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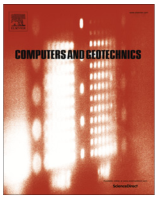

Research Paper

The interplay between moisture sensitive roof rocks and roof falls in an Illinois underground coal mine

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ABSTRACT

This study focuses on the performance analysis of mine roof rock due to moisture variation using a case study, which experienced roof falls. The roof layer types, thicknesses, and properties were determined using extensive lab and field data. A novel numerical model is developed using site information and observed field performance to incorporate: (1) the interaction between roof rock unit beddings, (2) the interaction of roof bolts and rock units, and (3) the effect of moisture increase on roof deformation and failure. Using the proposed methodology, the mine roof layers' allowable maximum moisture contents prior to failure can be estimated.

1. Introduction

Long term stability of underground mine is very critical issue [1,2]. The geomechanical properties of rocks are of great importance in construction of tunnels and underground excavations. Compressive strength is one of the most important geomechanical properties of rocks which can be evaluated using Unconfined Compressive Strength test (UCS) and Axial Point Load (APL) following American Society of Testing Methods and Materials (ASTM) guidelines [3,4]. The strength parameters of rocks are believed to be highly affected by moisture content (MC) variation [5]. It is common to observe moisture content increase in the immediate roof rocks of the mine due to water dripping from water bearing rock layers into the mine entries or flooding of abandoned mines. The effect of moisture content on strength parameters plays an important role in stability of abandoned mines [5]. As water penetrates into the rock, the electronically polar water molecules stick to the surface of rock particles. As a result, the frictional contact surface as well as the bond between the rock particles will be decreased and the strength of rocks will be reduced [6].

The effect of strength reduction due to moisture content increase has been studied and shown previously by several researches [6–10]. In a study by Mohamad et al. [10] a series of 96 shale rock samples were collected from Ayer Hitam, Malaysia and were immersed in water for various time periods. The APL tests were performed on weathered shale rock samples with various moisture contents. According to the results, APL indices on average decreased from 4.4 to 1.1 MPa as the MC values increased from 0.9% to 4% (i.e., approximately 24% strength reduction per 1% moisture content increase), respectively. It was also concluded in their study that the rocks with higher APL indices such as shale-limestone or gray shale, are more sensitive to moisture content increase comparing to weaker rocks such as black shale. In another study, Osouli and Moradi Bajestani [11] investigated the moisture sensitivity of various shale rocks collected from roof units of the underground mine case study, which is presented in later sections. In their study, APL and moisture content tests were performed on rock specimen with two different humidity conditions:

- Natural MC values (W_n): Determined from samples being tested shortly after collected from underground. This value represents the insitu rock moisture content.
- Air-dried MC values: Determined from samples being tested after being exposed to air and loosing moisture.

In the Illinois studied mine, Osouli and Moradi Bajestani [11] concluded that shale rocks with APL index of higher than approximately 1000 kPa at their natural MC are more sensitive to moisture content increase comparing to weaker rocks. In that study, the gray shale specimens with APL strength indices of more than

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1000 kPa at their natural MC state, experienced on average 29% reduction in APL per 1% increase in moisture content. However, for gray shale rocks with APL values of less than 1000 kPa at their natural MC, the rock cores experienced 21% reduction in their strength per 1% MC increase. The black shale rocks of the studied mine that had APL indices of more than 1000 kPa at natural MC, experienced on average 19% reduction in APL per 1% increase in moisture content. However, among the studied black shale rock samples, weaker specimens do not show noticeable strength sensitivity to moisture content variation. Finally, the sandy shale specimens of the studied mine show similar behavior toward moisture content variation regardless of their APL strength magnitude at their natural moisture content. The APL indices of sandy shale specimen decrease on average 17% by 1% MC increase.

In many underground mines the roof is stable in active mine panels. However, during the mine life, roof failures are observed in those panels after mining due to humidity absorption or further water exposure [12]. The initial moisture content of immediate rock units is important. It is common that these moisture contents decrease during mining operation because of the mining drainage and/or ventilation, and then increase when the mine is abandoned. For example, in case of the studied mine by Osouli and Moradi Bajestani [11], the average moisture contents of roof black shale and sandy shale units prior to mining were 6.0%, and 5.7%, respectively. After mining operation, the average moisture contents of 4.5% and 3.7% was measured for black shale and sandy shale rock units in the active panels, respectively. However, in the abandoned parts of the mine, where there is no ventilation, the moisture contents of the rock units have increased to higher than pre-mining levels. A better understanding of moisture variation effect on stability of underground mines, not only result in safer and more efficient design of roof control measures but also allows to predict the potential hazardous areas and eventually prevent the fatalities.

This paper aims to study the effect of moisture content variation on stability of underground openings and predict roof fall incidents in the same underground coal mine case study that investigated by Osouli and Moradi Bajestani [11]. They conducted strength tests on shale rock samples from same rock units but with different moisture contents. Using the extensive test results database, Osouli and Moradi Bajestani [11] developed correlations between MC variation and UCS index for black shale, sandy shale and gray shale rock units existing in the studied underground coal mine located in the Illinois Coal Basin. In this paper, those correlations are used to determine the compressive strength of the roof rock units as the moisture content of the mine strata is increased. To study the effect of MC variation on the stability of the moisture sensitive roof rocks and to predict failure, a novel numerical analysis was conducted. The required geomechanical and rockmass parameters for the mentioned model are extracted using laboratory and field test results. The developed models were verified using underground information collected during mine visits for both stable and roof-fall locations in the studied mine. Furthermore, the verified model was used to study the effect of influential parameters such as room entry width and thickness of immediate weak roof rocks on roof stability of the mine. The presented methodology can be used in the design of roof support in mines, dealing with similar roof conditions, to avoid major roof falls. Furthermore, it is discussed how the presented results could identify the timing for the development of mine panels, predict the failure incidents in advance, and keep the main entries open during the mining activity in the studied mine, which has very weak moisture sensitive roof rocks.

2. Stability of moisture sensitive roof units

The Illinois Coal Basin covers most of the Illinois State extending into southwestern Indiana and western Kentucky [13]. This basin mainly contains Paleozoic sediment and dolomite rock units followed by limestone, shale and sandstone [13]. The mine roof condition for this case study was examined during a couple of underground mine inspections at two Locations of A and B, shown in Fig. 1. The mine is at depth of 73 m from the ground surface. The mining method was room-and-pillar with typically 19 m pillar sizes and entry widths of 5.5 m, which results in an extraction ratio of about 40%.

Location A with stable roof is in proximity of Location B, which had massive roof failure. Fig. 2 shows the condition of roof at these locations. The mine visit locations are selected based on their proximity to the available boring locations, accessibility from underground entries and availability of rock laboratory test data related to their immediate roof units. The room height, thickness and rock type of immediate roof and floor units were determined based on the boring logs and underground inspections and are shown in Fig. 3.

Several previous studies investigated on roof failure criteria. The stability and failure initiation of coal mine roof can be detected by monitoring the roof deformation. Maleki and Owens [14] has

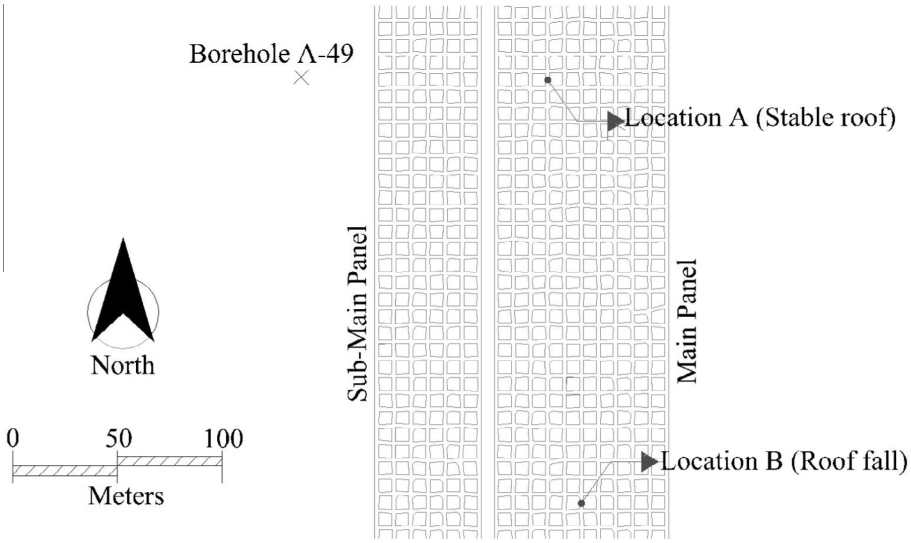

Fig. 1. Underground coal mine map showing Locations A and B.