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Assessment of roof stability in a room and pillar coal mine in the U.S. using three-dimensional distinct element method

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ABSTRACT

This paper examines the effect of different geological and mining factors on roof stability in underground coal mines by combining field observations, laboratory testing, and numerical modeling. An underground coal mine in western Pennsylvania is selected as a case study mine to investigate the underlying causes of roof falls in this mine. Three-dimensional distinct element analyses were performed to evaluate the effect of different parameters, such as the variation of immediate roof rock mass strength properties, variation of discontinuity mechanical properties, orientations and magnitudes of the horizontal in-situ stresses, and the size of pillars and excavations on stability of the immediate roof. The research conducted in this paper showed that the bedding planes play an important role on the geo-mechanical behavior of roofs in underground excavations. Therefore, an appropriate numerical modeling technique which incorporates the effect of discontinuities should be employed to simulate the realistic behavior of the discontinuous rock masses such as the layered materials in roof strata of the underground coal mines. The three-dimensional distinct element method used in this research showed the capability of this technique in capturing the important geo-mechanical behavior around underground excavations.

1. Introduction and brief literature review

Roof falls have been one of the most common ground control problematic issues affecting the safety and economy of underground coal mines. Although, over the last decade there have been major improvements in the way which coal mines have managed the roof fall hazards through the application of safety measures, technological improvements, alternative mining methods and extensive support systems, still, roof fall accidents remain a leading cause of coal mining injuries. Roof stability is associated with the ability of the roof rock to span the openings and is dependent, in part, on the size of the opening, different rock mass material strengths and deformability, geologic discontinuity geometry and their mechanical properties, in-situ stress system, possible groundwater conditions and possible dynamic loading.

It is well known that the discontinuities not only weaken the rock masses but also they change the mechanical behavior of rock masses. The lithology of the immediate roof plays an important role on stability of the roof in underground excavations. Laminated, or thinly bedded shale, is one of the most frequently seen overlaying strata above the coal deposits. The bedding planes and interfaces have very low or close to zero tensile strength in the direction perpendicular to the bedding planes, and their shear strength is much lower than of the rock layers. As a result, the bedding planes are much weaker than the rock layers. Therefore, due to the stress concentrations caused by excavations, slippage and separation can easily happen along the bedding planes before initiation of failure within the rock layers. The slip or separation of existing discontinuities in roof strata can amplify the negative impacts of stress concentrations around underground excavations.

In the past, several attempts have been made to understand the mechanism behind the roof failure in underground coal mines. Most of these earlier attempts were based on empirical techniques and continuum based numerical methods that have limited capability in simulating the response of discontinuum rock mass behavior due to excavation. In previous studies, different factors such as the magnitude and direction of the horizontal in-situ stresses, type and mechanical properties of roof rock, surface topography, geological anomalies, gas pressure, slippage and separation of bedding planes at the roof and floor, entry width and excavation sequences are identified as key factors that could significantly impact the stability of the roof. Among all of the aforementioned factors, in spite of its importance, the impact of slip and separation of bedding planes on roof stability has not received enough attention from

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researchers. In a few available numerical modeling studies, the bedding planes are modeled using the continuum based numerical codes such as ABAQUS (Chen, 1999) and FLAC3D (Ray, 2009). Both of the aforementioned computer programs are developed based on the continuum mechanics concepts. The continuity of deformations is the intrinsic assumption of the continuum theory and clearly it is not necessarily valid for discontinuous materials such as layered rock masses. In the presence of discontinuities, deformations can be discontinuous across the discontinuities; these displacements can be large and also the rotation of rock blocks is possible. The aforementioned two computer programs have limited capability to simulate the discontinuity behavior in a

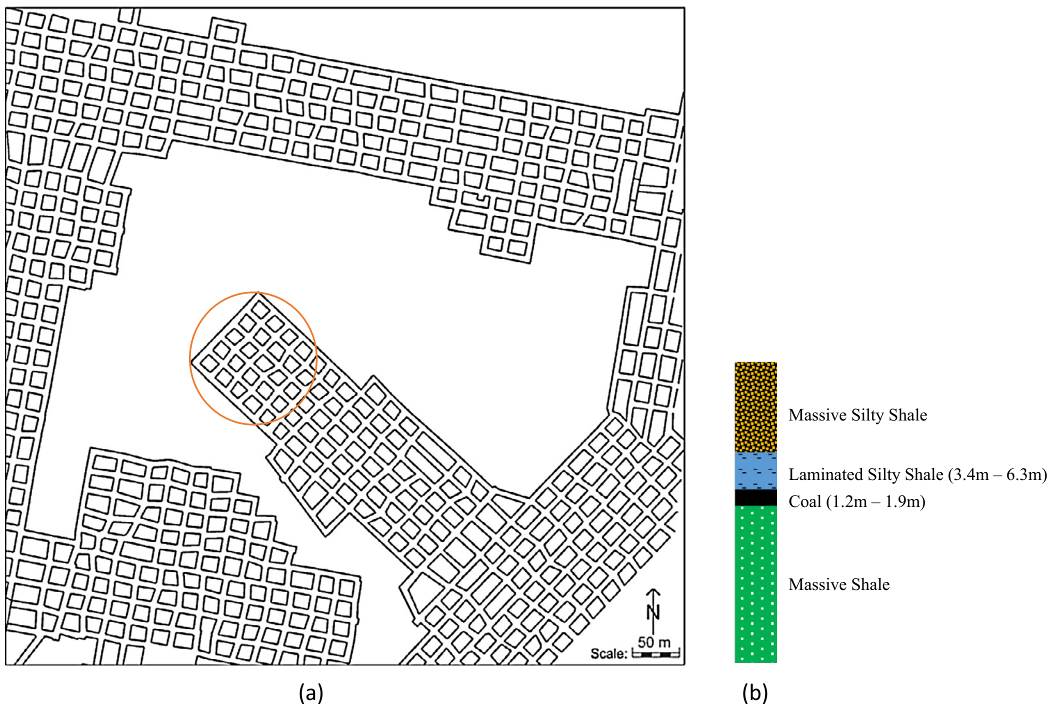

Fig. 1. (a) The plan view of the study area. (b) Typical geological column of the mine site at the study area.

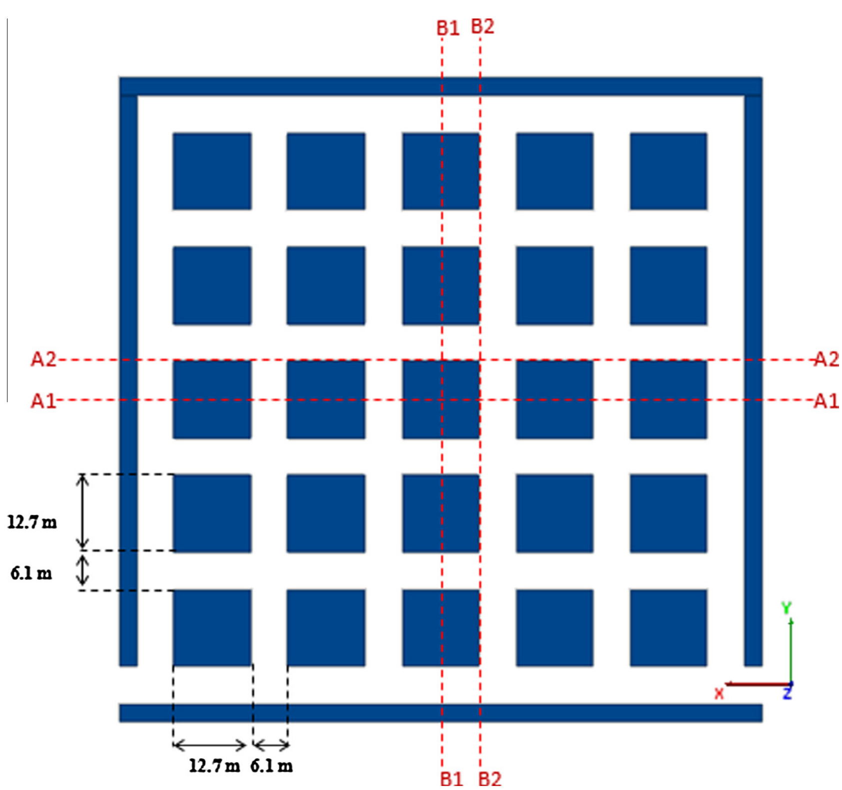

Fig. 2. The plan view of the room-and-pillar mining layout.