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High-resistance controlled yielding supporting technique in deep-well oil shale roadways

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ABSTRACT

In order to avoid the deep-well oil shale roadway being deformed, damaged, or difficult to maintain after excavating and supporting in Haishiwan coal mine, this paper has analyzed the characteristics of the deformed roadway and revealed its failure mechanism by taking comprehensively the methods of field geological investigation, displacement monitoring of surrounding rock, rock properties and hydration properties experiments and field application tests. Based on this work, the high-resistance controlled yielding supporting principle is proposed, which is: to "resist" by high pre-tightening force and high stiffness in the early stage, to "yield" by making use of the controlled deformation of a yielding tube in the middle stage, and to "fix" by applying total-section Gunite in the later stage. A high-resistance controlled yielding supporting technique of "high pre-tightening force yielding anchor bolt + small-bore pre-tightening force anchor cable + rebar ladder beam + rhombic metal mesh + lagging gunite" has been established, and industrial on site testing implemented. The practical results show that the high-resistance controlled yielding supporting technique can effectively control the large deformation and long-time rheology of deep-well oil shale roadways and can provide beneficial references for the maintenance of other con-generic roadways.

1. Introduction

Kerogen shale, which is also known as oil shale, as its name implies, is a type of shale with high oil content and is a fine sedimentary rock containing primary organic matter. Hence, large amounts of shale oil can be extracted from it when subjected to pyrolysis. Moreover, it is the most realistic resource of oil, having similar physical and mechanical properties with soft rock, which can partially replace conventional oil and gas which is currently being used. According to the records of *Oil Shale Industry in China*, the reserves of Chinese oil shale is about 2000 billion tons, which ranks only second to the United States, Brazil, Estonia, being fourth in the world. The primary methods of recovery of oil shale in China are underground dry-distillation, surface mining and underground mining, of which, underground mining is the main method [1–6].

The Minhe and Xining basins, located between Lanzhou and Xining in western China, both have abundant coal and oil shale resources. Therefore, economic growth in western China will be greatly promoted if these resources, especially oil shale, can be exploited and utilized efficiently. Owing to the geological phenomenon of oil shale and coal occurring together in the Yaojie mining area of Gansu, the exploitation of oil shale in the upper protective layer can not only free the lower coal seam, which is prone to coal and gas outbursts, to make preparations for the exploitation of the oil shale, but also can replenish the demand of oil gas sources for western economic development, which has realized co-exploitation of coal and oil shale.

Domestic and overseas experts have carried out much useful research into the failure mechanism of soft rock roadway deformation and control technology, but research on specific oil shale roadways is sparse [7–9]. The deformation failure characteristic of oil shale is different from general soft rock roadways because of differences in composition, mechanical properties, water-physical properties, etc. As a result, this paper describes the results of a study on the deformation failure characteristic of an oil shale roadway in terms of the properties of oil shale, and has proposed a pertinent technology for the control of the surrounding rock, and has thus solved the problem of supporting an oil shale roadway in the Yaojie mining area of Gansu.

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2. Engineering situation

2.1. Geological conditions

The coal seam in the well field of Haishiwan coal mine is in the Yaojie group of the Jurassic, which centers on the second group below the Yaojie group. It includes six coal seams, among which the second is the most stable and is the main seam for exploitation. However, the second coal seam is prone to coal and gas outbursts and several accidents have occurred resulting in a serious threat to safe coal production at the mine. After careful planning and design, the upper protective layer of oil shale is exploited first to produce intense tension damage between the upper and lower layers, so as to efficiently release the ground stress in the lower coal-series strata which causes the osmotic coefficient of the lower coal seam to increase significantly. Thus, the gas pressure and content will decrease and render the outburst-prone coal seam to become a non-outburst one, and the high gas content coal seam to become a low gas content one [10,11]. The existing support method and coefficient of roadway can only refer to the old method of support of the in-seam roadway. A lack of systematic study of mechanical and water-physical properties, as well as roadway deformation failure mechanism, has resulted in difficulty in the maintenance of roadways, causing slow advance rates, and serious deformation failure. Hence, any improvement in mine production is extremely limited.

Transportation down-dip is the main haulage system in oil shale with an average burial depth of more than 800 m advancing along with the roof of oil shale. The east side is the return airway for the working faces of 6113 and 6213, being unaffected by mining influence during advance. Their relative positions are shown in Fig. 1. Many different support patterns, including cable anchor, brickwork and shed, have been applied since excavation, maintenance results in all cases are unsatisfactory, forming a vicious circle of repair after excavation, with a roadway repair rate of 100%; some of them have even be repaired four times.

2.2. Lithology of roof and floor

The roof and floor of the surrounding rock in the oil shale roadway are marl and oil shale respectively, determined from field sampling and laboratory experiment:

(1) Roof plate marl
The immediate roof is marl, with a uniform thickness of 6.0 m. It is black green in color with a coefficient of hardness of 2–3, strong water absorption with a water content of 52–66%. The illite–smectite mixed layer swells to powder in water and is classified as a non-aquifer.

(2) Floor oil shale
The floor is oil shale, brown–black in color and about 4.5 m thick with a layered structure and high oil content. It is liable to weathering which transforms it into schistose and is classified as a weak aquifer. The lithology of the roof and floor of the oil shale horizon is shown in Fig. 1.

3. Deformation failure characteristics of a roadway

3.1. Primary support pattern

The roof and the two sides of the roadway all use HRB335 left-hand thread steel anchor bolts of Φ20 mm and L2400 mm, combined with plain nuts and aluminum–magnesium composite plates. The row-line spacing is 800 mm × 800 mm with end anchorage. In the roof, two lengths of seven steel strand anchor cable of Φ15.24 mm and L7300 mm are used with a row-line spacing of 2000 mm × 2400 mm, being combined with locksets and 14# channel steel. The whole fracture surface is covered with 10# diamond metal net woven with iron wire, and the two sides of the section are covered with 12# steel ladder beams.

3.2. Deformation failure characteristics of the roadway

(1) The surrounding rock of the roadway can quickly be subjected to pressure, rapid deformation velocity and high degrees of deformation. The deformation velocity of the roadway can reach 30–40 mm/d when excavation is carried out over 1–2 d. When excavation is carried out over 30 d, maximum deformation can be more than 500 mm and the surrounding rock deformation can still unstable after three months. Deformation failure conditions in a roadway are shown in Fig. 2.

(2) Roadway deformation can be described as the rapid development of fracture surfaces due to compression of the entire rock mass, the most obvious result being roof convergence. Displacement monitoring in the rock surrounding the roadway indicates that the displacement between the roof and floor is similar to that of the two sides, in which roof convergence was 70–80% of the displacement between the roof and floor. Cumulative roof convergence can reach 1200 mm, and extrusion deformation in the middle-lower part of the two sides is distinct. Hence, the roof and the two sides have been the key components in support of the transportation dip in oil shale. The displacement monitoring curve of the roadway surrounding rock is shown in Fig. 3.

(3) The surrounding rock deformation failure of the roadway displays an obvious time effect with a significant rheological characteristic. Fig. 3 shows that the surrounding rock displacement curve of the roadway shows gradient "S" type characteristics, except for the elastic deformation which is produced instantly, and can be divided into three phases: (1) deceleration creeping phase; (2) stable creeping phase; (3) acceleration creeping phase which coincides with the typical non-attenuation creeping curve [12].

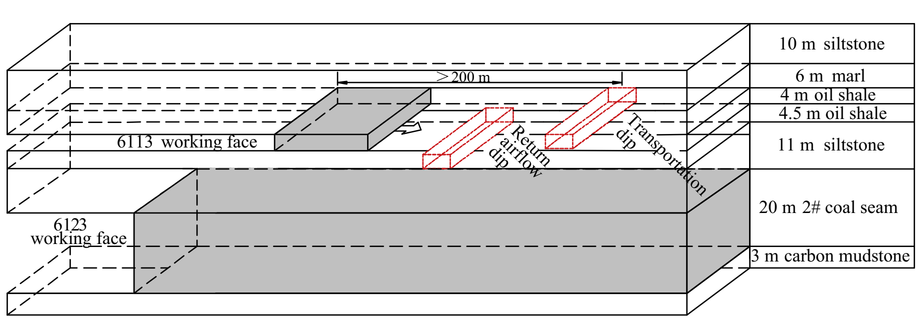

Fig. 1. Relative position of roadway.