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Failure mechanism and control technology of water-immersed roadway in high-stress and soft rock in a deep mine

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ABSTRACT

Aiming at soft rock ground support issues under conditions of high stress and long-term water immersion, the ground failure mechanism is revealed by taking the deep-water sumps of Jiulong Mine as the engineering background and employing field investigation, tests of rock structure, mechanical properties and mineral composition. The main factors leading to the surrounding rock failure include the high and complex stress state of the water sumps, high-clay content and water-weakened rock, and the unreasonable support design. In this paper, the broken and fractured rock mass near roadway opening is considered as ground small-structure, and deep stable rock mass as ground large-structure. A support technology focusing on cutting off the water, strengthening the small structure of the rock and transferring the large structure of the rock is proposed. The proposed support technology of interconnecting the large and small structures, based on high-strength bolts, high-stiffness shotcrete layer plugging water, strengthening the small structure with deep-hole grouting and shallow-hole grouting, high-pretensioned cables tensioned twice to make the large and small structures bearing the pressure evenly, channel-steel and high-pretensioned cables are used to control floor heave. The numerical simulation and field test show that this support system can control the rock deformation of the water sumps and provide technical support to similar roadway support designs.

1. Introduction

With the continuous increase of the strength and scale of coal mining in China, many mining areas have gradually turned to deep mining. The problems of high stress and soft rock roadway support have become a major concern and repair after excavation commonly occurs [1,2]. After the above-mentioned types of roadway undergo water issues, the nonlinear large deformation and rheological characteristics of the surrounding rock become more significant and the extent of fragmentation and damage of the surrounding rock experience a substantial increase under the influence of water-rock interaction [3–5]. This also results in support failure and weakening of rock bearing capacity, which can easily lead to roof caving, rib spalling and floor heave. It is difficult to guarantee the stability of the surrounding rock of a roadway with single support method. Numerous scholars have carried out beneficial exploration of the deep soft rock roadway support issue and achieved good results. He [6] proposed that the soft rock tunnel has many kinds of deformation mechanism, which transforms the mechanical mechanism of the compound deformation into a single one and is the key to the success of the support system. Kang [7], aiming at deep and complicated difficult roadways, proposed the high-prestress and strong support theory, by improving the initial stiffness and strength of the supporting system, which can effectively control the deformation of the surrounding rock. It emphasized the importance of first support to avoid the second support and roadway repair. Wang [8], aiming at high stress and extremely soft broken rock roadways, proposed the use of high-strength rock bolts and cables, and the technology of high-resistance and intensive support by grouting, to reinforce the surrounding rocks. Liu [9] proposed that, using ultrahigh anchor bolt with high initial anchorage forces and grouting, energy- releasing measures as subsidiary can keep the deep roadway stable. Guo [10] proposed the employment of the combined supporting technology of constant-resistance and large deformed anchor bolt, steel belt and grouted anchor pipe to prevent deep soft rock roadway from deformation on a large scale. This technology shows obvious on-site effects. Meng [11] analyzed the different failure courses of deep soft rock

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roadway under the influence of different factors with numerical simulation, and put forward five different failure modes.

The influence of water on the stability of the surrounding rock of a roadway has been a long-lasting issue of the research of mining workers [12–15], but previous studies mainly concentrated on the effects of gushing water in the aquifer on the surrounding rock of the roadway; research into deep high-stress soft rock roadways enduring prolonged water immersion is rarely discussed. The main mining area of Jiulong Mine in the Fengfeng area is the second level of −850 m, the hydrogeological condition is complex, and the mine inflow is large. Both the internal and external water sumps serving this level are arranged in high stress soft rock. Coupled with the effects of prolonged water immersion on the surrounding rock in the process of impounding water, the water sumps appear to suffer serious deformation, and their storage capacity cannot meet the needs of safe production. Repeated repair has a limited effect, which has affected the regular production of the mine. The key to safe production is to choose reasonable repair-control technology, ensure the long-term stability of surrounding rock in the water sump and make it capable of enough storage. Therefore, this study which takes the deep water sumps in Jiulong Mine as the engineering background, analyzes the failure mechanism of the high-stressed and long-term water-immersed soft rock roadway. Based on previous research and effective control measures are proposed to provide reference for the design and construction of roadway support under similar conditions.

2. Field overview

The internal and external water sumps in Jiulong Mine second level are at a depth of 980 m; the horizontal distance of the internal water sump is 89 m and the external water sump is 159 m. The horizontal distance between them is 20 m. The internal and external water sumps have the same shape and size, with a straight wall semicircle section, excavated section height is 3250 mm and the width is 4300 mm. The internal and external water sumps are less affected by digging other surrounding caverns. The layout of the internal and external water sumps is shown in Fig. 1. In the case of the internal water sump, the component of the roof is siltstone, the rib is mudstone and coal and the floor is mudstone. In the case of the external water sump, the roof and floor and rib are composed of siltstone. The coal seam dip angle is 15°. Located in the area of siltstone and mudstone, the clay mineral content is high, and easily swells with water. The initial plans of the internal and external water sumps involve the use of an anchor net spray support. The bolt has a standard of Φ20 mm × L2400 mm of 20MnSi high strength without longitudinal reinforcement steel, each bolt is equipped with one K2860, one Z2860 resin drug volume. The distance between the rows is 700 mm × 700 mm and staggered, both the left and right sides near the corner position are laid with bolts which have a 30° angle with the horizontal direction. Hanging steel mesh, whose diameter is 6.5 mm, specification is 1.5 m × 0.8 m, grid is 150 mm × 150 mm, mesh lap length 100 mm, every 300 mm with double 12 lashing wire. The roof and ribs of both internal and external water sumps are injected concrete with a thickness of 150 mm and strength grade C20, the floor is injected concrete with only a thickness of 100 mm and strength grades of C20.

3. Failure mechanism of surrounding rock of roadway

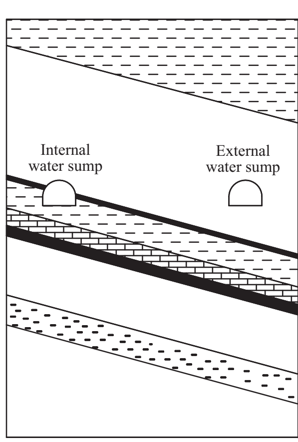
3.1. Failure characteristics of surrounding rock

3.1.1. Failure modes of surrounding rock

The capacity of water sumps gradually reduced with time, resulting in a serious shortage of water storage capacity. By investigation into the internal and external water sumps after pumping water, it was found that the water sumps had been severely deformed, as shown in Figs. 2 and 3. The whole section converged, basically closed in some sections of the internal water sump, the concrete spray layer appeared to have a large area cracking and peeling, steel mesh was badly torn, many bolts had bending and breaking failure, the floor was seriously heaved and the concrete spray layer had flexed on the roof and rib of both internal and external water sumps. Both internal and external water sumps appear to have different degrees of roof caving and spalling, exposed rock was broken and argillization phenomenon was serious. The characteristics of deformation and failure of the water sumps surrounding rock are mainly reflected in the following aspects: large deformation, long duration, sever damage and high repair rate.

3.1.2. Failure depth of surrounding rock

The extent and scope of damage of the surrounding rock of the water sumps are the basis for selecting the reasonable support method and parameter. For this reason, the TS-C0601 multi-functional borehole imaging analyzer has been used to drill holes in the roof and ribs of the internal and external water sumps. According to the result, it can be seen that the damage extent and scope of the surrounding rock are roughly the same in both internal and external water sumps under the condition of long-time water immersion and bulking. Rock in the shallow area is broken, while the deep surrounding rock is fracture. Fig. 4 is the result of the internal water sump surrounding rock. The surrounding rock



Lithology	Thickness (m)	Lithology characteristics	Floor buried depth (m)
Mudstone	12.01	Grey black, containing calcite vein, turtle iron and tuberculosis	961.45
Siltstone	17.00	Grey black, more argillaceous, containing fossils of animals and plants, bedding development	978.45
No.3 coal	0.55	Black, powder and block, a sigle coal seam	979.00
Mudstone	3.76	Grey black, containing fossils of plants roots and 0.1 m siderite tuberculosis	982.80
Yeqing limestone	2.30	Grey black, dense and hard, containing calcite vein	985.10
No.4 coal	1.35	Black, powder and block, a sigle coal seam	986.50
Siltstone	7.80	Grey black, containing fossils of plants roots	994.30
Fine sandtone	3.36	Dark grey, containing fossils of plants, mica, iron sulfide	997.70
Siltstone	2.07	Grey black, containing plants fragments and pyrite	1000.00

Fig. 1. Surrounding rock columnar section of water sumps.