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Analysis of Geomechanical Factors Affecting Rock Bursts in Sedimentary Rock Formations

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Abstract

Rock bursts are defined as sudden, violent failures of rock mass that are of such a magnitude that they expel large amounts of coal and rock into the face area during longwall or pillar extraction in sedimentary rocks. In an attempt to develop tools for assessing stress bump potential, the first author initiated a comprehensive study using site specific information from 25 case studies undertaken in U.S. mines. This effort builds on an initial study while expanding the data base and including additional variables and analyses. Multiple linear regression and numerical modeling analyses of geological and mining conditions were used to identify the most significant factors contributing to stress bumps in coal mines.Twenty-five factors were considered initially (mechanical properties of strata, stress fields, face and pillar factors of safety, joint spacings, mining methods, and stress gradients, among others). Allowances were made for favorable local yielding characteristics of mine roof and floor in reducing damage severity. Pillar and face factors of safety were calculated using displacement-discontinuity methods for specific geometries in case studies having experienced both violent and nonviolent failures.This work identified the most important variables contributing to coal bumps and violent failure of near seam strata. These are [1] mechanical properties of strata, including local yield characteristics of a mine roof and floor, [2] gateroad geometry and/or gate pillar factors of safety, [3] stress gradients associated with the approach of mining to areas of higher stress concentrations such as abutment stresses from multiple seam mining, and [4] roof beam thickness, joint spacing, and stiffness characteristics, which influence cave conditions and dynamic loading. The latter variables, combined together to form a new variable called “strata rigidity-cavability”, reflect some of the most important aspects of violent failure, i.e. having massive and stiff near-seam stratigraphic units capable of absorbing high strain energy, forming high stress on mine structures and poor cave conditions, and thus the potential for dynamic loads.

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Keywords: Rock burst; coal bump; seismicity; multi-variable regression; cavability

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1. Introduction

Rock bursts are defined as sudden, violent failures of rock mass that are of such a magnitude that they expel large amounts of coal and rock into the face area during longwall or pillar extraction in sedimentary rocks. Typical ejected material varies from 5-100 tons filling up the pan at the longwall face. Rock bursts and coal bumps are an important safety concern in U.S. coal mines. However, U.S. experiences reflect just one part of what is really an international problem; Safety and resource recovery have been affected in many other countries, including Germany, England, Poland, France, Mexico, China, India and South Africa. Gradual or progressive failure, which is commonly experienced in coal mines, has less effect on mining continuity and safety and is generally controlled by timely scaling, cleaning, and bolting.

The occurrence and mechanism of these failures have been studied for decades in both hard rocks and coal mines [1–5]. While unstable slip along geologic discontinuities is known to be associated with many large seismic events in hard rock mines [6], many coal bump events in the U.S. coal fields are related to the failure of marginally stable structures under high stress conditions (stress bumps) triggered by dynamic energy resulting from failure of stiff enclosing stratigraphic units in the overburden and underburden [7, 8]. These stress bumps (the focus of these investigations) are influenced by geologic conditions, the geometric design of coal mine excavations, and the sequence of extraction.

In spite of significant progress in understanding the mechanics of violent failure within the last fifty years, there is still an urgent need to develop practical, predictive techniques for assessing coal bump potential. Cook [9] suggested comparing the stiffness of the testing frame to post-failure modulus of coal samples to determine whether a test sample will fail violently or nonviolently. Salamon [2] proposed a criterion for assessing mine stability (not coal bump potential) using the concept of mine stiffness. For a discussion of other criterion including Energy Release Rate, the interested reader is referred to Maleki [10]. Many practitioners have suggested simple indices for assessing coal bump potential using either near seam mechanical properties or energy concepts. For instance, Maleki [5] proposed a strata stiffness index, the ratio of strata stiffness-strength to that of the coal seam, for identifying bump-prone conditions. However because coal bumps are influenced by a number of geologic and mining factors, these indices have limited usefulness in a preliminary evaluation of burst-prone nature of mining properties.

Advancements in numerical modeling has made it possible to back analyze both static and dynamic (i.e., excess shear stress [11]) conditions leading to violent failure. However, most applications are challenged by poor availability of complete data sets regarding geologic, geometric and geotechnical data which include post-failure behavior of coal pillars and cave conditions [7, 12, 13]. Statistical techniques, on the other hand, are powerful tools for studying failure mechanisms where there is good data but poor understanding of the contributing factors.

By combing the strength of computational and statistical techniques, it is possible to advance the understanding of violent failure mechanisms through identification of the significant factors affecting the failure. This is the approach undertaken in this research. This research utilizes the first author’s observations and back analyses of violent failure in twenty five US operations including both single- and multiple-seam operations in flat lying and dipping seams. Although not all data could be collected at the exact location of failures, the existing data base is the closest to the source of the event as feasible. Where possible, field activities included coring and mechanical property testing of rocks with stress measurements within 50-ft of coal bump events. Back analyses of stress conditions from case studies provided additional insights regarding poor, cyclic cave conditions [7, 8] influenced by stiff strata.

2. Data Analysis

Twenty-five geologic, geometric, and geomechanical factors were first identified as having the potential to contribute to coal bump occurrence. Table 1 lists these variables excluding averages, ranges, and standard deviations due to limitations in this publication size; these case studies provided good coverage of the variables [6].