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Numerical model of dynamic rock fracture process during coal burst

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NUMERICAL MODEL OF DYNAMIC ROCK FRACTURE PROCESS DURING COAL BURST

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ABSTRACT: Coal bursts present one of the most severe hazards challenging the safe operations in underground coal work environments. In Australia, these events are becoming increasingly frequent as coal measures are mined progressively deeper. This study is supported by the Australian Coal Association Research Program (ACARP) which aims to better understand the phenomena of coal burst. In this paper the dynamic fracture process of coal bursts was successfully simulated in the coal roadway. This was achieved using dynamic analysis utilising DRFM^{2D} routine by Venticinque and Nemcik (2017) in FLAC^{2D} (Itasca, 2015) which complemented previous study observations by Venticinque and Nemcik (2018). This is significant because until now the evolving dynamic rock fracture process during coal burst remained unknown. Additionally, coal/rock burst events were shown from simulation as being largely driven by the propagation of shear fractures from within the rib. This was demonstrated to produce effect forcing the dynamic conversion and release of potential energy stored as compressive strain in the rib into kinetic movement of the entire rib section. This entire process was shown to occur very fast taking approximately 0.2 seconds for a coal burst to fully establish, with ejection of several meters of rib at a velocity of 1.6 m/s produced in the model of an underground coal roadway having 550 m depth of cover.

INTRODUCTION TO MODELLING COAL BURST

Coal bursts are very difficult to predict as they are inherently not frequent, isolated and occur without warning. To minimise the occurrence of coal burst it is necessary to first understand how the mechanism of coal burst arises. 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 such as coal bursts. This highlights the serious shortcoming of trying to model dynamic material response behaviour of strata around excavations; hence such models should not be used. The importance of built in dynamics is therefore recognised in dynamic analysis for incorporating inertial effects, enabling real time simulation of dynamic ground movement. Likewise, when using these models, correct approach is necessary to isolate and observe what mechanisms are taking place.

A 2-Dimesional Dynamic Rock Fracture Model (DRFM^{2D}) has been undergoing development at the University of Wollongong for more than 5 years. The theoretical basis of this model has been successfully implemented across numerous problems with outputs producing model fractures as observed in laboratory tests Venticinque and Nemcik (2017). Subsequently the DRFM^{2D} subroutine in FLAC (Itasca, 2015) is capable of producing the associative dynamic effects from fractures in real time and in doing so is well suited towards capturing the conversion of kinetic motion response naturally produced in the rib during coal burst.

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MODELLING PROCEDURE

Using FLAC^{2D} (Itasca, 2015), an excavation of a standard underground coal mining roadway 5m width by 3m height was modelled within in a 3m thick coal seam bound by competent sandstone roof and floor strata at a depth of 550m, illustrated in Figure 1 and having rock mass strata properties listed in Table 1.

Table 1 – Rock mass strata properties.

Sedimentary Floor and Roof Rock		
Mechanical Properties		
Density	2500	kg/m^3
Bulk Modulus	6.67	GPa
Shear Modulus	4.0	GPa
UCS	40.1	MPa
Internal Friction ϕ	37	°
Working Coal Seam		
Mechanical Properties		
Density	1400	kg/m^3
Bulk Modulus	3.33	GPa
Shear Modulus	1.11	GPa
UCS	0.8	MPa
Internal Friction ϕ	35	°

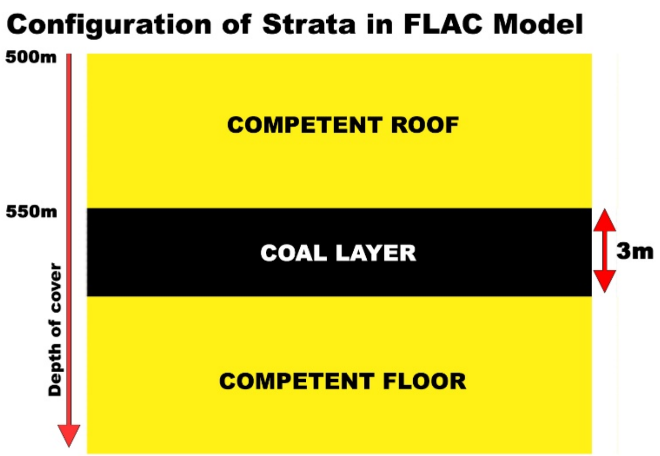

Figure 1: Model of strata

Initially, the model was brought to static equilibrium prior to dynamic solution being initiated as per described in Itasca (2015). In order to simulate the dynamic coal burst event, bond failure was artificially induced within a single interface element located at the roofline between the coal and sandstone strata 4m from the rib side. With reference to the vertical stress profile of the rib the artificially failed zone coincided with the maximum vertical and horizontal stress location at the coal/rock interface as well as the inflection point of the stress gradient profile before steeply declining towards the rib side shown in Figure 2. From Venticinque and Nemcik (2018), this was identified as being the most appropriate region for coal burst to be initiated from.

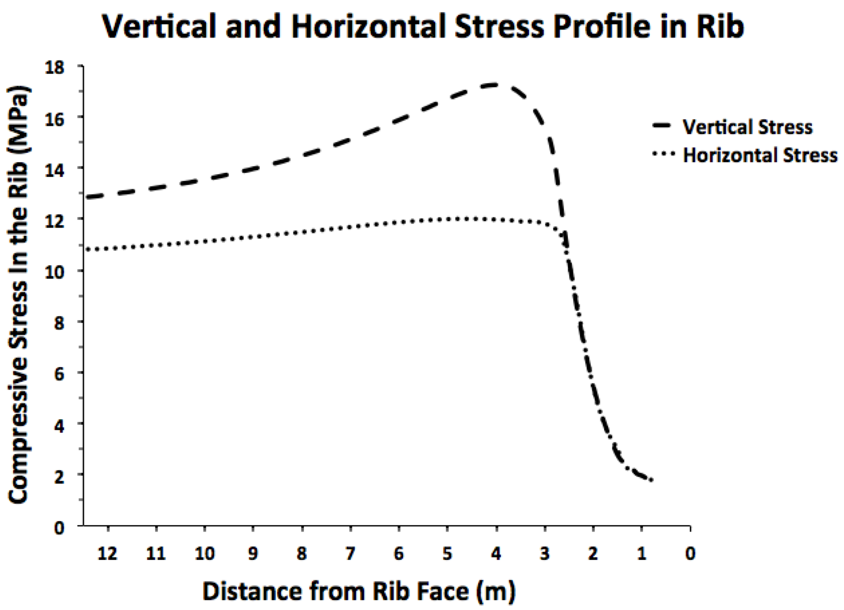

Figure 2: Stress profile along coal roof line adjacent to rib face prior to coal burst occurring.

Following artificial initiation of coal burst from behind the rib, the DRFM^{2D} subroutine was executed enabling the real time dynamic propagation of fractures to naturally evolve concurrent with the dynamic response effects evolving within the rib. During simulations, dynamic fracture propagation and velocity mass response of the rib was monitored with respect time.

RESULTS

Monitoring the dynamic fracture propagation and velocity mass response over time, model outputs revealed the development of coal burst phenomena to occur over several distinct stages. These are presented in Figure 3.

Through interpretation of simulation results in Figure 3, the evolution of a coal burst event is identified to occur several distinct stages. In sequential order these are:

a. Generation of initial compression wave produced from a shear fracture initiating behind the rib and propagating in the direction towards the free surface of the rib-side.
b. Arrivals of the compression wave at the rib face promoting tensile dislocation with possible block spall ejection.
c. Displacement of near-face rib mass from the free surface, producing a cascading effect of shear failure towards the higher stressed rib mass behind. It is understood that the displacement of rib
d. mass from the initial rib surfaces results in a sudden drop of confinement being supplied to the higher stressed rib mass behind. This effect drives unstable shear fracturing attributing further subsequent dynamic release of stored energy to occur from behind.
e. Entire rib movement dynamically driven by the release of potential stored energy through fracturing. This movement eventually causes previously fractured surfaces in shear to open in tension becoming dislocated from the rib mass behind, with ejection of a large rib mass.

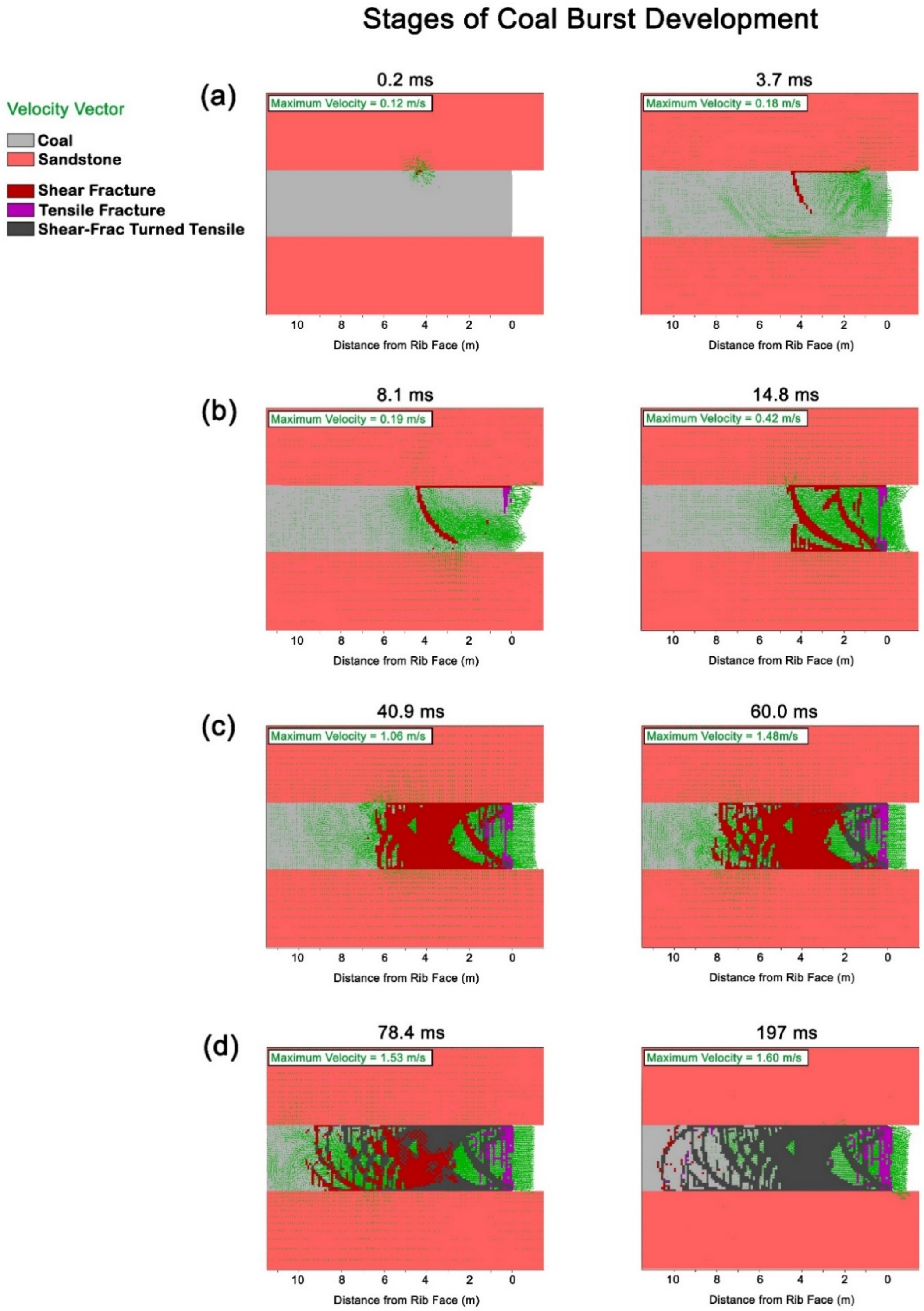

Figure 3: Development of coal burst phenomena over time.

From simulation, the phenomena of coal burst can be recognised to initiate from shear failure localised behind the rib which continues being driven by shear fracture afterwards. This is where the initiated fracture continued propagation along the coal/rock interface towards the rib, while another shear fracture continued through the coal, downwards curving towards the rib side as shown in Figure 4.

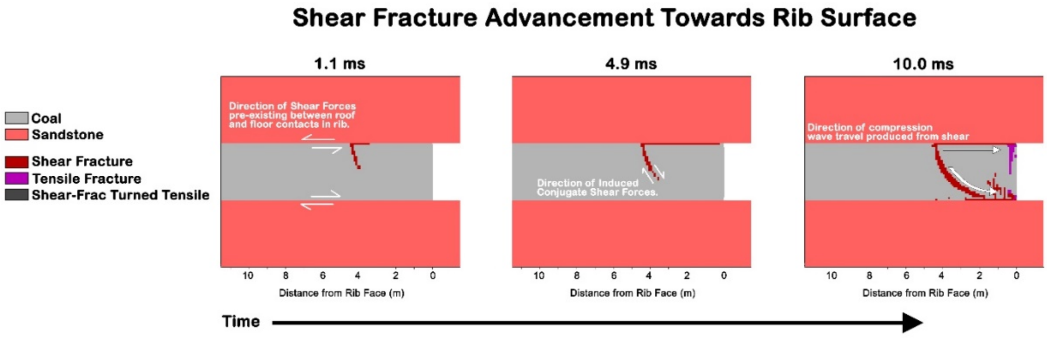

Figure 4: Shear failure mechanism driving coal burst production

The dynamic effect produced these from these shear fractures forces the dynamic conversion and release of a significant amount of potential energy stored as compressive strain into kinetic movement of the entire rib section. This is demonstrated by the migration of high vertical stresses deeper into the pillar and increase of rib-mass ejection velocity in Figure 5.

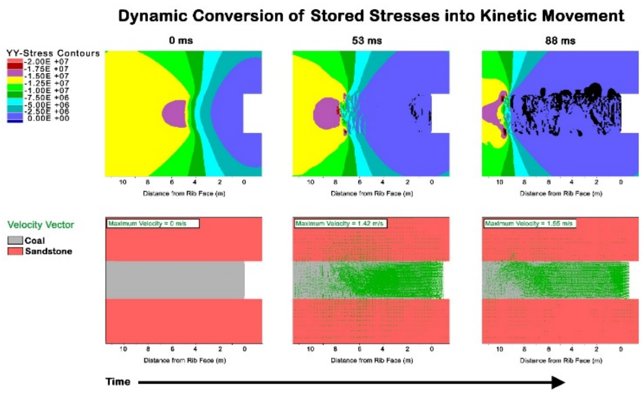

Figure 5: Evolution of compressive stored stresses into kinetic movement with time.

As the velocity of the rib mass accrues momentum, unloading from displacement of the rib removes confinement from the seam, causing failure to be driven deeper into the seam producing further subsequent dynamic release. The final fracture pattern supplied in Figure 6 can be noted to produce similar triangular wedged velocity and hence displacement profile to that initially observed in previous simplified simulations by Venticinque and Nemcik (2018). Subsequently the final ejection velocity of 1.6 m/s of the entire coal mass rib reinforces the observed mechanism involving release of potential energy stored as compressional stresses and strains into kinetic movement of the relieved unconfined/loosened coal rock mass.

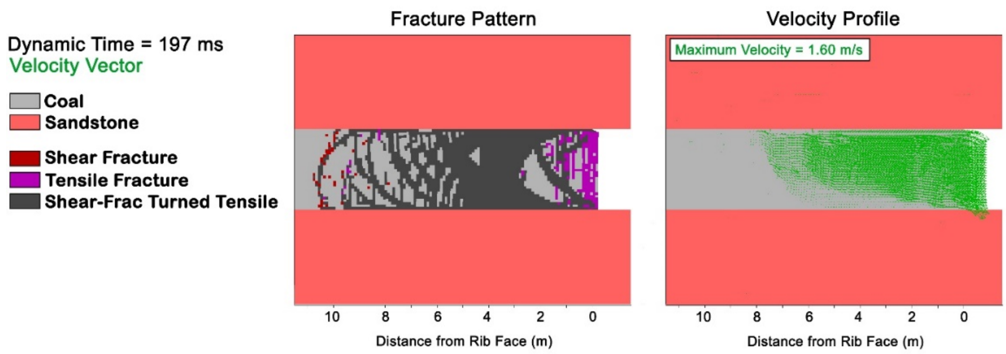

Figure 6: Final fracture pattern and velocity profile produced by DRFM^{2D}

Finally, the simulated duration of process producing coal burst phenomena in the model is remarked as matching average measured time period durations of approximately 0.2 seconds obtained from monitoring roadways in coal burst prone collieries by Li, *et al*., (2018). This adding further degree of relevance and confidence in the simulated dynamic coal burst phenomena produced from the model.

CONCLUSIONS

Numerical models using dynamic analysis with DRFM^{2D} in FLAC successfully simulated the real time dynamic evolution of coal burst phenomena in detail about the coal roadway. This is significant because until now coal bursts have not been able to be numerically reproduced or able to be studied at this level of detail which has restricted many of their features from being studied. For the first time the stages occurring during a developing coal burst event were sequentially identified and explained.

The ability to generate dynamic fractures in real time during the model proved to be valuable in helping realise important characteristics of underlying complex dynamic processes involved during coal burst. This where the propagation of shear fractures within the rib is evidenced from outputs as having a significant role in driving the coal burst phenomena. In conclusion, the aim of the study and ACARP objectives based on an improved understanding on coal burst is considered to have been achieved.

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