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NUMERICAL MODEL OF COAL BURST MECHANISMS

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ABSTRACT: Coal bursts present one of the most severe hazards for the underground coal mining industry. In Australia, coal burst events are becoming increasingly frequent as coal measures are mined progressively deeper. Until now, coal burst mechanisms haven't been properly understood. A significant ongoing effort and a large number of research activities are searching for answers. This work is supported by the Australian Coal Association Research Program (ACARP) which aims to provide explanation of the probable mechanisms and key factors behind the coal burst phenomena. The available energy required to eject the coal rib into the mine opening has seeded the idea of momentum transfer from within the seam towards the rib side. This mechanism has a strong analogy to Newton's Cradle device and hence conservation of momentum and energy principles that can account for momentum transfer between confined seam masses at a distance and ejected unconfined fractured mass at the free surface of the rib. Using dynamic analysis, preliminary numerical models successfully simulate fast ejection speeds of coal rib material and thus identify a probable common cause of coal bursts in mine roadways. Modelled coal mine roadway in 3 m thick seam at a depth of 550 m successfully simulated coal burst phenomena; laterally ejecting 3.92 tonnes of coal from the rib with velocities ranging up to 2.3 m/s. Recognising that ejection speeds are dependent on material properties, extent of trigger induced failure between coal/rock boundary and chosen geometry; a few modelled cases are presented here.

INTRODUCTION

Several coal burst occurrences with loss of life in underground Australian coal mines have prompted the government inspectorate and coal mining industry authorities to devise safer working methods of mining deeper coal deposits. Coal bursts are very difficult to predict as they are inherently not frequent, isolated and occur without warning. To minimise the occurrence of coal bursts it is necessary to first understand how the mechanism of coal bursts arises. Up to now this remains elusive with many researchers investigating different combination of stresses, mining geometries, fault locations and other factors to predict coal burst occurrence Hebblewhite and Galvin (2017), Dou, et el., (2016), Bräuner (1994), Mark and Gauna (2016), Moodie and Anderson (2011), Calleja and Porter (2016). Many numerical attempts have proven unsuccessful; largely due to unsuitable methods or programs employed. Consequently existing models have been unable to explain the coal burst mechanisms satisfactorily Chengguo and Canbulat(2017), Muller (1991) and others. Frequent miss-use of conventional elastic-plastic, strain softening and hence otherwise static based models are attributed towards significantly limiting both theoretical derivation and computational ability in analysing fast dynamically occurring events. This highlights the serious shortcoming of trying to model dynamic material response behaviour of sedimentary or igneous rock strata around excavations; hence such models should not be used. The importance of built in dynamics is therefore recognised in dynamic analysis for enabling real time simulation of dynamic ground movement. Likewise, when using these models, correct approach is necessary to observe what mechanisms are taking place.

Supported by ACARP, this project is focused on computational systems to mimic natural ground dynamics and model possible types of dynamic events that simulate the coal burst process. At this stage only simple, reproducible models were chosen with various parameters and geometries to achieve coal ejection from the rib side; supporting the concept of the energy transfer and conservation of momentum $p=mv$ where m is the coal mass and v its velocity. Several parameters influence the coal rib ejection speeds. These include material properties, initiation of coal/rock interface failure, its extent and the propagation of failure. At this stage the modelled depth of cover of 550 m was kept similar to the Austar mine coal burst

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incident location. To simulate the dynamic coal burst event, coal-rock bond failure was trialled at various distances from the mine roadway. The aim of this model was to investigate whether coal burst events, such as that observed in Austar mine at 550 m depth can be reproduced via simulation.

NUMERICAL MODELS OF COAL BURSTS

Using the 2-dimensional Fast Lagrangian Analysis Continua (FLAC), (ITASCA 2015), an excavation of a standard underground coal mining roadway was modelled in a 3 m thick coal seam bound by a strong sandstone stratum at a depth of 550 m as shown in Figure 1. Initially, the model was brought to static equilibrium prior to dynamic solution being initiated (as described in FLAC 2015) while removing part of the coal-rock interface bond to evaluate the system response to coal-rock interface failure.

The simplified strata properties are provided in Table 1 while the model geometry grid is shown in Figure 1. It is known that during dynamic fracture propagation, cohesion will drop to zero while the coefficient of friction can drop rapidly from its static value to a much smaller value. Brown (1998) noted from his experiments that during rapid sliding, the friction coefficient reduced by a factor of up to about seven times. Brown's comparison with other experimental results suggests the reduction of normal stress by interface separation waves is the most likely explanation. Therefore for the purpose of this study only (proof of concept), the bond properties 1 m in length along the coal-rock boundary at the roof level were removed at various locations.

Table 1: Modelled strata properties

Rock Type	**Density (kg/m^3)**	**Bulk Mod (MPa)**	**Shear Mod (MPa)**	**Friction (Degrees)**	**Cohesion (MPa)**	**Tension (MPa)**	**Dilation (Degrees)**
Floor rock	2,500	6.67e^9	4e^9	37	10e^6	4e^6	0
Coal	1,400	3.33e^9	1.11e^9	35	0.2e^6	0.2e^6	0
Roof rock	2,500	6.67e^9	4e^9	37	10e^6	4e^6	0

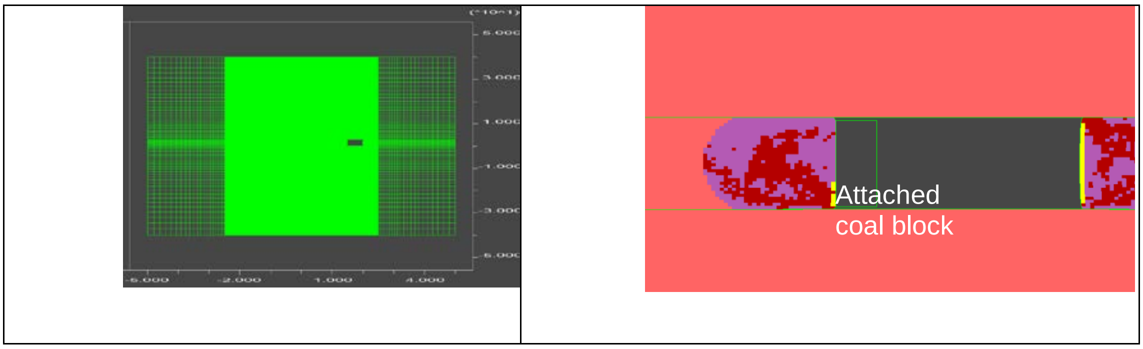


Figure 1: (a) FLAC model grid, (b) Yielded rib of mine roadway and attached coal block

Preliminary dynamic simulation trials clearly indicate that the ejection of a large coal mass from the rib side is only possible if the stored compressive energy within the pillar is released and accumulated as the compression wave travels towards the rib face. Stemming from the "Newtons Cradle" idea shown in Figure 2, this is only possible via the conservation of momentum that begins several metres into the pillar, propagating towards the unconfined rib side.

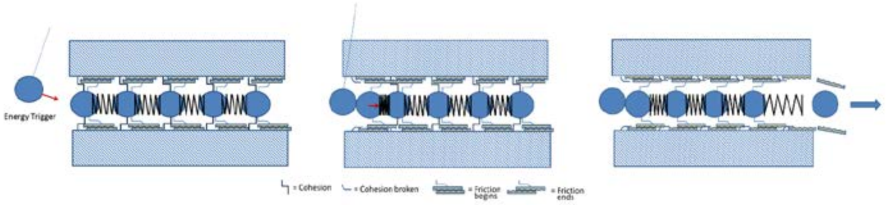


Figure 2: Modified Newtons Cradle - Analogy of the rock burst

For the energy trigger to occur, a dynamic event such as a fault slip is needed to generate seismic waves and break some of the already stressed bonds that exist between the coal seam and the rock surface. This failure needs to occur either at the top or bottom of the seam several metres away from the rib side. If loss of cohesion occurs simultaneously at both top and bottom of the seam, the coal burst may become more violent.

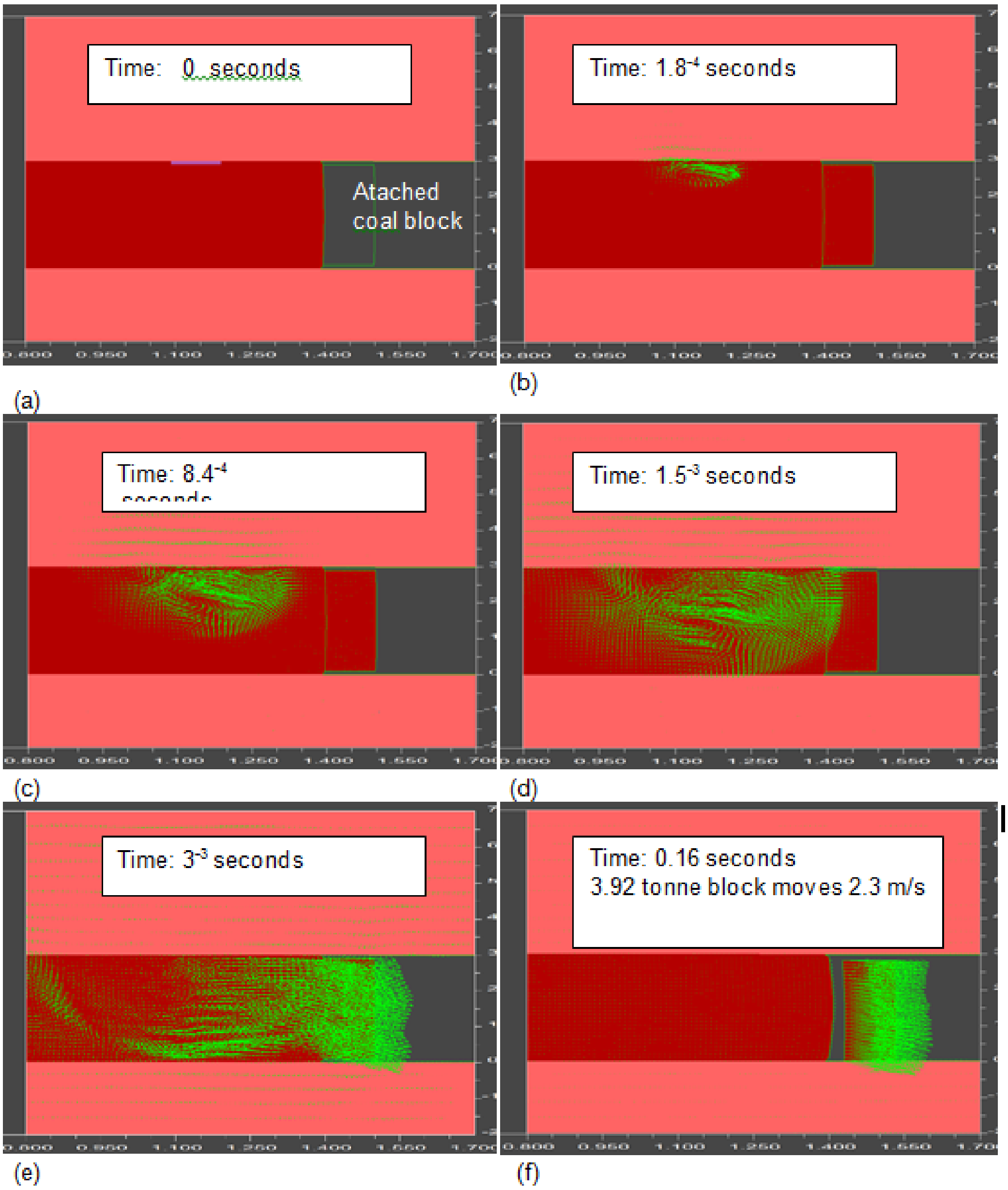
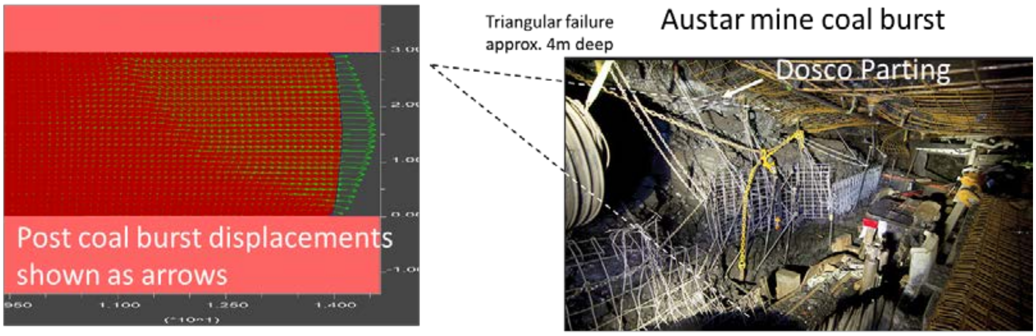


Figure 3: Dynamic response to coal/rock interface failure resulting in rapid coal expansion and ejection of the loose coal block at the rib boundary.

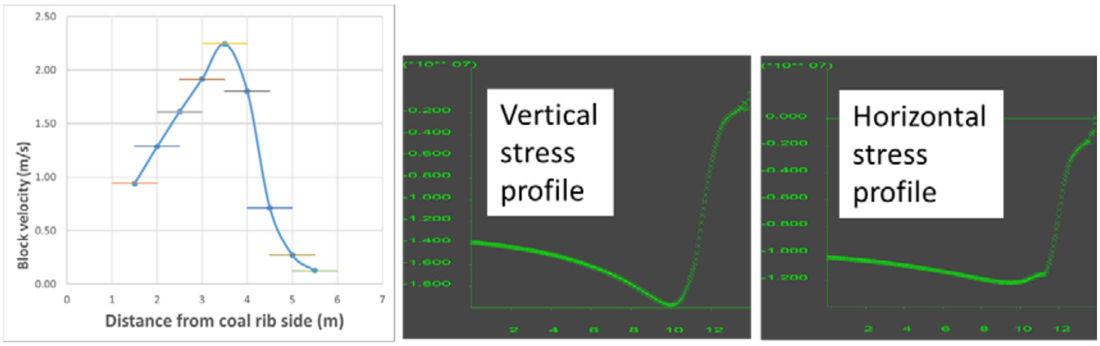
In this model a 1 m section of total bond failure between the coal and rock at the roof level only was initiated at various distances from the rib side. Once the bond was broken, the dynamic chain reaction took place where the released elastic compression energy was carried at great speeds across the seam towards the rib side. The ejected coal rib is usually fractured and unconfined, for simplicity this was modelled as a 1 m thick loose block of coal 3.92 tonnes in weight as shown in Figure 3 (a). The dynamically generated mass velocities that propagated towards the rib side propelled the loose coal block in the lateral direction at up to 2.3 m/s depending on the location of failure. This momentum transfer in the model can be clearly observed in Figure 3 (b, c, d, e and f). Prior to the ejection, velocities within the seam are high. Once the coal block is ejected, the velocities in the seam decay to negligible levels as the accumulated energy from the seam is transferred into the kinetic motion of the detached block shown in Figure 3(f).The modelled displacements shown in Figure 4 indicate the triangular shape disturbance that starts at the beginning of the disturbed zone and gets wider towards the rib side. This disturbed shape is similar to the ejected coal cavity observed after the coal burst event at the Austar mine. This mechanism further reinforces the findings that the coal-rock bond failure occurred along the “Dosco parting” which is the dominant bedding plane located at the roof level in the Austar mine.



(a) (b)

Figure 4: (a) Modelled displacements within the coal seam after coal ejection indicate the triangular shape of seam disturbance (b) Austar coal burst ejection along the Dosco Parting (Photograph after Australian Mine Safety Journal, 2016)

To study how the rib block ejection velocities vary with the coal-rock bond failure, various locations of cohesive/frictional bond loss 1 m in length between the roof rock and coal seam were artificially induced. In the first model, the edge of 1m de-bonded roof length was placed 1 m from the rib (rib located at 15 m). In all subsequent models the disturbance was gradually shifted in 0.5 m intervals further away from the rib. Altogether nine cases were modelled. The ejected velocities of the 3.92 tonne block were graphed and are presented in Figure 5 (a).



(a) (b) (c)

Figure 5: (a) Modelled location of the 1 m long coal-roof bond loss versus the ejected velocities of the 1 m thick rib coal block. (b and c) Vertical and horizontal stress profile in the coal at the roof level adjacent to the coal rib before the rock burst occurred.

The results show that the most violent coal burst occurred when the 1 m long bond failure along the roof occurred between 3 and 4 m from the rib side. This failed zone (at the chainage between 11 and 12 m in the model) coincided with locations where the maximum vertical and horizontal stresses were on the steep decline towards the rib side as shown in Figure 5 (b and c).

POSSIBLE COAL BURST TRIGGER MECHANISMS

Many coal burst trigger events may exist such as: failure of a highly loaded fault plane, geologically weakened coal-rock interfaces, on high additional loads due to nearby mining. As the nearby fault planes were present adjacent to the coal burst location in the Austar mine (Figure 6.) it is assumed that their failure may have generated enough seismic energy needed to disturb the Dosco coal parting strength and trigger the coal burst.

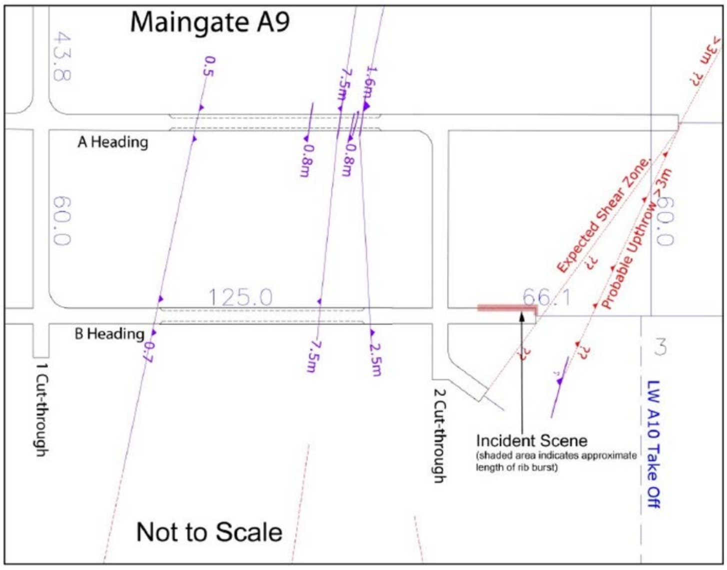


Figure 6: Location of faults at close proximity to the coal burst site in Austar mine (Hebblewhite, 2017)

Mining activities may have unloaded some of the compressive stress normal to the fault plane causing the rapid slip movement along the fault. The rapid release of seismic energy propagates as a compressive wave through the solid strata that can provide enough energy to trigger the coal burst.

It is worthwhile to discuss the attenuation of seismic energy from the fault plane source. From basic physics (neglecting the effects of damping over short distances), when considering the point energy source in three dimensions, seismic energy through the elastic medium attenuates with a distance squared as shown in Figure 7 (a), whilst for sources of energy generated along a long line, attenuation with distance is linear as shown in Figure 7 (b). When the energy source is a large fault plane area and within a relatively short distance that is smaller than the fault geometry, the energy does not decrease with the distance as illustrated in Figure 7 (c).

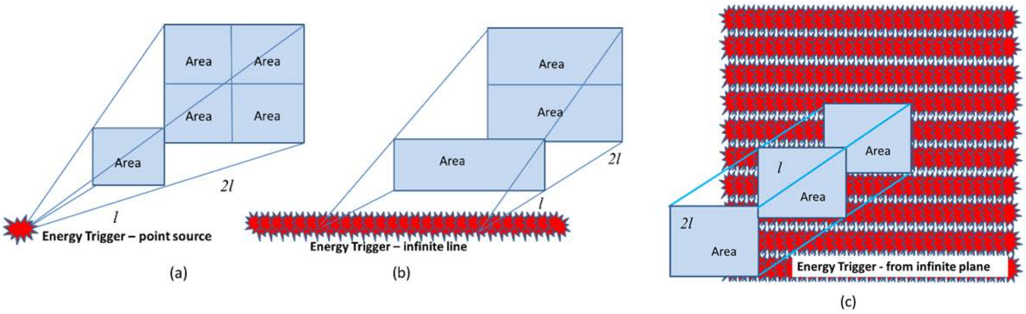


Figure 7: Aerial expansion of the seismic energy in 3-dimensional space from (a) the point source (b) the line source and (c) the plane source

A simple numerical model of the fault slip oriented at approximately 45° dip towards the left and approximately 10 m from the roadway rib side, is depicted in Figure 8. The compressive waves refracted through a coal seam (shown as grid velocity waves) indicate how a violent behaviour can easily disturb the already highly loaded coal-rock bonds. Note that the waves propagate faster in rock and slower in coal due to the different material stiffness. This creates refractions and interference patterns at the coal-rock interfaces.

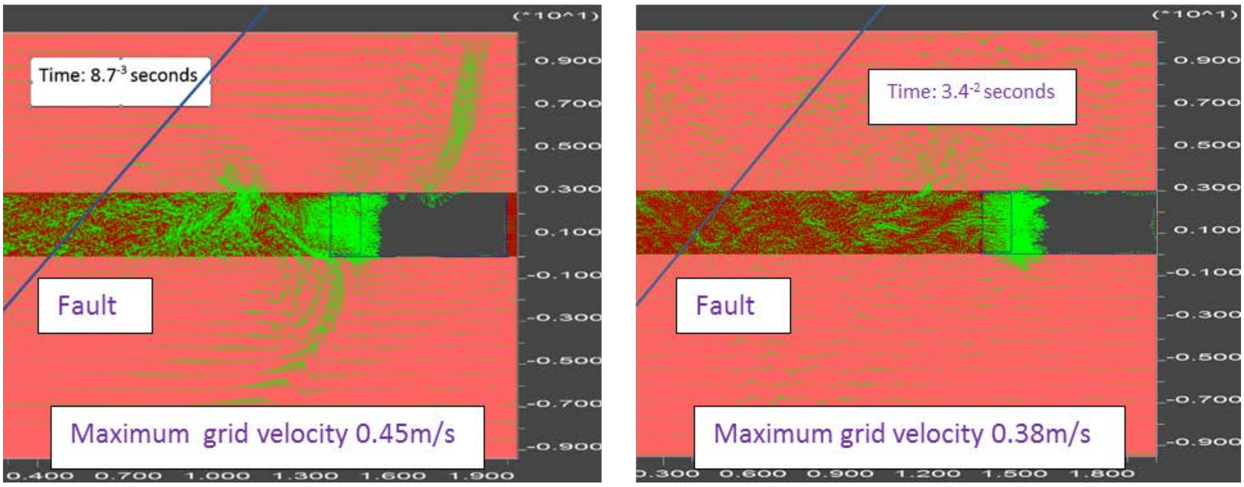


Figure 8: A simple simulation of fault slip adjacent to the mine roadway demonstrates an example of fast compressive waves presented as grid velocities movement away from the fault zone.

CONCLUSIONS

The main purpose of this research is to explain the concept of the coal burst mechanism in a coal mine roadway. The initial idea originated from the Newton's Cradle, where the energy transfer occurs via the conservation of momentum principle. The dynamic numerical FLAC model proved suitable in demonstrating this concept. The aim of this work was to approximate the coal burst event that occurred in the Austar mine, Australia. In a nutshell, the model clearly demonstrated the release of stored potential energy (compression) within the seam and its conversion into kinetic movement of the unconfined/loose coal mass. A large portion of this energy was transferred via the conservation of momentum into the 3.92 tonne coal block located at the free surface, ejecting it at velocities of up to 2.3 m/s. After the coal block was ejected the modelled displacements within the rib indicated a triangular deformation mode of failure. This type of failure and its location was similar to the Austar mine coal burst failure geometry. It can therefore be concluded that the Dosco roof parting failure in Austar mine caused ejection of the triangular portion from the upper seam section to a depth of approximately 4 m.

At this stage of research presented here, the main aim is to explain the mechanism of coal burst adjacent to the mine roadway. Material properties, geometry of mine workings, geological disturbances, level of stress and other factors that may influence the likelihood of coal bursts are yet to be thoroughly investigated in detail. As part of the follow-up work more accurate models are being prepared to enable simulations of other coal burst cases, eventually leading to better understanding and prediction of these events. Mathematical calculations of the energies locked in the seam and the energy release have been pursued in parallel to provide better prediction methods against coal/rock bursts.

Many different types of coal bursts have been experienced mainly in deep overseas mines. As the Australian mines are getting into deeper ground all styles of coal/rock burst need to be investigated. A similar dynamic analysis approach will need to be undertaken in order to establish potential variations of coal burst mechanisms and search for methods that can minimise their hazardous occurrence.

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