Development and Application of Roof Support of Roadways in Mines

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Abstract. Underground mining is always the most dangerous industry. The mines' inside support structures are always the most critical part of studying in order to increase safety. The inside roof support has three main categories: frame stand support, anchor rock bolt support and reserved column support. Each method has its own advantages, but the disadvantages are also inescapable; thus, using a single design would heavily impact field practice, safety measurements and economic benefits. Therefore, under the situation that current methods can hardly have a technical breakthrough, it is very necessary to have more profound studies to combine two or more methods organically to adopt each's good points and avoid shortcomings. In the end, it would increase the underground support results and safety. Also, it can save massive initial costs and further maintenance fees, reduce labour intensity, improve the working environment and increase production efficiency.

Keywords: Mining · Mine Roof Support · Anchor Rock Bolts

1 Introduction

Frame support is the oldest support method of all. It is a passive support method and mainly uses I beams and U beams in the design. This kind of design is relatively easy to locate the problem once failure occurs and easy to maintain after construction; however, the high cost and low support strengths are the most significant constraints [1]. Anchor rock bolt is an active support method. It drills holes in the rock and inserts the anchors and grouting when necessary. The friction between the anchors and the rocks is the key to supporting weights. This kind of support method is simple to construct, and the costs are low compared to other methods. But when cracks and deformations happen, it is hard for technicians to locate the failure spot in the first response. There is not a simple best method now. Each one has its own benefits and disadvantages. This research aims to examine the development stage of frame and anchor support techniques and evaluate the possibility of combining them.

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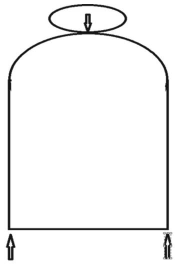

Fig. 1. Frame Support.

2 Current Research Status of Frame and Anchor Rock Bolts Support

2.1 Frame Support Theory

Traditional frame support has the longest history of all. It is a passive supporting method. The beams and trusses are easy to maintain or replace and technicians can quickly discover any deformations or failures. Wood was the most commonly used material for a long time because it is easy to access, and the costs are relatively low. However, since the twenty century, with the progression of smelting technology, metal materials have replaced wood to become the most widely used materials. The metal supports are I beam and U-shaped steel mostly [2].

Right now, most countries use I beams or U beams to make frames. The strength of frame support slightly increased over the past decades. However, it is still gradually replaced by the anchor rock bolt design because the construction difficulties are too great, and related costs are too high compared to anchor rock bolts. There is only temporary hydraulic support still in use in the heading face [3] (Fig. 1).

2.2 Anchor Rock Bolt Support Theory

Compared to frame support, the anchor rock bolts method is an active support method and the most commonly used worldwide because anchors are simple, easy to construct, and the overall costs are low compared to other methods. Recently, the design of anchor rock bolts has been based on the suspension theory, combined beam theory and combined arc theory. The strength of support is improved with theories and materials innovation, and the active support method is more advanced, while the main bodies are immersed inside the rocks, so it is very hard to monitor and assess the effects of these structures once they are constructed [4].

There were already some applications of anchor rock bolts in the late nineteenth century, but the relatively complete theory was the basic suspension theory published by Louis A Panek and his group in 1952. The core idea is to use anchors and rock bolts to suspend the weak rocks that came from the explosion to relative firm rocks above. Also, while the top stones are stratiform, the anchors can direct push the weak rocks onto the rock bed to prevent layer separations [5]. In practice, the rocks that are being suspended are the primary weight sources; therefore, these rocks are the major consideration during

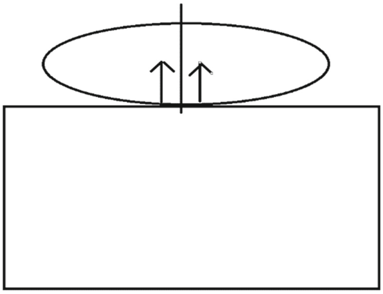

Fig. 2. Suspension Theory.

the design stage. When the theory first came out, it was thought that the anchor rock bolts could only be used when the rooftop reached a certain level of strength, which means that when the rooftop was slightly broken or was not strong enough, the suspension theory would not apply [5]. But later, massive on-site samples proved that anchors could still have some performance even if the rooftop was not strong enough. This result shows the limitations of the suspension theory. However, it still indirectly proves that anchors could change the stress state of surrounding rocks and could somehow reinforce the support and make a solid foundation for future research (Fig. 2).

In the same year, Jacbio and his group from German published the combined beam theory. This theory is mainly used in stratiform rock beds. It believes that even if the top rocks are not firm enough and cannot support the suspension, anchor rock bolts can still be used to combine several weak layers together like a stapler to form a relatively thick and firm layer. This theory has changed the traditional thought that the anchors can only be suspended on a solid rock and allowed them to play their roles even without firm rocks. Both suspension theory and combined beam theory used the multi-layer structure in the roadway rooftop; however, unlike suspension theory which transfers all the forces to the rooftop, combined beam theory will still use the side rocks to support forces. By assembling multiple layers into one, combined beam theory increases the frictions between each layer. In the end, it not only improves the integrality but also increases the rocks' strength to resist bending and shearing [3]. But in practice, the complexity of each rock layer and the possibility for broken stones to form vertical cracks make it very hard to calculate the correct resistance capacity, hence leading to the result that there are too few successful samples on combined beam theory (Fig. 3).

T. L. V. Rabeewice published combined arc theory in 1995. He believed in arranging the anchors in an arc shape and letting each anchor press the rocks with prestressing force to form a pyramid-shaped compression zone, and the compression zones formed by multiple anchors will overlap with each other to create a continuous compression zone. This theory fits with the tunnels that have thicker top layers. The anchor and the rocks will form a strengthful rock arc when the construction is done. It increases the stability of rocks, letting them resist the outside stresses while also preventing loose and deformations. Although combined arc theory correctly describes the performance of anchors, it only considers the supporting structures and ignores the relations between supporting structures and surrounding rocks, which means there are still limits [6] (Fig. 4).

Fig. 3. Combined Beam Theory.

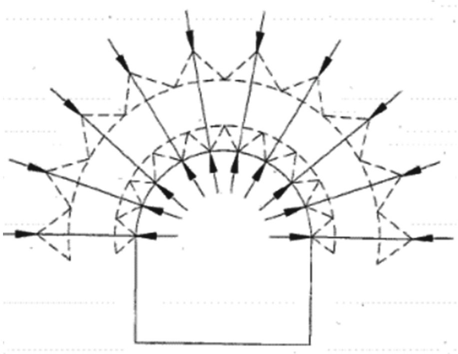

Fig. 4. Combined Arc Theory.

2.3 Current Underground Mine Support

Frame support has been the mainstream method since recorded because of its intuitive support results, and wood was the most commonly used material among all because woods are easy to access and construct. However, the wood's strength is low and is very poor to resist deformation, causing massive wood to need to be used. At the same time, the complex environmental underground, especially the high concentration of dust and gas, makes the wood very easy to catch fire and explode. This will not only cause a support failure, but the toxic gas produced also threaten the mine safety [3, 7].

In twenty century, metal gradually replaces wood to become the major material of mine support. Although its strength is stronger and is inflammable, it still lacks plasticity and cannot adapt to deformations in the tunnels. In order to prevent these problems, the amount of steel used in the roadways continuously increased, and the spaces between each support frame kept shrinking. In the end, both money and time costs reached sky-high and the mines no longer profitable [7]. Technology innovation is undoubtedly in the offing.

The anchor rock bolts technology then entered into view. However, the earliest anchor rock bolts technology is mainly based on suspension theory. There was no connection between each anchor. The anchors could only play a fundamental suspension role but cannot put the rock itself to good use. Also, the technology was immature. People use anchors blindly in any situations, causing the support result to be unsatisfactory. There are always loose rocks and anchors' deformation and breaking. Roof fall happens all the time; hence, anchor rock bolts technology did not prove to be much better than beam and truss support [6].

In the late twenty century and early twenty-one centuries, frame support had a massive development because of the breakthrough in forging technologies and material science. There is a new type of frame called retractable frames. This new type of frame can absorb the inner force to some extent, hence preventing the beam and truss from deforming or breaking and finally losing efficacy. Retractable frames are made with several small regular frames, and each tiny piece is connected by a link structure. When there is a deformation in surrounding rocks, it tries to shrink the frames. Initially, the pushing force exerted by the rocks is smaller than the friction in the links, and the frames do not shrink. Once the pushing force becomes larger and larger and eventually exceeds the friction between the links, the shelves start to shrink to reduce the pushing force [7]. When the pushing force becomes smaller than the friction again, the frames stop shrinking. Retractable frames can form relative stability between supports and weights and are conducive to maintaining the strength of the whole surrounding rocks. In practice, most of the weights are on the frames' connection part, and the links' mechanical property is the most important, but current technologies cannot guarantee reliability. There is still a high probability that deformation will happen.

Anchor rock bolt also developed fast. Other than wood and steel anchors, some new materials are being used in anchors, such as cement and resin. Anchors also introduced trays, nuts and other small pieces as supplement structures. The overall design has shifted from single-anchor-based to multi-anchors-based. Bar-mat reinforcement, shotcrete and grouting are also used. These innovations made the anchor rock bolt suitable for soft and broken rock layers, and the theory breakthrough brings combined anchors and prestresses anchors that slightly increase the integrality and stability of anchors [6]. The simplicity and low costs soon made anchors popular and replaced beams and trusses to be the mainstream of mining underground support designs. In countries that have relatively simple geological environment situation such as the United States and Australia, it will be considered not profitable to exploit such a mine if it cannot apply anchor rock bolts design [6].

2.4 Problems in the Research of Mine Support Theories

Frame support is intuitional but has been gradually replaced in recent years since the overall costs are too high compared to anchor rock bolts to achieve the same result. Anchor rock bolts have a relatively low cost and are easy to construct; thus have become the mainstream in underground support designs. However, the developments are concentrated on materials and construction methods. The core supporting theories lack development. Most designs still use basic suspension theory and combined arc theory, while these theories ignore the connection between anchors and surrounding rocks. Engineers only focus on the geometrical property of the anchor itself and do not include the mechanical properties of surrounding rocks into consideration, finally making the design not reliable enough [8].

At the same time, combined arc theory is based on arched shape tunnels, but most roadways, especially coal roadways, are rectangular-shaped in real-life practice. Different roadway shapes have different mechanical properties in surrounding rocks. Particularly, it is very easy to have concentrated stress on the corner of rectangular roadways, which will cause failures and risks in safety.

Most importantly, the major structures of anchor rock bolts are immersed in rocks. Current technologies can hardly track its performance once the construction is finished. When there is a deformation or a break, it is very tough to discover the problems without delay; therefore will cause unforeseen roof fall accidents and brings serious safety risks to production.

As the mining depth increases, the pressure on roadways inside the mine becomes more obvious. The support work in complex geological environments such as deep tunnels and soft rock roadways has become a serious issue which needs to be solved urgently. Regular anchor rock bolt support can no longer guarantee stability and safety when facing weak, fragile or easily deformed surrounding rocks. In addition, it is challenging to monitor performance and do further maintenance. When there is a local failure, it is hard to locate the problem at once, which will lead to subsequent roof collapse accidents. It is imperative to find a better way to support the stability of roadways under existing technology conditions. Combining the anchor rock bolt technology and retractable metal frames can solve the problem to a certain extent. The primary design uses anchor rock bolts to support and reinforce the support with retractable frames in the complex environment. This method can not only strengthen the support but also make the performance of the support system trackable, and if there is a failure, technicians can find the problem at once because the beams and trusses are explicit. If the frames at a certain location do not deform or shrink, the anchors around the frames are still effective. While the frames have already twisted or shrunk, there are likely problems with surrounding anchors, and these anchors have already lost their effectiveness.

3 The Combination of Frame and Anchor Rock Bolt Support

Anchor rock bolts have higher overall stability and support strength. Its fast and convenient erecting mode can timely support the broken surrounding rocks to form a whole and improve the general mechanical properties of the surrounding rocks after the roadway excavation. The follow-up retractable metal frames can further prevent the deformation of soft and broken surrounding rocks and keep the shape and size of the roadway. This combination can fulfil not only the fast, high strength and other advantages of anchor rock bolts but also avoid the extremely high cost of pure frame support.

4 Conclusion

With the development of production and industrial technology, the demand for coal is also increasing. It is bound to promote the development of coal mines that were once too deep or too hard to exploit. With the gradual increase of mining depth, pressure conditions, and surrounding rock complexity, single roadway support technology can not sufficiently meet the standards of low cost and high safety. With the development of support theory and the progress of related materials, the combination of multiple support modes can significantly improve the overall geometric parameters and mechanical properties of the support structure so as to better adapt to the complex and changeable support conditions under the mine, and maintain the stability of surrounding rock around the roadway.

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