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Analysis of alternatives for using cable bolts as primary support at two low-seam coal mines

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ABSTRACT

Cable bolts are sometimes used in low-seam coal mines to provide support in difficult ground conditions. This paper describes cable bolting solutions at two low-seam coal mines in similar ground conditions. Both mines used support systems incorporating cable bolts as part of the primary support system. Two original cable bolt based support systems as well as two modified systems are evaluated to estimate their ability to prevent large roof falls. One of the support systems incorporated passive cable bolts, while the other used pre-tensioned cable bolts. The results and experience at the mines showed that the modified systems provided improved stability over the original support systems. The presence of the cable bolts is the most important contribution to stability against large roof falls, rather than the details of the support pattern. It was also found that a heavy steel channel can improve the safety of the system because of the 'sling' action it provides. Additionally, the analysis showed that fully-grouted rebar bolts load much earlier than the cable bolts, and pre-tensioning of the cable bolts can result in a more uniform distribution of loading in the roof.

1. Introduction

Cable bolting is sometimes used as primary support in coal mines experiencing difficult roof conditions. In low-seam mines the flexibility of the cable bolts allows greater length supports to be installed near the advancing face without the use of couplers. When used as primary support, the cables are typically installed in the same row as fully grouted bolts, replacing two or more of the bolts in each support row. A heavy steel channel may be used as a strap to spread the support load over a greater portion of the roof. Historically, the Mine Safety and Health Administration (MSHA) has not allowed widespread use of partially grouted un-tensioned bolts (e.g., passive cable bolts) for primary support; however, pre-tensioned cable bolts have been accepted.

Various solutions using cable bolts as primary support were attempted at two low-seam coal mines in Western Pennsylvania that were experiencing difficult roof conditions. Both mines originally used fully grouted rebar bolts as primary support and cable bolts as supplementary support. It was found that when a large roof fall occurred, the cable bolts may be contained within the dome of fallen rock. As problematic roof conditions continued to exist, both mines decided to use cable bolts as part of the primary support system. The cable bolts were located near the ribs of the entry, to increase the likelihood that they would be anchored outside the dome of potentially unstable roof. The cable and rebar bolts were installed on a heavy steel channel that acts as a "sling" to distribute the load across the width of the entry. At the first mine, Mine A, pre-tensioned cable bolts were used while at Mine B, un-tensioned cables were used. The two support systems consist of essentially the same support components installed in different patterns and with varying degrees of pre-tension.

The original and modified support systems were selected for analysis as part of current research into roof support design at the NIOSH Office of Mine Safety and Health Research (OMSHR). The objective of the analyses was to determine whether there was a significant difference in the potential of the support systems to prevent large roof falls. The analyses were focused on large roof falls in which the height of roof collapse extends more than 90 cm above the roof line of the entry, and typically extends above the bolted horizon. Smaller roof falls that occur between bolts or that are associated with individual geological structures are excluded from the analyses.

The effectiveness of the support systems was initially evaluated using an equation that estimates the stability factor an entry against large roof falls [1]. The initial assessment was followed up by FLAC3D numerical model analyses to investigate the contribution of the different support units to roof stability. The models

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also provided insight into the likely modes of roof and support failure. Scenarios without any support, using fully grouted bolts only, and cable bolts with fully grouted bolts were considered.

2. Geotechnical parameters

The two case study mines both extract the Lower Kittanning coalbed. The mines use the room-and-pillar method in a mining height of about 1.2 m. The depth of cover is approximately 120–150 m at both mines. In certain locations of the two mines the roof consists of laminated, dark gray, silty shale that is associated with difficult ground conditions.

3. Geology

The silty shale responsible for difficult ground conditions can be up to 10 m thick and may contain sandstone intrusions. It is overlain by a stronger interbedded sandstone and shale unit. Sandstone is occasionally found close to the coalbed being mined, but typically was found no closer than 2.4 m above the coal bed in the area studied at Mine B. Observations of the rock exposed in roof falls show that it tends to delaminate in thin slabs that are about 25–75 mm thick. Fig. 1 shows the delaminated roof exposed at Mine A and Fig. 2 shows the laminated shale exposed in a roof fall at Mine B.

Point load strength testing of the silty shale roof at Mine A showed that the compressive strength is approximately 55–60 MPa perpendicular to the bedding. Uniaxial compressive strength tests at Mine B showed higher strength, but underground observations and index testing of roof rocks indicated that the lower strength determined at Mine A was likely to be more representative of the observed roof response. These properties are similar to the Lower Kittanning roof properties published by Zhang et al. [2].

The available rock strength and bedding information were used to classify the rock mass using the coal mine roof rating (CMRR) [3]. The CMRR classification of the silty shale roof is as follows: uniaxial compressive strength (UCS) of roof rocks = 55–60 MPa, rating = 17; bedding strength rating (weak planar), rating = 16; bedding intensity rating (bedding spacing 25–75 mm), rating = 12; and total unadjusted CMRR unit rating, unit rating = 45.

Owing to variability of the rock strength properties, the unit rating can be expected to vary between about 40 and 50. For the purpose of the analysis, the average values shown above were used.

4. Horizontal stress

Stress measured in the vicinity of the two mines shows results typical of Northern Appalachia with a relatively high pre-mining horizontal stress associated with regional tectonic loading [4,5]. At Mine A, the major horizontal stress is estimated to be oriented N70E and at the Mine B it is estimated at N80E. The orientation of the major horizontal stress is considered in the mine layouts. Where possible, the mining direction is oriented so that the development is directed favorably relative to the stress field. For the analysis of the support systems, it was assumed that the entries were developed in a horizontal stress field associated with tectonic strain components of 0.0005 and 0.0006.

Fig. 2. Large roof fall at Mine A showing laminated nature of the silty shale roof rocks and steep-sided collapse cavity.

5. Large roof falls

At Mine A, forty large reportable roof falls occurred over a period of ten years. The falls occurred in spite of intensive roof support in the form of primary rebar bolts and secondary cable bolts. Primary bolts up to 2.1 m long and cable bolts up to 4.8 m in length were used. Despite these efforts, falls were typically in the north–south orientation and would progress upwards to the top of the laminated shale, which was typically about 3.6 m above the mine roof. Fig. 2 shows the laminated nature of the collapsed roof at Mine A. The presence of cutter roof and other signs of stress-induced roof damage confirm that the mine was located in a relatively high horizontal stress field, often encountered in mines in the Northern Appalachian area.

At Mine B, roof control in the areas where the low-strength silty shale is present was generally satisfactory until a 300-m-long roof fall occurred in 2013. The roof also exhibits signs of excessive horizontal stress, with cutters and stress fractures observed. Fig. 3 illustrates the roof damage caused by a cutter that formed well outby the advancing faces at Mine B. The mine layout is adjusted so that the development direction is favorable relative to the major horizontal stress. Prior to the major roof fall, cable bolts were used as part of the primary support system. The large roof fall prompted a change in the mining layout and support system.

Fig. 1. Laminated silty shale roof rocks observed at Mine B.

Fig. 3. Severe cutter formation and roof cantilevering at Mine B.