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Research Paper

Physical and numerical study of strain burst of mine pillars

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ABSTRACT

Strain burst is a spontaneous dynamic failure of rock that can cause serious injury to the miners and damage to the underground excavations. To simulate the strain burst in the lab, a steel beam was designed and connected to the compression loading machine. The beam acts as an energy absorber and is in direct contact with the rock specimen which is under uniaxial compression loading. Upon failure of the specimen, the absorbed energy in the beam is transferred to the rock specimen to simulate the strain burst in underground pillars. Based on the physical tests, rock fragment velocities of more than 4 m/s were measured using a high speed camera. The interaction between the steel beam and the rock was modeled using a hybrid discrete-finite element computer program. The effect of different parameters such as pillar's length and diameter, friction coefficient between pillar and roof, compressive strength of pillar, rock post-peak behavior, roof stiffness, and pillar and roof rock densities on the intensity of the strain burst were studied. The strain burst intensity was defined as the kinetic energy of the simulated rock. Dimensional analysis was applied to find relationships between the dimensionless parameters in the numerical simulation. The proposed scaling model together with the numerical analysis appears to be able to show the significance of different parameters involved in the strain burst. In particular, it is shown that the pillar diameter and its uniaxial compressive strength have significant impacts on the induced kinetic energy during a strain burst.

1. Introduction

Rock burst is the dynamic failure of rock that poses serious threat to the underground activities. This is particularly the case in deep underground mining in which high in situ stresses and brittle rocks are involved. Ortlepp and Stacey [1] based on source mechanisms, categorized the field rock bursts as: strain bursting, buckling, face crushing, virgin shear in rock mass and reactivated shear on existing faults or discontinuities. They described the strain burst that is involved with violent ejection of sharp rock fragments as the most common damage mechanism observed in underground excavations. During a rock burst, rock particles can be ejected with a velocity of 8–50 m/s [2] which can cause fatal injuries and damages to the underground equipment. Stacey et al. [3] reported that during a rock burst, the thickness of the ejected rock can be in the order of 1 m and hence supports for the rock must be capable of absorbing the rock kinetic energy. Rock burst had been known in mining since the 18th century; however it remained essentially a subject of qualitative study [4]. Cook [5,6] discovered the fundamental requirement for violent fracture of rock (rock burst); energy release rate plays a critical role in rock burst. Based on Cook's studies, rock burst occurs when an excess energy becomes available during the post peak deformation stage of rock. One of the first attempts to model rock burst in a room and pillar mining system was proposed by Salamon [7] who used the stiffness matrix (K) of the mining layout together with the slope matrix (A) of the complete load convergence relations of pillars to predict the stability of the rock structure. He showed that the stable situation is achieved if the system matrix $K + A$ is positive definite. Petukhov and Linkov [8] considered the interaction between a linear elastic rock mass with a softening material and used some energy equations to introduce a criterion for the stability of the system. Burgert and Lippmann [9] studied models of translatory rock bursting in an idealized coal seam. A model material and a model technique were suggested. They divided the coal ahead of tunnel face to three regions: (1) Passive elastic zone, (2) active elastic zone and (3) active plastic zone. Their model was able to explain some of the observations in the field. Zubelewicz and Mroz [10] considered rock burst phenomenon as a dynamic instability problem. In their approach, a dynamic perturbation was superimposed into the static solution of the problem and then the possibility of kinetic energy growth of the system as an indication of rock burst was investigated.

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Rock burst has been considered as a problem of surface instability by some researchers. Biot [11] performed the pioneering work on surface instability of a half space. Vardoulakis [12] used the bifurcation theory to analyze the rock burst as a surface instability phenomenon. Bardet [13] used a finite element formulation to study rock burst as a surface instability problem. The bifurcation of the solution was detected by evaluating the eigenvalues of the tangential stiffness matrix. Whyatt and Loken [14] utilized the boundary element method to simulate sudden dislocation along a fault plane. Their model was able to explain some of the odd dynamic phenomena that are observed during the rock bursts.

Some researchers have investigated the phenomenon of rock burst experimentally. A double rock sample model was studied both physically and numerically by Chen et al. [15]. The physical sample was made of granite and marble specimens of cylindrical shape and was tested in uniaxial compression. From the results of the tests, they concluded that it may be possible to predict the occurrence of rock burst when a sudden decrease of micro-seismic rate occurs in one zone while the micro-seismic rate continues to increase in an adjacent zone. A true triaxial rock test system was used by He et al. [16] to study the rock burst. The limestone specimen, 15 × 6 × 3 cm in dimension, was loaded initially in three mutually perpendicular directions and then abrupt unloading of the minimum principal stress in one loading face was performed, creating a stress state and boundary conditions in the rock sample relatively similar to those that exist at a tunnel face. The physical tests by these authors showed the ejection of rock fragments from the unloaded surface of rock that was interpreted as rock burst. Kuch et al. [17] simulated coal mine bumps using a model material. Their experimental investigation showed that the scatter in the critical rock stress, necessary for bump initiation, is due to variations of the post-peak stiffness of the material.

In this paper, strain burst in pillars was studied by using a soft loading system. Strain burst is a type of rock burst that is associated with gradual accumulation of strain in rock. Uniaxial compression tests were conducted on sandstone specimens using this loading system to allow for accumulation of the strain energy and sudden release of this energy when the rock approached to its post-peak regime. A high speed camera was used to measure the peak particle velocity. In addition, a numerical model was utilized for simulation of the rock burst. The rock was represented by a bonded discrete element domain while the loading system was modeled as a linear elastic body. Different parameters that are involved in the induced dynamic rock fracture and strain bursting such as the loading system stiffness, the rock strength, the pillar dimensions, and the rock-loading system interface friction coefficient were investigated in this study. Furthermore, a scaling approach was used to define some dimensionless parameters that play important roles in strain bursting of the rock.

2. Experimental study

A soft steel loading frame was designed and attached to the MTS loading machine to absorb and store some strain energy that can be released when the post-peak regime of the rock is approached. The steel frame which is made of two W5 × 16 steel profiles with the yield strength of about 345 MPa is shown in Fig. 1. The frame is to represent the roof structure in a room and pillar mining system. The top of the frame is bolted to the loading machine cross-head and the rock specimen is accommodated between the platen connected to the bottom of the frame structure and the machine actuator. Experimental tests were conducted on the frame structure to obtain its stiffness. Fig. 2 shows the load–deflection curve for the frame structure which suggests that the stiffness of the structure is about 14.1 kN/mm.

The experimental tests were conducted on the Pennsylvania blue sandstone which has the following average mechanical properties: Elastic modulus = 26.3 GPa, Poisson's ratio = 0.15, uniaxial compressive strength = 110.9 MPa, and Brazilian tensile strength = 9.9 MPa. Rock specimens 25 mm in diameter and 68 mm in length were used for strain burst testing. The tests were conducted under stroke control. Each test took about 20–30 min to finish; the applied displacement rate was 0.0025 mm/s. The results of the uniaxial compressive tests using the frame structure are reported in Table 1. All tests were finished by violent failure of rock specimens. A high speed camera was used to record the bursting event (Fig. 3a). During the strain burst of the rock specimens, the velocities of some rock fragments flying in the camera plane were

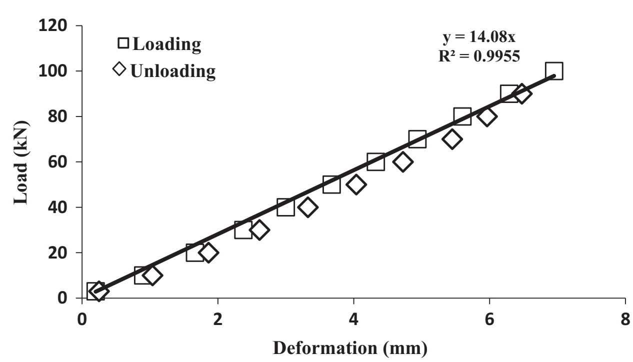

Fig. 2. Load–deflection data for the frame structure.

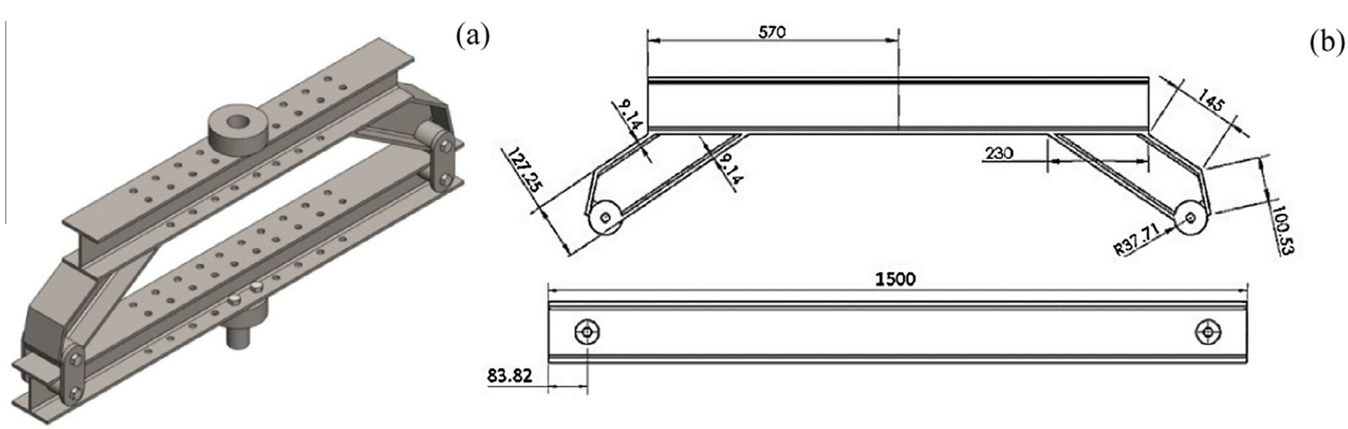

Fig. 1. (a) The frame structure and (b) its dimensions (in mm).