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Geotechnical risk management to prevent coal outburst in room-and-pillar mining

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ABSTRACT

A coal outburst is a severe safety hazard in room-and-pillar mining under deep cover. It is more likely to occur during pillar retreating. Multi-seam mining dramatically increases the risk of coal outburst within the influence zones created by remnant pillars and gob-solid boundaries. Though coal outburst is generally associated with heavy loading of coal pillars, its occurrence is difficult to predict. Risk management provides a proactive tool to minimize coal outburst in room-and-pillar mining under deep cover. Risk assessment is the first step in identifying and quantifying outburst risk factors. The primary risk factors for coal outburst are overburden depth, roof and floor strength, geological anomalies, mining type, multi-seam mining, and panel width. A risk assessment chart can be used to proactively screen out mining sections with high risk of coal outburst for further analysis. Gob-solid boundaries and remnant pillars are critical factors in evaluation of the coal outburst risk of multi-seam mining. Risk identification, risk assessment, geologic influence mapping, geotechnical evaluation, risk analysis, risk mitigation, and monitoring are essential elements of coal outburst risk management process. Training is an integral part of risk management for risk identification and communication between all the stakeholders including management, technical and safety personnel, and miners.

1. Introduction

A coal outburst is a sudden violent burst of coal from a pillar with broken coal or blocks of coal forcibly ejected into open entries. A coal outburst is a severe safety hazard as the mining crew is highly exposed at the site when the event occurs. Though deep cover and strong roof and floor are underlying geologic conditions of a potential burst incident, its real occurrence is also the result of additional mining factors. In room-and-pillar mining, a coal outburst could occur during both development and pillar retreating, but the latter greatly increases the risk of outburst. The other risk factors of coal outburst also include mining layout, multi-seam mining, and presence of adjacent gob, cutting sequence, and local abnormal geologic conditions. Over the years, the cases of coal outbursts have been studied by many researchers and mining practitioners [1–6].

It is commonly believed that the coal outburst is the result of a sudden release of elastic strain energy stored in coal pillars and is highly associated with cutting into heavily loaded coal pillars, but its occurrence is a rare event and is difficult to predict. A number of engineering controls have been recommended to mitigate outburst potential. For room-and-pillar mining, sufficient pillar sizes have been the primary control for coal outburst prevention. The pillar design tools, such as ARMPS and AMSS developed by NIOSH, have played an important role in the design of stable pillars to prevent pillar collapse and squeezing as well as coal outbursts. In fact, with the implementation of pillar design using proper stability factors, pillar collapse and squeezing have been almost eliminated, and the number of coal outbursts has been greatly reduced in the US over the past decade. However, after a few outbursts occurred during pillar retreating in the US over the past a few years, it has been realized that sufficient pillar size is still not enough to prevent coal outbursts.

The investigations of the incidents showed that other factors such as multi-seam mining, panel layout, cutting sequence, and local geologic factors also seemed critical in causing the events. Therefore, it has become imperative that additional proactive measures beyond proper pillar design be implemented to prevent coal outbursts.

Room-and-pillar mining is the main mining method used by Alpha Natural Resources, and there are considerable sections that are practicing pillar retreating under deep cover and multi-seam mining situations. To reduce the probability of coal outbursts, the

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company has developed and implemented a risk management process to identify, analyze, and mitigate and control coal outbursts through geologic influence mapping, engineering evaluation, monitoring, and training.

2. Primary risk factors for outburst occurrence

2.1. Understanding coal outburst risk

Coal outburst is a type of pillar failure that can occur under excessive loading. It often concerns the local stability of an individual pillar or a small group of pillars under high stress. Most of the outburst incidents have happened during cutting into heavily-loaded pillars. Fig. 1 illustrates the conditions of a coal outburst occurrence. High vertical stress exerted on a pillar makes it store a great amount of energy. Strong roof and floor provide firm lateral confinement to the pillar so that the stored energy cannot be dissipated easily by rib deformation. An outburst could occur when the pillar or a portion of the pillar is loaded to a critical state at which no more elastic energy can be stored by additional loading. The driving force for an outburst event is the existing high stress level in the pillar and a release of the confinement that holds in the high stress.

It has been known that coal outbursts take place in Appalachia when mining with strong roof and floor under deep cover, but it is difficult to predict whether and where exactly they would occur. Because of the uncertainty of their occurrence, risk always exists when mining under burst-favorable conditions.

Coal outbursts are rare events, but their occurrence is detrimental to safety with a high possibility of injuries and fatalities. The risk of the outburst can be defined as the likelihood or probability of an outburst event under a given geologic and mining condition. It is a one hit event, which is in contrast with the general definition of risk by the number of events over population. It is so difficult to describe by a quantitative probability that a qualitative description such as low risk, moderate risk, and high risk can be practically used for the purpose of risk management. Although an outburst event is most likely to involve injuries or fatalities, some small scale bursts or precursor events, because they have no significant consequences, could be very likely neglected. To prevent outburst reoccurrence, it is very important to evaluate any small or precursor outburst incidents and to mitigate the risk of a subsequent large incident occurrence.

The other aspects of outburst risk deal with exposure and consequence. The exposure refers to the frequency, duration, and the number of people exposed at the risk site. As outbursts often occur when mining activity is going on, the exposure is always high. The outburst risk in pillar retreating can be reduced by safe positioning at the face as well as reducing the number of people working in by the pillaring line. The risk can also be reduced by administrative controls like setting up posts or shields to protect people who are frequently exposed to the risk. All of these are important to workplace safety, but this paper mainly focuses on the risk management process of how to reduce the probability of coal outbursts.

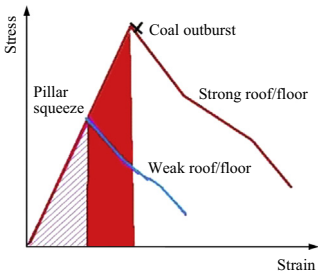

Fig. 1. Conditions of a coal outburst occurrence.

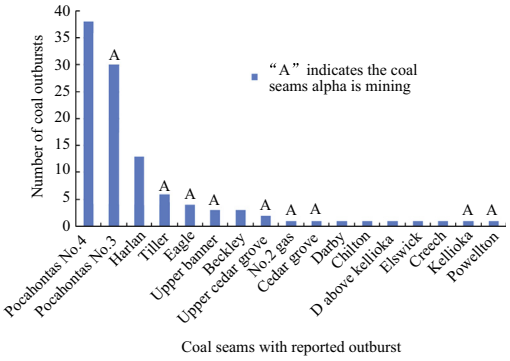

Fig. 2. Occurrence of coal outbursts in coal seams in central Appalachia.

2.2. Primary risk factors

Coal outbursts are more likely to occur in certain geologic and mining conditions. The primary risk factors for outbursts can be divided into geologic factors and mining factors. The geologic risk factors include: overburden depth greater than 200–250 m; strong roof which could overhang a certain distance over the gob; strong floor which does not heave readily; presence of geological anomalies such as faults, floor rolls, and sandstone channels; and abrupt change of coal seam thickness.

Coal outbursts are known to occur in both the eastern and western coal fields in the US. Coal's susceptibility to outburst seems to have little to do with its chemical compositions and mechanical properties, for outburst history has shown that any type of coal could burst under favorable conditions. Fig. 2 shows the occurrence of coal outbursts in the coal seams in Central Appalachia. The number of outbursts in a particular seam is not an indication that the seam is more prone to outburst. History has shown that outbursts occurred in almost all of the coal seams if the outburst conditions were met. A coal outburst is more likely to occur in a seam or in a mine with outburst history, but that does not preclude the possibility of an outburst event in a seam or in a mine with no outburst history.

Risk factors related to mining are associated with increase of pillar loading as a result of current and previous mining activities, and these factors include development, pillar retreating, multi-seam mining, panel layout, and cutting sequence. Development mining and pillar retreating are primary driving factors that increase vertical stress in pillars. Pillars at the pillaring line could be heavily loaded if there are strong roof overhangs over a large area into the gob. The increase of pillar loading could also come from the adjacent pillared gob separated by barrier pillars and from multi-seam mining with the existence of gob-solid boundaries and remnant pillars. Panel width is also an important factor for pillar loading during development due to the arching effect, and during retreating due to smaller abutment load with subcritical gob width. The stress in the pillars in the retreat face changes dynamically as mining take places from cut to cut. Local high stress in a particular pillar or a group of pillars in a retreat face could be created by a certain mining sequence, delayed roof caving, or unsystematically-left stumps or blocks.

3. Coal outburst risk assessment

3.1. Quantification of primary risk factors

In order to proactively manage the outburst risk, it is important to quantitatively describe the primary risk factors. The effect of the primary risk factors on the probability of an outburst occurrence