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Study of seismic activities associated with Australian underground coal mining

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STUDY OF SEISMIC ACTIVITIES ASSOCIATED WITH AUSTRALIAN UNDERGROUND COAL MINING

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ABSTRACT: This paper reviews the seismic events that occurred within the New South Wales (NSW) mining regions in the past 10 years, using the seismic data obtained from Geoscience Australia. The frequency and magnitude of the seismic events were assessed to investigate the correlation between underground mining activities and the associated seismicity. The study also reviewed the seismic events associated with coal bursts in Australia to understand its nature and its proneness in Australian conditions. Based on the study conducted, there is no clear correlation between the past recorded seismic events and the underground coal mining activities. It is also suggested that the coal burst in Australia appears in low energy magnitude, occurring in isolated manner. In comparison to international experience, coal mines in China and United States have encountered significantly higher frequency and magnitude seismic events associated with coal burst. Based on the findings, it is recommended that localised seismic monitoring methods should be used to monitor low magnitude events with higher accuracy in regards to depth and location of events. The analysis and results produced from this study contribute to the knowledge and understanding of mining induced seismicity in Australian underground coal mines.

INTRODUCTION

Seismicity is a widely known phenomenon that is inevitable and associated with mining activities. Seismic events are associated with all types of rock failures. In underground mining, large seismic events can occur from various sources including pillar punching, disturbance of geological structure from active longwall mining, failure of overburden strata and events of coal bursts. A coal burst is defined as a pressure bump that actually causes consequent dynamic rock/coal failure in the vicinity of a mine opening, resulting in high velocity ejection of this broken/failed material into the mine opening. The energy levels, and hence velocities involved in pressure/coal burst can cause significant damage to, or destruction of conventional installed ground support elements such as bolts and mesh.

Despite of decades of research and experience, the source and mechanics of seismicity associated with coal bursts are inadequately understood (Mark and Gauna, 2015). The lack of understanding of such phenomena has made it difficult to implement effective coal burst control and mitigation measures. Seismic events associated with coal burst is regarded as one of the most dangerous hazards in coal mining which have accounted for considerable number of fatalities and substantial disruption to production capabilities (Westman *et al*, 2012). While there have been only two publically reported events of coal burst in Australia, coal burst events have been a serious prevalent issue in international mines located in countries such as China, Europe and United States. The burst events encountered by these mines have revealed that powerful seismic events associated with coal burst can occur due to various combinations of geological and mining operational factors such as deep depth of cover, inadequate pillar designs and presence of thick competent strata. This study aims to improve the understanding of the mining induced seismicity in Australian underground coal mines. The results will also form an important component in providing insights to seismic events associated with coal bursts in Australia.

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PAST SEISMIC EVENTS

As part of this study, comprehensive research into Australian and international coal mines affected by mining induced seismicity were conducted. The review of these mines involved examining the frequency and magnitude of the mining induced seismic event and assessing various factors that has contributed to the seismic activity. It also included comprehensive review of past coal burst events associated with these mines to gain improved understanding of the nature and casualties of these coal burst incidents.

Experience in United States

In the USA, events of coal burst and high magnitude of seismic activity have been closely associated with longwall mining. Study conducted by Arabasz and Pechmann (2001) has revealed that Utah has experienced high frequency of seismic activity induced by underground mining. By operating a regional seismic system, 148 mining induced seismic events were recorded between 1978 and 2000. These events have been identified with a local Magnitude (M_L) of greater than 2.5 with 18 occurring with magnitude greater than 3.0 M_L. In addition, the severe impacts of coal burst have been assessed, as 87 fatalities and 163 injuries were associated with coal burst within the database of 172 coal burst events recorded between 1936 and 1993 in the United States (Iannacchione and Zelanko, 1995). According to Mark (2016), states of Utah and Colorado have experienced a series of fatal coal burst events that have had detrimental impacts on both safety and production of mining operation. Mine A located in Book Cliffs region experienced several powerful coal burst events throughout the life of mine. In response, various mitigation strategies such as interpanel barriers and abandoning of working panels were implemented. However, the persistent coal burst risks were not eliminated and claimed the life of a shearer operator when mining at a depth of 840m (Mark, 2016). Consequently, due to inadequate management of coal burst hazard with prevalent risks associated with continual mining at greater depth, the operation was terminated. Similarly to Utah, mine B located in Colorado also experienced severe seismic events associated with coal burst. Since 2009, the mine experienced several powerful coal burst events with three events identified with local Magnitudes (M_L) of over 3 (Mark *et al.*, 2012). These events led to extensive pillar failures and severe ventilation damage, eventually leading to the closure of the mine.

Experiences in Australia

Until the recent event of coal burst that occurred in Austar Mine in New South Wales, coal burst events were rare phenomena that posed minimal risk to Australian mines. According to the NSW Department of Industry (2014), the 2014 incident involving two fatalities experienced magnitude and volume of the pressure burst that “rendered the installed rib support ineffective”. Prior to the 2014 coal burst event, Austar has experienced numerous coal bump events in the past. Coal bumps are different to coal bursts where it is a dynamic release of energy from intact rock failure that produces audible signals and ground vibrations. In the past, workers in Austar have accepted these audible sounds as normality associated with underground coal mining activity (NSW Department of Industry, 2014). It was also reported that prior to 24 hours of the coal burst incident, a powerful pressure bump was experienced at a location that was in close proximity of the incident scene (NSW Department of Industry, 2014). The pressure bursts were not identified as a risk as the geological conditions at Austar have not been previously encountered in Australia. Consequently, this has led to inadequate understanding of the sources and mechanisms of the coal burst incident.

Experience in China

In China, seismic events associated with underground coal mining activities have been a long existing prevalent issue, dating the first mining induced seismic event in 1933 at Shengli Coal Mine in Fushun City, Lianing Province (Li *et al*., 2007). From a wide collection of coal mines in China, Mentougou Coal Mine in Beijing and the Fushun Coalfield in Liaoning Province are renowned for the significant number of seismic event frequency. A total of 111,913 seismic events with a local magnitude of greater than $1.0M_L$ were recorded in the Mentougou Coal Mine between 1980 and 2000. The mine also experienced one of the strongest mining-induced seismic events during its mine life with an event magnitude of $4.2M_L$ detected in 1994 (Li *et al.*, 2007). In the Fushun Coalfield, 92,630 seismic events greater than $0M_L$ were detected between 1968 and 2005 with greatest number of activities recorded in 2001 with 7222 events (Li *et al.*, 2007). The mine also experienced a gradual increase of coal burst event in terms of its frequency and magnitude. Since 1990, there have been an increasing number of powerful coal bursts with magnitudes over $3.0M_L$. Through to 2005, a total of 86 strong coal burst events with magnitudes over 3.0 were experienced with largest event registering at a magnitude of $3.7M_L$ recorded in 2002 (Li *et al.*, 2007).

In China, the increasing depth of coal mining and its operational scale are becoming a serious concern. While only 32 coal mines were associated with coal burst events in 1985, there have been an increase to 142 mines that have experienced the burst event in 2012 (Wen *et al*, 2016). The significant growth of coal burst events are likely to coincide with the increasing depth of mining with more than 50 coal mines operating at a depth of more than 1000m between 2006 to 2013 (Wen *et al*, 2016). During this period, more than nine coal mines have experienced 35 powerful seismic events associated with coal burst resulting in 300 fatalities (Wen *et al*, 2016).

METHODOLOGY

In this study, seismic dataset was acquired from Geoscience Australia, consisting of parameters such as magnitude, depth, date, time and coordinates of the event. A monitoring period of 10 years was considered appropriate and sufficient for the scope of this study. The criteria considered for the dataset utilised for this study is summarised in Table 1**Table 1**. To gain a greater knowledge about the validity of the seismic data, direct enquiries were made to Geoscience Australia in regards to the accuracy of the produced results.

Table 1: Parameters used for seismic dataset produced from Geoscience Australia

Location	**New South Wales (NSW)**
Recording Period	From 01/06/2016 to 01/06/2016
Depth (km)	0 – 1000
Magnitude (M_L)	0 – 9

To represent the relevance and correlation of the seismic data with underground coal mining, the seismic dataset was plotted with overlays consisting of mining leases and operating coal mines in NSW as of 2014, as illustrated in Figure 1.

Figure 1: Overlay of NSW of coal mining district

The seismic dataset in NSW was closely reviewed to isolate the events that have occurred on or in close proximity of the coal mining region. To represent a greater relevance of seismic data for the scope of the study, the depth of these events were subsequently reviewed. As underground coal mines in NSW operates within a depth of 1km, the “0km” events expressed by Geoscience Australia was considered relevant for this study. The updated sets of seismic data produced from these criteria were plotted on Google Earth software to examine the possible correlation between seismic activity and underground coal mining. From this process, details such as clusters of seismic events and event magnitude were analysed to gain an understanding of seismic activities in NSW coal mining districts. In addition, past coal burst events were assessed and enquired to respective mining companies to draw a correlation between recorded seismicity and reported coal burst incidents.

RESULTS

Assessment of seismic events in NSW coal mining district

Within the monitoring period of 10 years, 699 seismic events were recorded in NSW. The assessment of these events has revealed that 80 events were present on or in close proximity of NSW coal mining district. As seen in Figure 2, the majority of seismic events occurred within a depth of one kilometer, followed by considerable number of events occurring at depth of 10 kilometer and deeper. While the “0km” events can be attributed to human activities such as commercialised surface blasting and mining activity, events occurring at significantly deeper depth at around 10 kilometer are likely influenced by natural causes. According to the USGS earthquake magnitude scale, majority of these events were low energy events with vast number of them occurring at a magnitude between 2 to 2.6, as shown in Figure 3.

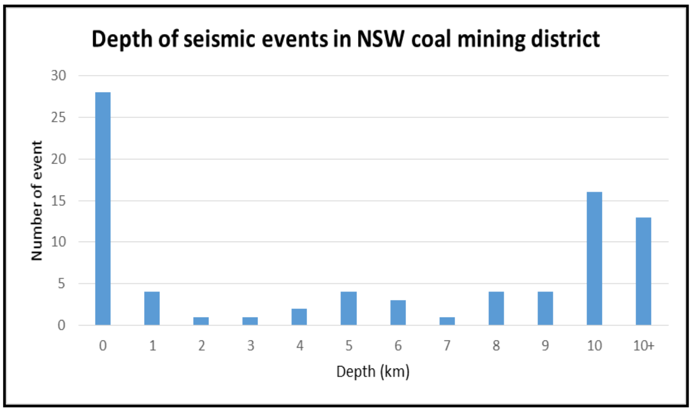

Figure 2: Varying depth of seismic events that has occurred in NSW coal mining district in the past ten years

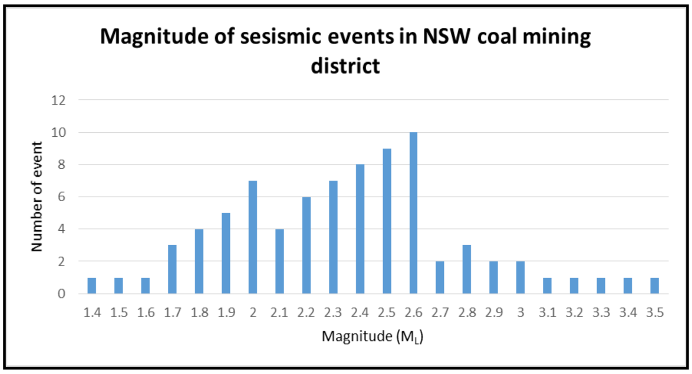

Figure 3: Varying magnitude of seismic events that has occurred in NSW coal mining district in the past ten years.

Assessment of low depth seismic events

For the scope of this study, seismic events that have occurred within the depth of one kilometer were focused. Out of the 80 events that were presented on or in close proximity of NSW coal mining districts, 28 events have occurred within the depth of one kilometer. The magnitudes of these events are presented in Figure 4 and the associated locations of these events are shown in Figure 5.

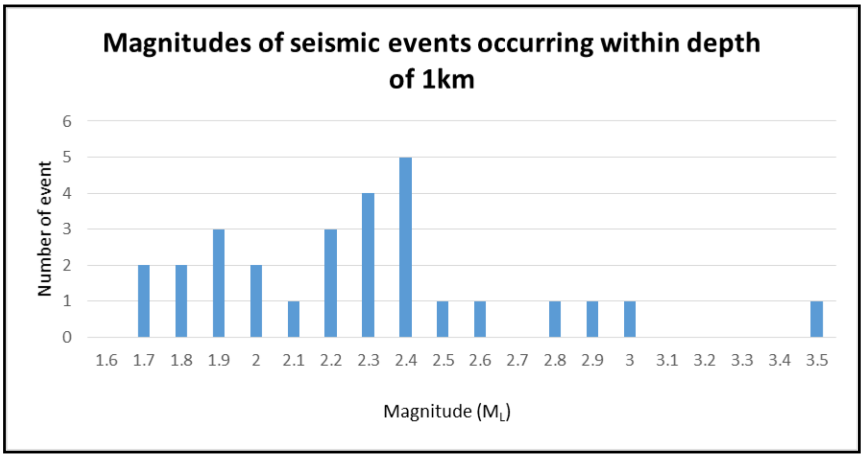

Figure 4: Magnitude of seismic events occurring within the depth of one kilometer

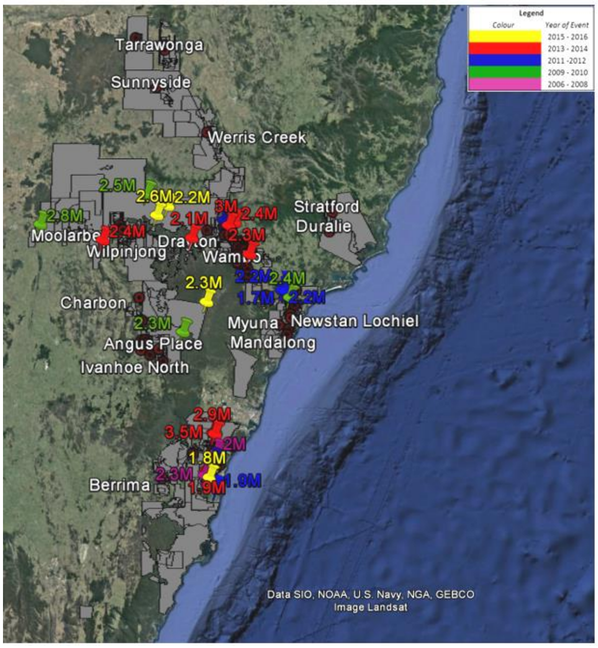

Figure 5: Location of seismic events within a depth of one kilometer presented in NSW coal mining district.

Figure 4 reveals that vast majority of the “0km” depth events have occurred at a low magnitude manner with an average of $2.3M_L$. In addition, observation made from Figure 5 reveals a relatively well spread of events within given monitoring years with slightly more seismic events occurring between 2013 and 2014. To provide clarity in the particular regions with cluster of seismic events, a closer view of these districts is provided in Figure 6 and Figure 7. It is evident that there have been clusters of events occurring in Austar and Appin districts during the period of between 2011 to 2012 and 2013 to 2014, respectively. Relative to Austar, Appin has experienced slightly greater intensity of events with strongest event registering at a magnitude of $3.5M_L$. In addition to this, it is evident that the collective events in Appin region has occurred much close to each other than in other mining district, which may indicate a common source of causality.

Figure 6: Close up view of Appin mining region

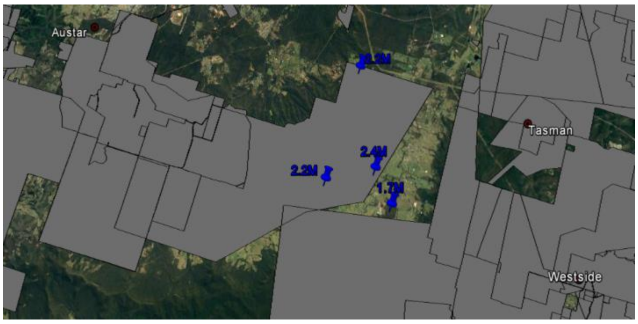

Figure 7: Close up view of seismic events in Austar mining region

Investigation of seismic events

With past seismic events associated with coal burst reported in areas such as Austar and Appin, these two districts were selected for further investigation. From the seismic data produced from Geoscience Australia, seismic activity on the 15th of April 2014 was searched, the day when two workers were killed due to a coal burst event. Although the magnitude of the event was described as a powerful event by NSW Department of Industry (2014), no seismic data was detected on that day or in proximity of the incident date. Similarly, coal burst event reported in Appin region also resulted in the absence of data recorded by Geoscience Australia. This was followed by conducting a direct enquiry to the mine operators in Appin and Austar about the seismic events that was recorded in close proximity of their underground coal mining operations. The enquiry consisting of event location, magnitude and time was conducted, however it was responded that no event of coal burst were present on neither the given details nor any reports of mining related incidents/events. Due to the lack of seismic event data, a clear correlation between underground mining and seismicity could not be found.

ANALYSIS AND DISCUSSION

Comparison with overseas experience

The observation of the seismic events in NSW mining districts revealed that Australian mines experiences significantly lower frequency of seismic activity compared to international coal mines. It has also suggested that the coal burst events in Australia appear in low energy magnitude that occurs in an isolated manner. The seismic data produced from Geoscience Australia has indicated that only 28 potentially relevant mining induced seismic events were recorded within the NSW coal mining districts in the past 10 years.

Furthermore, coal burst event has been a rare phenomenon in the Australian coal mining environment. In comparison to coal mines in United States and China, mining induced seismicity have been a persistent challenge with several presence of events with magnitude exceeding $3M_L$. Consequently, the impacts associated with these international coal burst events were considerably greater than of Australian experiences. Previously, coal mines in United States and China has experienced powerful seismic activities associated with coal burst that has led to severe ground failures. In United States, coal mines in Utah and Colorado has experienced collection of severe and persistent coal burst hazard in the past which ultimately led to the closure of the mine.

From the assessment of mining induced seismic activity from both Australian and international coal mines, it was revealed that the frequency and magnitude of seismic events are highly dependent on the depth of mining operation. In Australia, mining activities are relatively shallow with Austar mine reportedly to be operating at a depth of 555m when the coal burst incident occurred (NSW Department of Industry, 2014). In comparison, coal mines in Utah and Colorado that has experienced devastating impacts of coal bursts were reported to be operating at a much greater depth, reaching up to 840m and 800m, respectively (Mark, 2016). Similarly, the collection of vast examples of severe coal burst in Chinese coal mines are highly attributed to significant mining depth with some Chinese mines operating at double the depth of some Australian coal mines. Ultimately, the collective experience of coal burst in Australia, United States and China has revealed that despite decades of research and experience, coal bursts events are difficult challenge to be adequately managed.

Limitation of seismic data

The lack of correlation between seismicity and underground coal mining activity can be highly attributed to the selected method of acquiring seismic data.

For depth of seismic events, Geoscience Australia has identified details of the depth parameter with a fixed value. For example, for an event that has occurred within the depth of 400 meter from the surface, Geoscience Australia produced this event as “0km” seismic event. The vague nature of this parameter can be a large problematic factor. Categorising the depth of events with a fixed value makes it highly difficult to identify the casualty behind the seismic event. If a more specified and accurate indication of event depth is given, for example as 300m or 400m depth events, it could be predicted with relatively high confidence that the seismic event has been influenced by mining related activity.

The use of seismic data produced from nationwide seismic monitoring stations such as Geoscience Australia can lead to a degree of inaccuracy when determining the location of seismic events. While the location of a seismic event can only be identified within a few tenths of a kilometre, it is possible that poorly located events can have a significant variance between the detected and actual event location. This can greatly affect the validity and accuracy of the analysed results. To resolve this issue, it is highly recommended that seismic records from regional seismic stations are used to locate the events with lower degree of uncertainty at a higher confidence level.

Another issue associated with using a nationwide seismic monitoring station is the inability to detect and monitor low energy magnitude events. Referring to Figure 3, there was relatively few low magnitude events recorded with lowest event being a magnitude of $1.4M_{L}$. The lack of these low energy events may indicate that the monitoring stations used by Geoscience Australia have difficulties in detecting low magnitude events. This is also supported by the absence of detected seismic data of the coal burst event that occurred at Austar mining region on the 15^{th} of April 2014. The lack of sensitivity of the monitoring system also indicates that microseismic events associated with mining activity cannot be detected. It is crucial that more sensitive seismic detection methods are employed to monitor smaller energy event. For example, in Utah a coal burst event registering at a magnitude of 1.1 was detected by using a regional seismic station (Mark, 2016)

CONCLUSION

This study analysed the seismic data produced by Geoscience Australia to assess the correlation between seismicity and underground coal mining in Australia. In particular, the study focused on the relationship between coal burst events and seismic activity. The overview of seismic events in the past 10 years that have occurred in New South Wales coal mining district has revealed that there is no correlation between seismicity and underground coal mining activity.

From the assessment of past coal burst events and seismic dataset produced from Geoscience Australia, it was suggest that coal burst in Australia appear in low energy magnitude, occurring in an isolated manner. In addition, based on the direct enquiries made to Appin and Austar in regards to past seismic events recorded in close proximity of their mining district, no correlation was found with underground mining activity.

The study also compared coal burst and mining induced seismicity between coal mines in Australia, United States and China. Compared to Australia, underground mines in China and United State encountered significantly larger frequency and magnitudes of seismic events associated with coal burst. While similar geological characteristics were encountered between these mines, the significantly greater depths of mining in international mines are highly attributed to increased seismic activity associated with coal burst.

The approach undertaken for this study has certain limitations. The seismic dataset produced from national seismic scale involved uncertainties in regards to depth and location of the events. In addition, the detection of small energy or microseismic events was proven to be highly difficult by using the chosen seismic monitoring method. Due to these limiting factors, a clear correlation between seismicity and underground mining could not be established. Upon the completion of this study, it is highly advisable that localised seismic stations are used for future studies.

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