficult and expensive to measure triaxial *in-situ* stress and stress change in coal with existing instruments. Whilst such stress measurements are very important and valuable for geotechnical design they do not provide the level of areal coverage required to identify coalburst risk zones. Test drilling is a traditional, proven, simpler and cheaper method of identifying high stress areas with better areal coverage in coal, in advance of mining, and it is used widely in China and the Czech Republic (Ptacek 2015; Konicek 2013 and Li *et al.,* 2007). When a borehole is drilled in highly stressed coal, it will burst during drilling and a significantly larger volume of coal cuttings will be washed out than would occur when the coal is not highly stressed. This process is often accompanied by the observation of a bumping noise in the coal while drilling and shocks on the drill rods. Brauner (1994) provided an example of drill cuttings from a 46 mm hole which produced 2-4 l/m cuttings under normal conditions and which increased to 15-22 l/m at the beginning of a high stress zone beyond 4 m into the rib line where dynamic effects occurred. It is also possible to identify high stress zones from the axial forces required to be applied during drilling. High stress areas prone to bursting can be identified when the drill rod is pulled into the hole and axial forces on the rods go into tension (Figure 2).

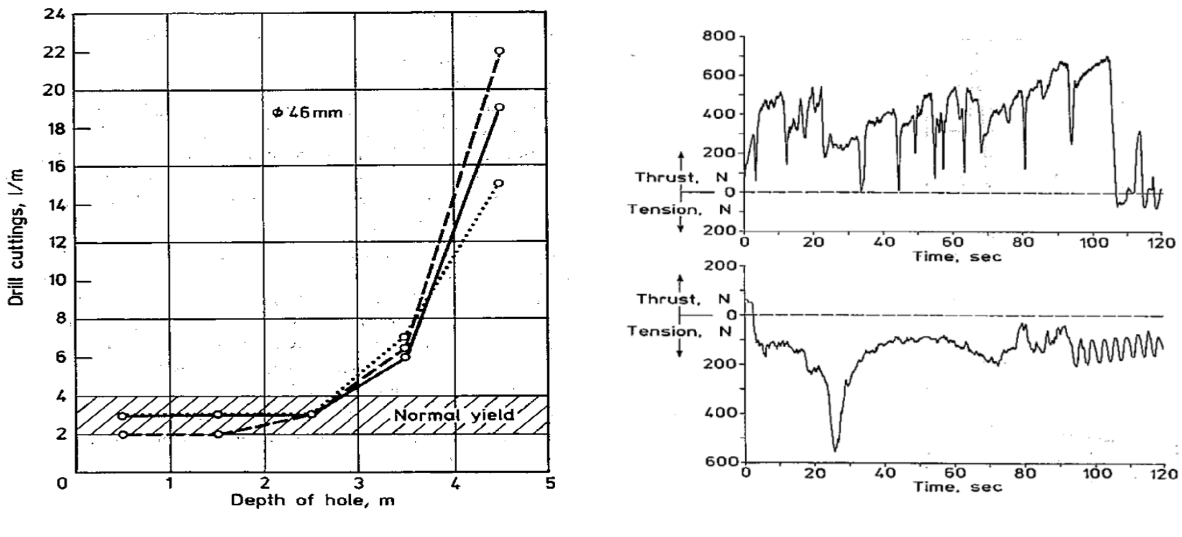

Figure 2: Yield of cuttings in boreholes approaching a high-stress zone and the axial forces on the drill in coal under normal (above) and high stresses (below) (Brauner 1994)

This approach could be applied to the longhole drilling which is conducted for gas drainage in order to identify coalburst risk areas after gas drainage has occurred, however, the application of this approach will need to be developed based on underground trials in Australia.

The level of static stress can change as a result of mining and new areas of high risk can develop after initial test drilling has been conducted. As a result repeated test drilling is sometimes required.

Seismic Monitoring

Ortlepp (2005) recognised that whilst seismic monitoring and numerical modelling could not provide real-time prediction of rockbursts, it would be likely to allow prognosis (risk identification). However, this would require adequate staffing of a sophisticated monitoring and analysis system by a dedicated experienced professional for mining operations experiencing bursting. Mendecki *et al*., (1999), describe the applications of seismic monitoring. It can be used to identify the location of possible coalbursts and can help guide rescue operations. It can be used to identify the location of important geological features such as faults and dykes ahead of mining. It can be used to identify unexpected changes in the location and timing of seismicity in the mine which can indicate increased risk and allow management to implement safety management and strategic controls. It can also be used to allow characteristic patterns of seismicity which precede coalbursts to be identified and used to help predict the potential triggers, location and timing of future incidents. It is a useful input to review the effectiveness of planned mine designs and production methods in managing seismicity.

Li *et al.,* (2007) highlighted the importance of seismic monitoring systems for managing mining seismicity in underground coal mines in China: "We find that the key problems of rockburst (coalburst) hazard mitigation in China are the lack of mine seismicity-monitoring networks in most mines, and the need for improvement of the accuracy of monitoring systems for mines that have been equipped with such systems."

A seismic monitoring system consists of transducers, data acquisition hardware and processing software. Geophones are useful sensors for larger spacing (e.g. 1 km) and surface installation whereas piezoelectric uniaxial or triaxial accelerometers are ideal for more closely spaced networks (e.g. 100 m). A single short period earthquake monitoring instrument should be installed in a mine network to allow data recovery of the largest events, which are not well recorded by geophones or piezoelectric sensors. A Global Positioning System (GPS) is employed to time-link regional and local systems (Urbancic and Trifu 2000).

The type of monitoring system required to manage mining seismicity is different from the approach applied both for monitoring earthquake seismicity and microseismic rock fracturing research investigations. In Australian and Canadian hard rock mines the inter-sensor spacing of seismic monitoring systems is mostly less than 200 m and the layout of these systems is substantially different to the systems used in South African gold mines which have sensors at 300 - 650 m spacing (Potvin and Wesseloo 2013). In order to manage mining seismicity the seismic monitoring data needs to be collected and analysed continuously in real time. The microseismic monitoring systems which have been used regularly in the coal industry to understand rock fracturing associated with mining would need to be modified to be used for seismic risk management.

Electromagnetic Radiation

It has been found that the deformation and failure process of coal generates both acoustic emission and EMR. Dou *et al.,* (2001 and 2004) demonstrated that the EMR intensity increased sharply in the case of burst failure of coal. Wang *et al.,* (2012) found that the EMR signal was linearly related to the applied loads. It was thus inferred that monitoring the EMR signal could be used to reflect the stress state of the coal rock mass. EMR intensity was monitored in a longwall from 10 locations in the tailgate and ten locations in the maingate in 2012. The monitored mean of maximum daily EMR intensity measured at two points in the tailgate located 200 m and 220 m from the longwall face was more than double the background levels 10 days before a coalburst occurred, and peaked at 5 times the background level one day prior to a burst which occurred at a distance of 178 m from the longwall face (Figure 3). This data was consistent with previous research results which indicated that EMR monitoring can be used to assist in predicting bursting. (Dou and Gong 2014)

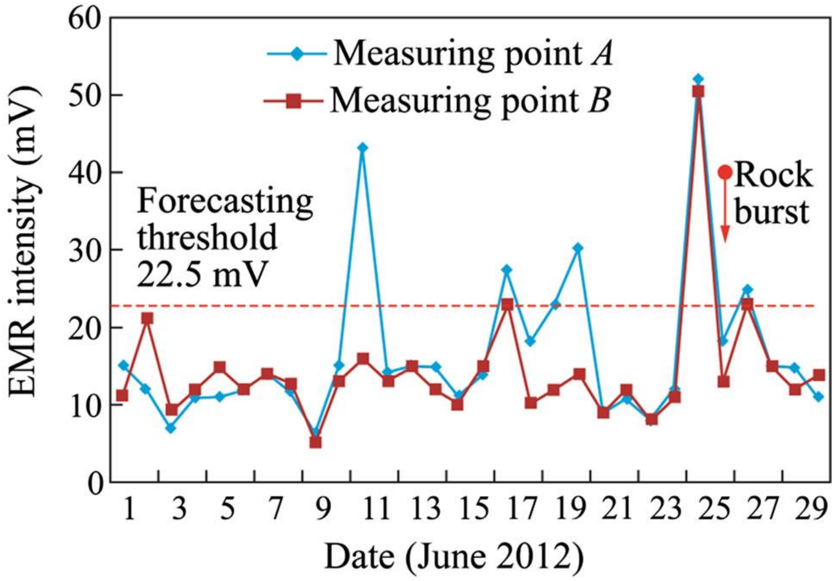

Figure 3: Variation of measured EMR intensity in the tailgate of a longwall face before and after a coalburst on June 26th, 2012 (Dou and Gong 2014)

Seismic Velocity Tomography

The seismic p-wave velocity in rock is known to vary as a function of the *in-situ* stress conditions (amongst other factors, such as density and porosity). Geophones can be used to monitor the arrival times of seismic waves and then calculate the velocity of seismic waves through the coal between the seismic source and the geophones. When multiple geophones are used, areas in the seam with higher and lower seismic wave velocities can be determined by using Computed Tomography (CT) and seismic CT plans can be generated. Areas of higher coalburst risk were shown to occur in high velocity or high velocity gradient areas, by Lurka (2008), in Zabrze Bielszowice Coal Mine in Poland. This method has since been applied in more than ten coal mines in China with useful results (Dou and Gong 2014). Wang *et al*., (2015) used Seismic Velocity Tomography (SVT) at Xingan Coal Mine in China and found that the development of high velocity regions in the coal, when located close to the coal face was a predictor for coalbursts.

PREVENTATIVE AND MITIGATING CONTROL METHODS

The most effective method of addressing risk is through elimination. In many cases where severe levels of coalburst risk have been recognised, the risk has been eliminated by avoiding mining in the high risk area, or by modifying the mine plan or extraction method. The Lynch No. 37 Mine in Kentucky chose to avoid longwalling through areas they had identified as high risk (Iannacchione and Tadolini, 2015). In other cases, bursting risk has been reduced through mine design by avoiding mining underneath remnant pillars, by using barrier pillars, by using yield - abutment gateroad pillar combinations, by avoiding the creation of goaf corners or by reducing the mined panel width. Numerical modelling and stress analysis are valuable tools that assist in identifying mine designs that will create high risk stress concentrations which may cause coalburst and assess the potential improvements available through alternative design approaches. Other measures to reduce coalburst risk, such as de-stress drilling, blasting and water infusion have been used in Europe and China.

Provocative Blasting (Pre-Conditioning)

Provocative blasting (pre-conditioning) is a technique which has been used primarily in hard rock mines, where blasting is the normal excavation method, to reduce the risk of development face bursts and was very successful in hard rock at Mponeng, South Africa (McGill 2005). It involves drilling and loading a number of holes which are longer than the production holes, and blasting them prior to the production holes so that the new face created will be fractured and unable to store the necessary elastic strain energy required for bursting. De-stress blasting in coal is one of the oldest methods of coalburst prevention. Blast holes are drilled around the development face or into the longwall face and are designed to fracture the coal and seam contacts in place rather than throw it. However it is not as effective as de-stress drilling and it is not amenable to routine application in high productivity longwall mines as holes need to be blasted every 2.5 m advance (Brauner 1994). It is currently used in The Czech Republic. Konicek *et al.,* (2013) describe a case where 42 mm holes 11-15 m long and at 5 m spacing were drilled and charged with 7-9 kg of explosives at the Lazy Colliery.

Long Term Water infusion

Long term water infusion is used to increase the moisture content of the coal which reduces its liability to bursting. During borehole - bursting laboratory tests it was found that fully saturated coal samples would not burst (Figure 4). In practice a 1-2% increase in moisture content may be sufficient to eliminate burst danger. The limitation on this method is that infusion may need to be conducted for between a few days and several months with fluid pressure between 1-40 MPa, and it may not work at all in existing highly stressed areas where it is difficult to drill and where the coal permeability is very low. However, the method is significantly more amenable to high productivity longwalling than roadway de-stress blasting and de-stress drilling and it has been used successfully in the past to prevent coalbursts (Brauner 1994). It is currently used as a standard technique to prevent coalbursts in the Czech Republic (Konicek *et al.*, 2013).

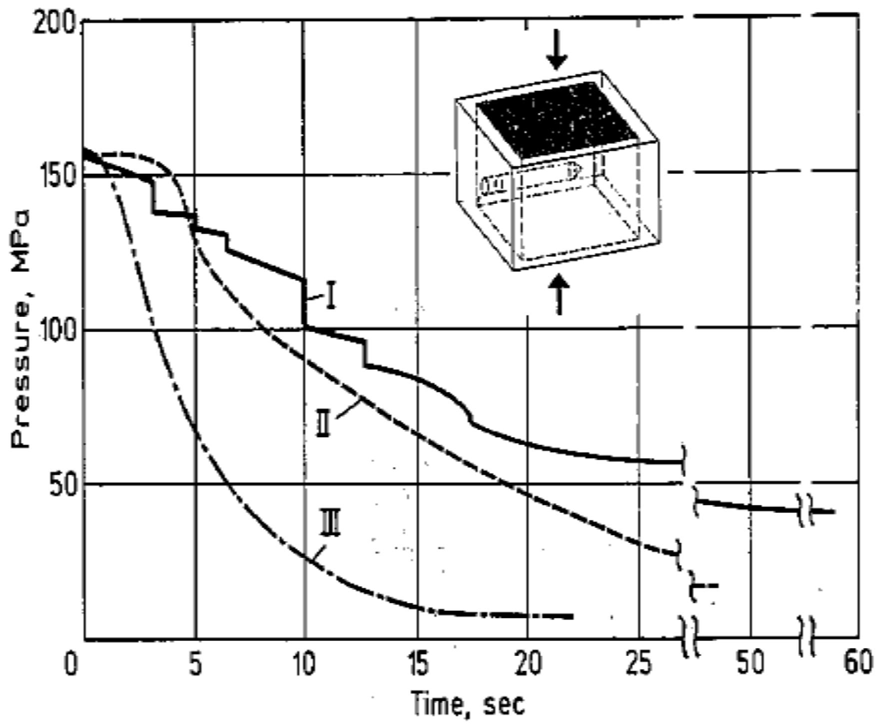

Figure 4: Different modes of stress decrease in coal specimens during drilling

In Figure 4 the Curve I sample was air dried coking coal and experienced six borehole bursts. Curve II was the same coal, but saturated with 2.4% moisture content. The Curve III sample was anthracite. No bursting occurred for the Curve II and Curve III samples (Brauner 1994).

Hydrofracking

Hydrofracking involves the injection of water into strata at high pressure to induce fracturing. Hydrofracking can be used to create fractures in the coal, to prevent it from being able to store sufficient elastic strain energy to burst. For example, 10 m long holes at 5 m spacing are drilled into the face and injected with water at 40 MPa for 20 minutes. A decrease in water pressure of 10 MPa or more can be indicative of adequate de-stressing. This method is suggested by Brauner (1994) to be the most economical de-stressing technique. Hydrofracking can also be used to fracture the strong stiff strata which is required to develop high stress concentrations and transmit seismic energy to the coal to trigger coalburst.

De-Stress Blasting

De-stress blasting of stiff, massive overburden strata over the longwall block is an important coalburst control technique which has been used successfully in the Czech Republic since the 1990s and internationally. Konicek *et al.,* (2013) described its application at Lazy Colliery where 43 mm boreholes were drilled at a 10 m spacing along the gateroads into the longwall overburden strata for a length of 40-100 m.

De-Stress Drilling

De-stress drilling is a very successful method of coalburst prevention which has been used in Germany and Russia. 95 - 600 mm diameter holes are drilled into the area of highly stressed coal at a spacing of between 0.5 m and 10 m and in the order of 6 - 10 m long depending on conditions. The holes will burst and fines are removed during drilling until the stress has reduced below bursting levels. It has to be repeated every 5 m or so of advance, so although it is effective, it is a slow process and is not amenable for high productivity mining.

PROTECTIVE CONTROL METHODS

Protective control measures have been used to prevent coalbursts from causing injuries. Some examples of these include the use of flippers and rubber mats on longwall shields, and the use of blast proof barriers on continuous miners (Mark and Gauna 2015). However, these measures are only useful for protecting miners against small coalbursts, and given the difficulty in predicting when and where a coalburst will occur, let alone whether it could be a large one or a small one, such measures should not be relied on to prevent injuries and fatalities.

If a coalburst is anticipated then a much more reliable approach is to remove people from the area at risk through the use of remote mining methods such as remote control cutting or drill and blast mining (grunching). The practice of specifying re-entry times is a common and successful method to separate miners from the area of risk after production blasts, cuts or de-stressing measures which can be developed based on seismic monitoring data (Hills 2013).

Dynamically rated (yielding) support systems can be used to minimise excavation and machinery damage, but the engineering design approach is not sufficiently advanced at this time for support systems to be adequate to protect people from coalbursts (Heal 2010). Dynamic support systems are designed to absorb high levels of kinetic energy and maintain support load whilst allowing large deformation (e.g. 200 mm). Yielding integrated support systems are composed of surface confinement (mesh, steel fibre reinforced shotcrete, laced cables), high strength anchoring bolts (fully encapsulated rebar and cables) and displacement capable bolts such as split sets, cone bolts and de-bonded cables (Heal 2010 and Hebblewhite *et al*., 1998). Heal (2010) dynamically tested thirteen yielding support systems and found the support system is only as strong as its weakest link which is usually the surface support (e.g. mesh), or connections between the surface support and bolts or cables.

CONCLUSIONS

Extensive research work and application of coalburst control methods has been undertaken internationally, however the applicability of these approaches will need to be tested in Australian conditions. Additional work will also be required to modify existing techniques to be amenable to the high productivity longwall mining which is conducted in Australia. The existing coalburst control methods can be broadly categorised into predictive, preventative, mitigating and protective measures. Ultimately successful coalburst management will require the ongoing development and refinement of operational seismic management plans which take a holistic approach to risk identification, risk monitoring and the application of risk management control measures.

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