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Rock support design based on the concept of pressure arch

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Abstract

A metal mine stope, located at a depth of about 1000 m below the surface, experienced drastic changes in roof displacement and wall fracturing within a short period of time. Thus, the stope needed additional reinforcement in order to remove the remaining ore. It was revealed from rock mechanics assessment that the stability problem was owing to the relatively low strength of the rock as well as the high in situ stresses. It was believed that both the roof and the hanging wall were heavily fractured. It was then proposed that the unstable section of the stope be reinforced with bolt–shotcrete ribs. The concept of the design was to form a pressure arch in the failed rock with the help of six bolt–shotcrete ribs. Displacement measurements showed that the roof displacement reduced from about 2 mm/day to a level of about 0.25 mm/day immediately after the reinforcement operation. Two hanging wall collapses occurred a few months later in the areas outside the bolt–shotcrete reinforced section in the stope. The collapses indirectly proved the effectiveness of the bolt–shotcrete ribs in reinforcing the failed rock.

Keywords: Rock support; Rock reinforcement; Pressure arch; Shotcrete rib; Mining

1. Introduction

The stability of a deep mine stope drastically deteriorated with fracturing of hanging wall and increasing rate of roof sagging. Additional reinforcement was carried out to stabilize the stope on the basis of the concept of establishing pressure arches in the fractured rock by bolting. The stope became stable immediately after the additional reinforcement in that rock fracturing ceased and the velocity of the roof displacement slowed down to a very low level. The practice of rock reinforcement in the mine stope was a successful application of a reinforcement concept for support design.

In this paper, the concept of pressure arch is first reviewed briefly and then the procedure of the work to stabilize the unstable section of the stope is presented, which includes assessment of the rock failure, the support design and the following-up. The objective of the paper is to demonstrate how the concept of pressure arch is used to guide the support design in a practical case as well as the result of the reinforcement.

2. The concept of pressure arch in rock

The concept of pressure arch was proposed for ground control in bedded strata as early as in the 1930s. In a report on the causes of falls and accidents due to falls by IME [1], it was stated that ‘‘the redistribution of weight results in the development of a pressure arch and a somewhat destressed zone therein. The beds within the pressure arch deflect slightly and no longer carry the weight of the superincumbent mass of strata’’. In another report by IME [2], it was further pointed out that ‘‘the pressure arch is thought to be set-up in the roof above every mining excavation and the load of the superincumbent strata is transferred to the two abutments of this pressure arch’’. Since then several pieces of work were published on the concept of pressure arch formed in bedded strata [3–6]. It is concluded from those studies that a pressure arch is formed above every opening. The stresses within the pressure arch are elevated, while the stresses below are diminished. In an un-reinforced stratified roof, the pressure arch may be located quite

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deeply in the roof, depending upon the thickness of the beds and other geological conditions. It is thought that the pressure arch can carry considerable load through diverging ground pressure to the wall rocks of the opening. It can be seen from the above review that the concept of pressure arch was originally developed for stratified rocks.

As a matter of fact it is the immediate roof that is most concerned since rock falls from the roof will hurt workers and even jeopardize the opening in an extreme case. Therefore, it is seen more than often that rock bolts are installed in stratified roofs, that is, the destressed zone under the pressure arch is reinforced by bolts. Bolting results in that part of the self-bearing beds in the destressed zone is bound together to build up a thicker layered beam so that a stable immediate roof is formed. A pressure arch can be formed also in this artificial beam when it is subjected to an external transverse load [7–9]. Roko and Daemen [10] conducted a laboratory study to demonstrate the development of the pressure arch in a laminated beam. They reported that the ultimate bending load on the bolted beam was more than double that on the beam without bolting. In the case of the beam without bolting, the individual layers of the beam had no interaction with each other and pressure arches were formed in every layer. In the case of the bolted beam, the layers of the beam were bound together by bolts. All the layers reacted together to the applied load and a common pressure arch was formed in the laminated beam so that it could bear a larger bending load. In this paper, the pressure arch formed in bolt-reinforced rock is called an "artificial pressure arch" to distinguish it from the one naturally formed in rock. The artificial pressure arch is different from the natural one in that it is formed only when the bolted portion of rock is subjected to an external transverse load.

All systematic bolt reinforcements can be classified into four types in accordance with the principles how bolts reinforce the rock [11]: Type 1—suspension bolting to hang up the weak roof to the overlying competent rock; Type 2—stitching thin layers of rock to build up a thicker beam; Type 3—confinement bolting to prevent fractured rock from disintegration, for instance bolting in mine pillars; and Type 4—bolting for establishing an artificial pressure arch in fractured rock. Among the four types of bolting, Type 4 is the most important one since most of the systematic bolting practices are based on that concept, particularly in blocky rock masses and also in the case that country rocks risk to be fractured under high in situ stresses. Type 2 actually becomes Type 4 in case that transverse fractures, no matter whether they are geological discontinuities or excavation-induced fractures, exist in a laminated stratum.

The concept of pressure arch is even valid for other types of rocks though it was originally limited to stratified rocks. In a weak rock that is subjected to high in situ stresses, for instance, a large amount of rock in the near field of the opening would fail. Systematic bolting would create an interaction zone in the failed rock and an artificial pressure arch would be formed in the interaction zone when it is subjected to a ground pressure (Fig. 1). This is the theoretical background for the bolting of Type 4. The reinforcement effect of an individual bolt is limited in the near field of the bolt. It is thought that the rock within a certain angle to the bolt ends would be reinforced effectively (Fig. 2). This angle is called the "reinforcement angle" in this paper. For systematic bolting, the reinforced areas of individual bolts will overlap each other so that an interaction zone is formed in the bolted portion of rock. Hoek and Brown [12] once employed this means to describe the interaction zone of bolts for a jointed rock mass. The thickness of the interaction zone is associated with bolt length and bolt spacing, which will be discussed in detail later. The shape and also the thickness of the pressure arch formed within the interaction zone would be dependent not only upon the thickness of the zone, but also upon the magnitude of the ground pressure exerted on the zone. Establishment of such a pressure arch in bolted rocks was demonstrated by Lang [13] in his bucket test as well as in his photo-elastic tests. In his bucket test, an ordinary household bucket was filled with small crushed rock that was bolted. The bucket was hung up upside-down. The

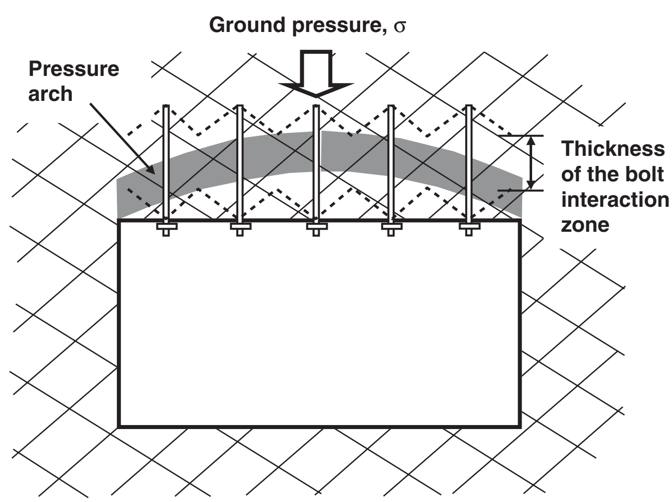

Fig. 1. Pressure arch formed in a bolt-reinforced roof.

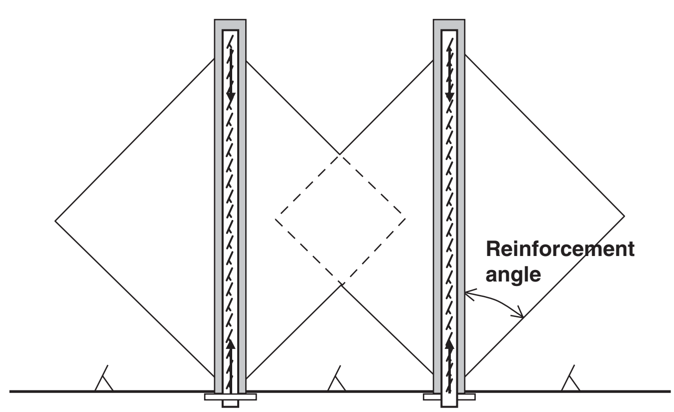

Fig. 2. A sketch illustrating the reinforced area by single bolt.