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Effects of overburden characteristics on dynamic failure in underground coal mining

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ABSTRACT

Dynamic failures, or "bumps", remain an imperative safety concern in underground coal mining, despite significant advancements in engineering controls. The presence of spatially discrete, stiff roof units are one feature that has been linked to these events. However, an empirical stratigraphic review indicates that no significant difference exists in the relative commonality of discrete units between bumping and non-bumping deposits. Instead an apparent relationship exists between reportable bumping and the overall stiffness of the host rock. However, this initial study is too simplistic to be conclusive; to weight the relative impact of changes in a single variable, such as the thickness or location of sandstone members, it must be examined in isolation—i.e., in a setting where all other variables are held constant. Numerical modelling provides this setting, and the effects of variability in a stiff discrete member in a hypothetical longwall mining scenario are investigated within the context of three stratigraphic "types", Compliant, Intermediate and Stiff. A modelling experiment examines changes in rupture potential in stiff roof units for each stratigraphic type as discrete unit thickness and location are manipulated through a range of values. Results suggest that the stiff-to-compliant ratio of the host rock has an impact on the relative stress-inducing effects of discrete stiff members. In other words, it is necessary to consider both the thickness and the distance to the seam, within the context of the host rock, to accurately anticipate areas of elevated rupture-induced hazard; acknowledging the presence of a discrete unit within the overburden in general terms is an insufficient indicator of risk. This finding helps to refine our understanding of the role of individual stiff, strong roof members in bumping phenomena, and suggests that a holistic view of overburden lithology and site-specific numerical modelling may be necessary to improve miner safety.

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1. Introduction

Dynamic failures, also termed "bumps", "bounces" and "bursts", may be defined as the violent ejection of coal or rock into a mine opening [1]. Despite evolving mining techniques and practices, these events continue to occur. Between 1983 and 2013, there were nearly 400 cases of reportable dynamic failure accidents in coal and nonmetal mines, resulting in 20 fatalities, 155 lost-time accidents, and an estimated 48,000 lost man hours. These events have been documented for well over 100 years within the American underground coal mining industry. Over this period of time, mining practices and support technologies have evolved considerably, resulting in an overall decrease in the rate of dynamic failure-related injuries and fatalities. However, despite this overall decrease in event rate, bump-related injuries and fatalities continue to occur. The events at Crandall Canyon, Utah, and the Brody No. 1 mine in West Virginia are two recent failure events that resulted in a total of eleven fatalities [2,3]. MSHA data further indicates that although reported incidents of these events are relatively rare, they result in worker injury up to and including death in more than 60% of cases. This is in contrast to injuries from the more common ground failure event of roof falls, which result in worker injury in less than 25% of cases (Fig. 1a and b). Clearly, dynamic failure events remain an imperative safety concern. Furthermore, their continued occurrence indicates that current engineering controls have proven inadequate at wholly mitigating the problem. The study described in this paper is part of a larger effort by NIOSH researchers that seeks to advance our current understanding of the causative factors behind dynamic failure phenomena, thereby allowing for more effective mitigation techniques.

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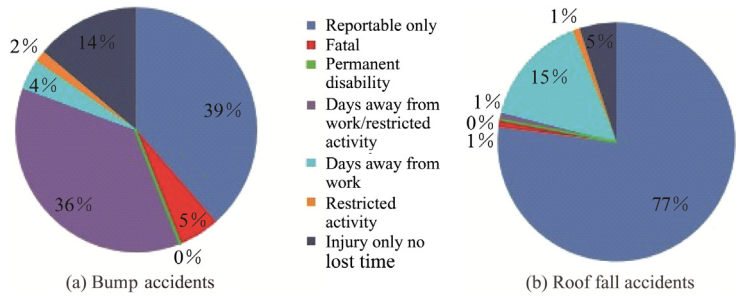

Fig. 1. Degree of injury as reported to MSHA between 1983 and 2014 by accident type.

2. Background

Many characteristics have been empirically linked to the occurrence of dynamic failure events, including design parameters, extraction techniques, and geologic factors. Identifying a set of conditions that will consistently produce bumping, however, has proven elusive; that is conditions generally associated with dynamic failure might produce an event at one site, but not another. Conversely and more troubling, dynamic failure could occur where relatively few of these factors exist.

The mechanical response of geologic structures plays a critical role in the development of dynamic failures. Regions that lack brittle strata are less prone to dynamic failure, although they may still experience roof falls, pillar failures, and other ground control difficulties. As a part of a larger effort to better define, the role of geologic risk factors in the occurrence of dynamic failure events, an empirical study was designed to examine the correlation of discrete stiff units to a reported history of bump phenomena. The role of discrete stiff units, such as massive sandstones and near-seam features, has been identified as a contributing factor to increased bump hazard.

Iannacchione and Tadolini define several fundamental factors contributing to dynamic failure occurrence [4]. Among these are strong strata surrounding the coal bed, which may "resist failure from elevated load conditions, and ... apply considerable stress and confinement to the pillars, increasing the potential for coal burst," and strata caving characteristics, in which "massive strata will often cantilever over areas...causing excessive levels of stress on coal pillars" [4]. Whyatt and Varley also describe failure of cantilevered, strong members as a significant mechanism of dynamic events [5].

Mark and Gauna provide a practical overview and generalized risk assessment matrix for bump events [6]. In their study, they describe several conditions of the overburden that have been associated with dynamic failure phenomenon, including thickness and location of near-seam strong or stiff units. They also note the lack of a quantitative, universal rating system for bump-risk identification, and identify as a qualitative intermediate risk factor, those roof conditions which are "typical Western US or Central Appalachian stratigraphy". While soft, compliant stratigraphic units are unambiguously not conducive to dynamic failure, and lithologies dominated by strong, stiff units are conducive to dynamic failure, the range of stratigraphic characteristics that pose an intermediate risk are less clearly defined.

The density of mining operations within the Western and Appalachian coalfields is illustrated in Figs. 2 and 3. Progress toward clarifying the degree of risk in these intermediate areas would benefit a significant number of active coal mines. The question, then, becomes: what are the critical thicknesses and locations of discrete stiff units, such as sandstones or competent limestones, at which they become truly hazardous to mining operations? This is by no means an easy question to answer, as influences on bump-proneness are multifaceted and identifying degrees of influence of these factors in a field setting remains elusive.

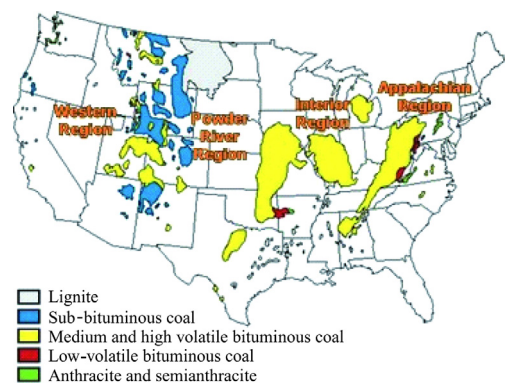

Fig. 2. Coal mining regions in the United States. (Minerals Education Coalition (MEC) of SME, 2016).

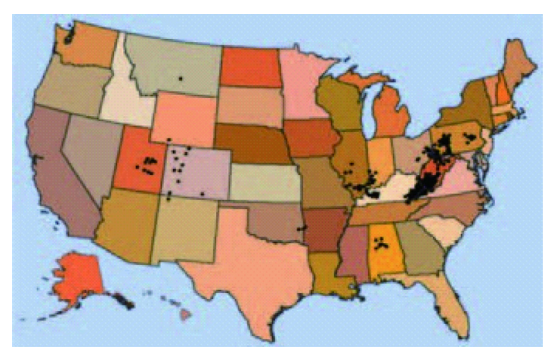

Fig. 3. Active underground coal mining operations within the United States, as of 2014.

Larson et al. demonstrate that load transfer distance correlates with different geology classifications (Fig. 4) [7]. These classifications fall into seven categories based on the proportion of sandstone (stiff) members to shale (compliant) members in the overburden, as well as the presence or absence of one or more massive or semi-massive stiff units. Strong, stiff strata may have the effect of increasing load transfer distances and resisting caving and loading of the gob, thereby increasing stresses in panel abutment.

The presence of stiff units in the overburden has the capacity to influence dynamic failure occurrence in two primary ways: First, failure of strong, brittle near-seam strata is likely to produce a seismic event. Second, bridging and cantilevering of strong strata shifts stress from gob to abutments. This paper seeks to identify the point at which these features transition from benign to hazardous. Toward this end, a review of reported failures was first compared

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