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The Ra&D of Automatic Mobile Emergency Rescue Support System for Coal Mine Roadway Roof

Zhi Geng[a], Zitong Qi[b], Huiyu Ban[c], Can Wang[d,*], Meng Liang[e]

College of International Education, Henan Normal University, Xinxiang, China

[a]2371014328@qq.com, [b]2112873251@qq.com, [c]1355375415@qq.com, [d]3316107610@qq.com, [e]2590823932@qq.com

Abstract. Coal mine roadway roof accidents occur frequently, but the emergency rescue research after roof accidents is too one-sided. This paper proposes out an innovative rescue channel system that can be formed quickly in the roof area. The system is mainly composed of two parts: support frame and traction frame. Experimental applications were carried out in coal mines. The application results show that the rescue channel has many advantages such as fast movement, high support strength, light weight and easy to carry, which can achieve the purpose of rapid emergency rescue and ensure the safe and efficient production of the mine.

Keywords: roadway roof; rescue channel; autonomous mobile

1. Introduction

Coal mine roadway roof disaster is more serious in the industry of various types of disasters, roadway roof accident frequency in all accidents accounted for more than 60%, the number of casualties reached about 40%.There are different mechanisms of roadway roof, roof height, hazard level, damage body characteristics, and geometry of roof area in different geological environments, The literature indicates that the causes of roadway roof are related to natural geology, support and mining technology, etc. Mingkui Jia, et al, classified the causes of roadway roof into four major categories, including inferior strata combination, rock structure defect, power mutation and poor construction[1,2]; Nianjie Ma, et al, categorized the coal tunnel topping as local block fall type in the roof of the roadway with fractured rock mass, weakly cohesive laminated surrounding rock mass roadway compound roof collapse type [3,4]..

From the existing literature, scholars study this accident of coal mine roadway roof mainly focus on the mechanism of roof [5] and support countermeasures [6], but less research on the rescue equipment after the roof accident [7]. There is less research on rescue equipment after a roof accident, and it is very necessary to study the emergency rescue access system for roof roadways in order to ensure the safety and efficiency of coal mine production.

2. Overview of how to Deal with Roof Accidents in Roadways

According to the damage parts of the surrounding rock, there are many types of roadway accidents, which can be divided into three types of top plate accidents: top plate falling gangue, coal wall flake gang and top plate two gang big fall. Rescuing people in distress, finding out the location of people under pressure, and cooperating with rescue teams to carry out rescue is the primary task in the event of an accident. Then allow the area where the accident restored to resume ventilation, transportation and operations in a timely manner.

(1) Fast repair method for light sections: It refers to the use of bumping wedge method to set up temporary supports smaller than the original size of the tunnel at the location of the roof, forming a small section that can be passed and ventilated, the section is used in first aid, restoration of ventilation, transportation, etc.

(2) Enclosed wedge construction method: It refers to the way of using steel pipe and bracket tools to manually hit the wedge to form the roadway when the roadway has a large area of roof in the loose rock body.

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(3) Pergola method: When the arch height of the roadway is not more than 1m, and the roof rock layer does not continue to fall and the roof area is not large, you can use 5~8 long materials to build in the roof at the two ends of the bracket position, and then under the cover of the pergola gangue, shelves.

(4) Timber crib treatment method: Refers to the gangue pile on the first laying through the rod, through the rod above the layer-by-layer erection of wooden pallets, the first layer across the rod, the second layer and the first layer perpendicular, in turn, from bottom to top, until the complete top plate.

(5) Anchor-plate retaining treatment method: When the whole topping roadway is blocked by gangue and the roadway continues to fall, first clean gangue roadway roof can be penetrated into the side and the top wedge, spray 3mm thick concrete, so that the gangue within the range of penetration wedge glued into a whole, and then set up metal bracket, spray concrete again, the metal bracket completely closed in the mixed soil.

3. The Overall Structural Design of the Rescue System

Rescue channel is a kind of hydraulic jack as the power, it can be in the roadway roof broken gangue pile to move forward and support the role of rescue device.

3.1 System Cross-sectional Structure Design

In the process of cross-section design in the support system. The first consideration is the advantages of simple structure, easy portability and high cross-sectional utilization. Compared with other common shape sections, the most stable is the triangular section support frame, in which the inclined force surface reduces the upper pressure and support resistance, and reduce the weight of the support bar, all three corners are equipped with auxiliary facilities, which effectively utilizes the entire access section while realizing the characteristics of simple structure and easy handling.

In order to reduce the construction work to a minimum to achieve the requirements of quickly constructing the rescue channel, the space size of the rescue channel operation should be reduced as much as possible. According to ergonomics, the basic size of Chinese human body is as follows: The kneeling height of a person is 1315mm; the height of a person's head and neck is 300mm; the width of a person's shoulder is 430mm.

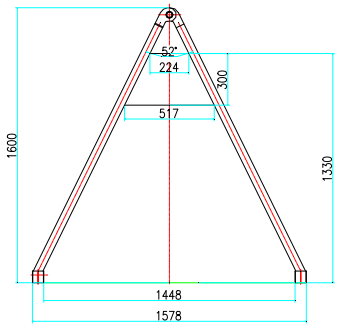

Fig.1. Schematic design of operating space for rescue access.

According to the above requirements of the design of the rescue channel section is shown in Fig. 1. The internal width of the section at 1330mm from the ground is 224mm, which meets the requirements of the kneeling height of 1315mm and the width of the helmet of 220mm; the width of the section 300mm down from 1330mm is 517mm, which meets the requirements of the head and neck height of 300mm and the shoulder width of 430mm.

3.2 Overall Structure of the Support System

The schematic diagram of the overall structure in the designed support system is shown in Fig. 2. The system is divided into two parts: the traction frame and the support frame. A jack is installed at

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each of the three end points of the traction frame to push the support frame forward, and the support frame follows the movement of the traction frame to set up an rescue channel under its shield.

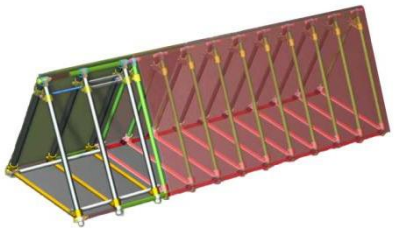

Fig.2. Schematic diagram of the structure of the rescue channel

3.3 Calculation of the Force of the Support System

From the above schematic diagram of the rescue channel structure, it can be seen that the relevant formula for calculating the maximum bearing pressure of the triangular section is as follows. Support system in each group of bracket support length is b, each rod support width is a; bracket support height is 1.6m, From the above schematic diagram of the rescue channel structure, it can be seen that the relevant formula for calculating the maximum bearing pressure of the triangular section is as follows. Mark the height of the arch as h; The density symbol of crushed gangue is γ , bracket rod angle is α. Then the gangue acts on the single group of bracket side of the vertical load on the rod as follows:

$$Q = \gamma \times \mathrm{b} \times \mathrm{a} \times \mathrm{h} \times \sin\left(\frac{\alpha}{2}\right) \tag{1}$$

The gangue acts on the vertical load of the rod on one side of each group of brackets related data Table 1 represents the data related to the

gangue acts on the single group of bracket side of the vertical load on the rod. The result obtained by bringing the data in Table I into the 1 equation is Q.

Parameter	Value	Parameter	Value
γ/kg/m3	2.1×103	h/m	8.0
a/m	0.34	α/ °	52
b/m	0.79	Q/kN	19.8

The length of each rod is recorded as L, L = 1.78m, and the maximum bearing moment of the rod is:

$$M_{\max} = \frac{QL^2}{8} \tag{2}$$

The result Q calculated in equation (1) with the above mentioned L substituted into equation (2) can be obtained as Mmax.

Its tensile yield strength is 920MP when TC4 titanium alloy is selected. If a titanium alloy tube with an inner and outer diameter ratio of 2/5 is used, Then the calculated diameter length of the pipe diameter is 37 mm.

According to this calculation, the cost performance of titanium alloy pipe material is relatively high, so the proposed titanium alloy pipe with cross section of φ40/16mm is used.

3.4 Calibration of the Material Strength of the Rod

Verify the strength data of the rod, and the following is the result of the calculation of some of the data.

Maximum bending moment of the material of the selected rod：

$$M_{\max} = \frac{920 \times \pi \times 0.04^3 \times (1 - 0.4^4) \times 10^3}{32} = 5.6kN \cdot m$$

The value is calculated to be greater than 4.4kN • m, which meets the requirements.

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The weight of the selected rod material：

$$Q = 4.5 \times 1.78 \times \pi \times \frac{(0.04^2 - 0.016^2)}{4} = 0.0085t = 8.5kg$$

The titanium alloy material used has a weight of 8.5kg per rod.

4. The Working Principle of the Power Part in the Rescue System

4.1 General Description of the Power System in the Support System

The rescue system relies on hydraulic type jack to move forward automatically, pushing the structure is described as follows:

(1) overall structure: three frames are grouped together, with one in front and two behind, as shown in Fig. 3.
(2) the way the product moves: the two frames at the back are fixed to push the front frame; the front frame is fixed to pull the two frames at the back to move.
(3) product pushing mechanism: a hydraulic jack is assembled at each of the three ends of the traction frame.

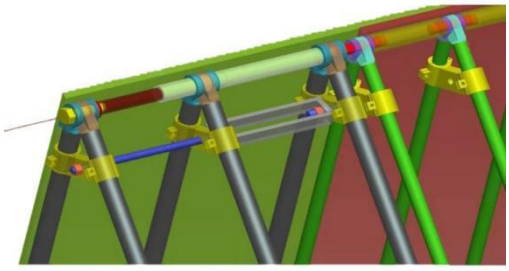

Fig.3. Schematic diagram of the rescue channel nudge mechanism

Assemble a hydraulic jack at each end of the traction frame. The symbol of cylinder diameter is noted as φ1, φ2 is the symbol of rod diameter, and The symbol of pump pressure is defined as P, the symbol of defined thrust is defined as F1, the symbol of jack pull is defined as F2, the maximum advance is expressed by the symbol L, the advance of the whole rescue channel is expressed by the symbol F3, the pull is expressed by the symbol F4, and the symbol of single stroke is noted as S.

Table 1. Data related to the hydraulic jack pushing mechanism located at the three ends of the traction frame

Parameter	Value	Parameter	Value
φ_1 /mm	50	F_1/kN	118
φ_2/mm	36	F_2/kN	56
P/MPa	60	L/mm	350
F_3/kN	354	F_4/kN	168
S/mm	350		

4.2 Power System Working Principle

In order to improve the ability of the pushing jack to withstand radial forces, the jack is designed into the inverted structure. Set up a cylinder sleeve on the outside of the jack, the piston rod in the sleeve, The radial force pushed out of the sleeve by the jack cylinder is carried by the cylinder, the guide sleeve between the sleeve and the cylinder body, thus enabling the jack to withstand the radial force generated by the rescue channel in pushing the bias load. In the process of rescue channel will inevitably produce the phenomenon of bias load, In order to improve the reliability of the rescue channel to move smoothly, a synchronization system was added to its hydraulic system to enable

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the three jacks to move synchronously, the hydraulic system of the rescue channel is shown in Fig. 4.

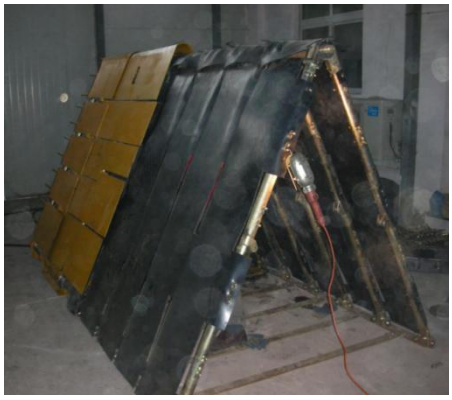

Fig.4. KJ-1 type self-moving emergency rescue support system physical diagram

5. Field Applications

The KJ-1 self-moving emergency rescue support system developed by the laboratory is shown in Fig. 4 and was applied to a coal mine in Datong, Shanxi Province. The mine belongs to the close coal seam joint integrated mining, the flat slope shaft adopts the mixed development method and adopts the total collapse method to manage the roof, one side of the main mining face 3108 is a Mined-out Area, the other three sides are solid coal area, The working face consists of a mining height of 3 meters and a coal release height of 22 meters, it has a strike length of 950 meters. Its deep length is 150 m. The inclination range of the coal seam from 1° to 5° belongs to the near-horizontal seam with a Pratt's coefficient of 2.66. The working face roadway is arranged along the bottom of the coal seam, the roadway has a rectangular section, the roadway has a width of 4.8m and a height of 3.2m, the machine rails are combined into one roadway, it is used for coal transportation, air intake and arranging trains, the anchor cable reinforcement is carried out by a combination anchor support system of resin extension anchors.

The roadway had a small-scale local topping during the excavation process and there were coal seam bubbles on both helpers or the top, the height of the bubble was about 8m, the length of the roadway topping was about 20m, the form of the roadway topping after the field collection is shown in Fig. 5.

(a)Top collapse (b)Sidewall fell off

Fig.5. Morphological characteristics of the roadway after caving

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Fig.6. Morphological characteristics of the roadway after cavin

The KJ-1 self-moving emergency rescue support system developed in this paper was applied to this roof area, and the application showed that the rescue support system can form the tunnel quickly and move forward rapidly. It can support the gangue falling from the top and cooperate with the rescue team to rescue the trapped people to the maximum extent, Through the successful rescue of trapped people and equipment in the tunnel, as well as the timely ventilation of the tunnel, there were no casualties in the roof area in the end, and the rescue support system has good application effect. Figure 6 shows our field test in the riser area.

6. Conclusion

The following main conclusions can be obtained from this paper.

(1) The paper summarizes the common treatment methods for existing coal mine roof roadways, including the small section rapid repair method, the closed crash wedge construction method and also analyzes the problems existing in different measures.

(2) An innovative ground rescue access system that can be quickly erected in the roof area is proposed. The system is mainly composed of two parts: support frame and traction frame, with low amount of gangue. Its traction part is a set of mechanical automatic propulsion mechanism, which can be quickly propelled forward in the falling gangue with the force of hydraulic jack.

(3) The field application in the roof rise area shows that the rescue channel developed in this paper has the advantages of fast handling and erection, high support strength and light weight, which can achieve the purpose of rapid emergency rescue and ensure the safe and efficient production of the mine.

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