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Surrounding Rock Control Technology of Strong Dynamic Pressure Roadway in Hudi Coal Industry

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Abstract

Aiming at the problems of large deformation and difficult maintenance of deep soft rock roadway under the influence of high ground stress and strong dynamic pressure, taking the surrounding rock control of 1105 lane in Hudi Coal Industry as an example, the deformation characteristics and surrounding rock control measures of deep soft rock roadway are analyzed and discussed by means of geological data analysis, roadway deformation monitoring, rock crack drilling and field test. The results show that the main causes of roadway deformation are high ground stress, synclinal tectonic stress, advance mining stress, roadway penetration and surrounding rock fissure development. Based on the deformation characteristics and mechanism of lane 1105, the supporting countermeasures of "roof synergic support, layered grouting, anchor cable beam support, closed hardening of roadway surface" are proposed, which can provide reference for the control of deep roadway surrounding rock under similar conditions.

Keywords

Deep Roadway, Combined Support, Surrounding Rock Control, Soft Rock Roadway

1. Introduction

In recent years, China's coal mines have gradually entered deep mining, and the geological conditions and mining technical conditions have become increasingly complex [1] [2] [3] [4]. Under the influence of "three high and one disturbance" (high ground stress, high ground temperature, high karst water pressure, mining disturbance), the rock mass of deep roadway is weak, broken, low strength, easy

to deformation, sensitive to mining stress disturbance and complex tectonic stress [5] [6]. In particular, for deep soft rock roadway under the influence of tectonic stress and mining stress, the surrounding rock of roadway has obvious creep, which will cause continuous large deformation and failure and is difficult to control [7] [8] [9] [10].

At present, many scholars at home and abroad have conducted in-depth studies on the support problem of deep soft rock roadway. Zhang Bin *et al.* [11] studied the deformation rule of surrounding rock under excavation disturbance by using the method of field measurement and simulation analysis, and concluded that excavation disturbance reduced the stability of shallow surrounding rock, and increased the fracture and deformation of surrounding rock. Cao Shenggen *et al.* [12] studied the evolution law of vertical stress of main roadway floor under the influence of repeated mining. With the continuous advance of mining face, the concentrated stress above the goaf is transferred to the floor rock through the coal pillar, which makes the floor stress increase rapidly and destroys the stress balance of surrounding rock. Jiang Chengyu [13] studied the deformation characteristics of deep high stress mud soft rock roadway, optimized roadway support parameters by numerical simulation, and proposed a combined support scheme of "anchor/cable + steel mesh + grouting + U-shaped steel shed", which has achieved remarkable results in field application. These studies have promoted the development of deep roadway support technologies, such as anchor net shotcrete support and concrete-filled steel tube [14]. However, with the continuous increase of mining depth, deep soft rock will show the characteristics of "big rheology". In this environment, the surrounding rock of roadway will be periodically damaged with the influence of mining disturbance. The previous single support method cannot solve the deformation problem of deep soft rock roadway well.

Because the deep roadway of Hudi Coal Industry has been seriously affected by mine pressure for a long time, the supporting effect of traditional bolt and anchor cable supporting structure and ordinary shallow grouting method is not ideal. Therefore, on the basis of previous studies, this paper takes the phenomenon of roof separation, floor heave and two-side deformation after the surrounding rock of deep soft rock roadway in Hudi Coal Industry is affected by deep mine pressure and mining as the research background. Aiming at the problem of instability and deformation of deep soft rock roadway affected by strong dynamic pressure, the deformation and failure mechanism of roadway surrounding rock under the comprehensive influence of deep mine pressure and mining pressure is analyzed by means of geological data analysis, roadway deformation monitoring and borehole peeping, which provides reliable theoretical and practical basis for roadway management.

2. Engineering Background

Hudi Coal industry is located in Jincheng City, Shanxi Province. The depth of

coal seam in the mine field is up to 730 m. The main geological structure in the mine field is mainly fold, and the fault structure is not developed. The ground stress test shows that Hudi coal industry has higher ground stress and the horizontal principal stress is dominant in the field, and the maximum horizontal principal stress reaches 21.7 MPa, which is a high ground stress mining area. The mine adopts pan-type arrangement, with fully mechanized mining face arranged on both sides of the main roadway in pan-area, and adopts long arm comprehensive mechanized coal mining method. The relation diagram of mining engineering near lane 1105 is shown in Figure 1.

Lane 1105 is the auxiliary air inlet lane, which is adjacent to Lane 1103 to the north and Lane 1104 to the south and the working face. The section of lane 1105 is a semicircle arch with a width of 4.7 m, a height of 3.95 m, a wall height of 1.6 m and an arch height of 2.25 m, and a design section area of 15.47 m^2. The current support of lane 1105 uses anchor cable + warp and weft mesh (or steel mesh) + double-layer steel ladder beam support; The top 22 m to 51 m of the 10 Hengchuan East side of Lane 1105 adopts φ22 × 10,300 mm steel stranded cable, the top 51 m to 67 m adopts φ22 × 14,300 mm steel stranded cable, the top of the alley from 67 m to 1309 bottom pumping cable, and the repair part of the 10# Hengchuan to 1309 bottom pumping lane adopts φ22 × 7300 mm steel stranded cable. The distance between cable rows is 1200 mm × 700 mm.

Considering production, geological conditions and ground stress comprehensively, it can be seen that lane 1105 is affected by high ground stress in depth, Panjiazhuang syncline and mining pressure of the adjacent working face, the surrounding rock stability of the roadway is poor, and its floor is not supported, so it is prone to severe ore pressure.

3. Deformation and Failure Characteristics of Roadway Surrounding Rock

Through the continuous monitoring of the ore pressure development in lane

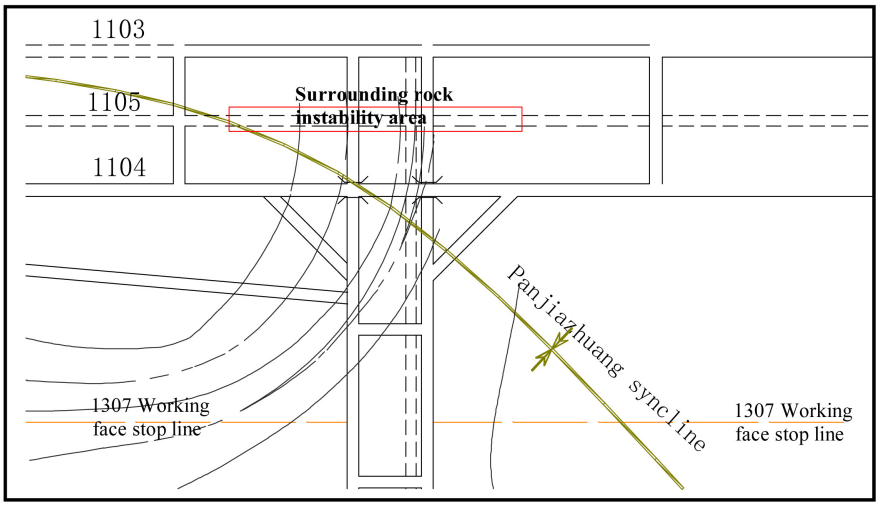


Figure 1. Excavation engineering plan of Lane 1105.

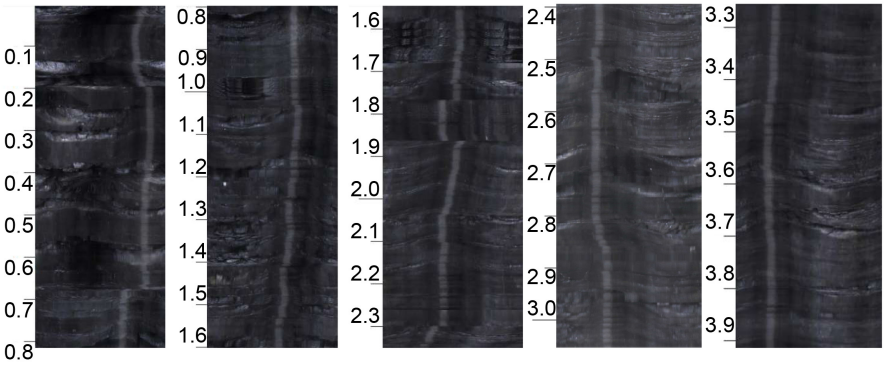
1105, it is found that since late April 2022, there has been an obvious ore pressure development in Lane 1105 due to the influence of the mining pressure of the adjacent working face. In the range of 1400 m to 1500 m (10# Hengchuan −11# Hengchuan), there are roof subsidence, tunnel surface grouting layer cracking, anchor cable breakage, serious floor heave and other phenomena. Among them, the floor heave is serious at 1410 m to 1420 m, the distance between the air duct and the belt is less than 200 mm, the cumulative displacement of the top and bottom reaches 3 - 4 m, and the cumulative displacement of the two sides reaches 2 - 3 m. At the same time, the grout on the right side arch shoulder of roadway 1450 m to 1460 m in Lane 1105 is cracking.

In November 2022, Lane 1105 was repaired with brush expansion, and obvious traces of stress release were observed in the surrounding rock of the roadway. The surrounding rocks of the two sides of the roadway are squeezed to the middle of the alley, and cracks are developed, the rock mass is broken and the strength is low, and the subsidence and bending of the roof strata are very obvious, as shown in **Figure 2**.

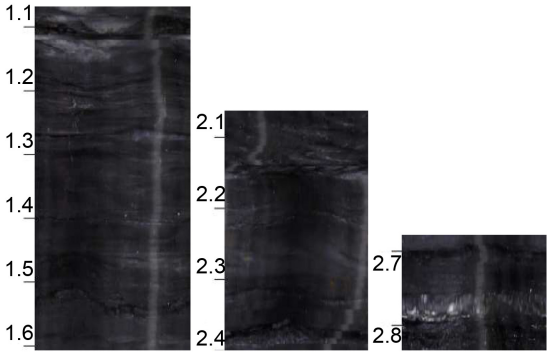
In the follow-up roadway repair project of Lane 1105, the borehole observation was carried out at the roof of the roadway 1390 m and 1440 m respectively. The peephole depth at 1390 m is 15 m, and the peephole depth is determined to be 8m because the deep drilling hole is relatively broken. Among them, 0 - 2.8 m is the rock layer, and cracks are developed at 1.1 m - 1.6 m, 2.1 m - 2.4 m, 2.7 m - 2.8 m in the rock layer. 2.8 m - 8.0 m is coal seam; At 1440 m of Lane 1105, the drilling depth of the roof is 15 m and the viewing depth is 7 m. Among them, 0 - 1.8 m cracks developed and were relatively broken. Horizontal cracks developed at 2.0 m - 2.2 m, 2.5 m - 3.0 m and 3.4 m - 3.8 m, and rocks were broken at 6.6 m - 6.8 m. **Figure 3** shows the drilling results.

It can be seen from the peeping results that under the comprehensive influence of deep high stress, syncline and mining stress near the working face, the surrounding rock failure depth of lane 1105 is relatively large, and the surrounding rock within 3 m from the roadway surface is relatively broken, with low strength and cracks showing a state of penetration. In the depth range of 3 - 4 m, horizontal cracks develop and the integrity of surrounding rock is reduced.

Figure 2. Deformation and failure characteristics of surrounding rock.



(1) 1390 m Surrounding rock fracture development



(2) 1440 m Surrounding rock fracture development

Figure 3. Tunnel 1105 surrounding rock crack borehole peek.

Outside 4 m, the shape of surrounding rock is relatively complete and the crack opening is relatively small.

4. Cause Analysis of Deformation and Failure of Roadway Surrounding Rock

Based on the analysis of site geological data, tunnel deformation and drilling observation results, the causes of deformation and failure of the surrounding rock of lane 1105 are as follows.

1) The original support strength is insufficient: The original support strength of lane 1105 is low, and there is no support on the floor of roadway. Moreover, due to the high ground stress of the surrounding rock of the roadway, sufficient development of the joint of the surrounding rock and weak breakage, the end of the anchor rod cable will be exposed and broken, the supporting effect will be lost, and the deformation of the roadway will be intensified. Because the floor of the roadway is not supported, the closed and complete supporting structure is not formed with the two sides and the roof, which leads to the deformation evolution of "floor heave - two sides moving closer - roof sinking".

2) Influence of deep high ground stress and mining pressure: Lane 1105 is mainly affected by the following factors: a) Deep high ground stress: Lane 1105 has a large buried depth and the maximum formation principal stress reaches 21.7 MPa, which is a roadway affected by high ground stress; b) The structural

stress is significant: Section 10# Hengchuan of Lane 1105 is located at the axis of the north wing of the Panjiazhuang syncline (Figure 1). It can also be seen from the revealed rock formation that the rock formation is concave and shows obvious syncline characteristics, resulting in the stress concentration of the surrounding rock of Lane 1105, and the structural stress has a great impact on the strength and stability of the surrounding rock of the roadway. c) Influence of leading supporting stress on the working face: When the distance between the working face of 1309 (top) and the stoping line remains 35 m, leading supporting stress has a severe influence on lane 1105. At the same time, the roadway is not effectively reinforced before mining, and the deformation control of surrounding rock is not timely, resulting in serious deformation of the roadway in this section.

3) Influence of surrounding rock structure: Since the surrounding rock of roadway 1105 presents a "through-layer" structure (Figure 4), the surrounding rock of roadway 1105 is prone to deformation and damage along the bedding plane. From Hengchuan (coal lane) of 10#, the roadway 1105 is driven through the strata to expose the coal seam of 5#, and the roadway is driven along the K6 limestone of the roof of coal seam of 5#. According to the data of drilling and drilling during the excavation of lane 1105, the coal rock stratum rises up to about 9˚. In addition, the surrounding rock of the roadway is mainly sandy mudstone with low strength, and there is 3# coal in some areas of the roadway roof, so the surrounding rock is weak. Under the common influence of deep ground stress, tectonic stress and advanced abutment pressure of the adjacent working face, the surrounding rock of the roadway presents significant flow plasticity, resulting in the failure of the roadway support system and the increase of deformation.

5. Surrounding Rock Control Technology of Deep Roadway with Strong Dynamic Pressure

In order to solve the problem of low strength and poor stability of surrounding rock in lane 1105, which is affected by high ground stress and strong dynamic pressure, the surrounding rock control technology of strong dynamic pressure roadway is put forward, which includes "roof coordinated support, layered

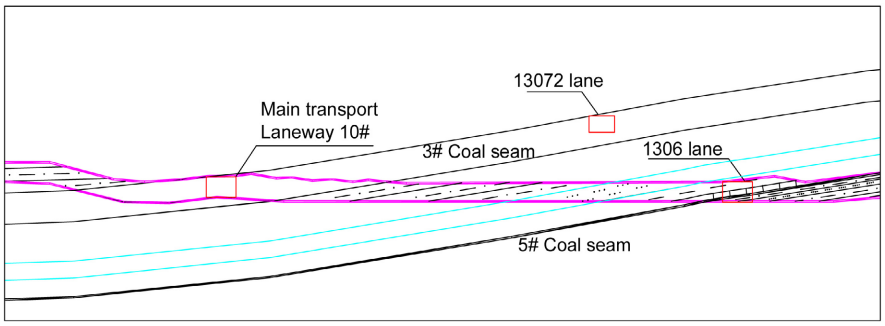


Figure 4. Excavation engineering plan of Lane 1105.

grouting, anchor cable bundle floor support and roadway surface sealing and hardening" [15] [16]. Firstly, grouting method is used to change the properties of roadway surrounding rock and improve the strength of roadway surrounding rock. The grouting holes are arranged in the whole section of lane 1105. The 8 m deep holes and 3 m shallow holes are arranged at intervals. The two sides are injected first, and then the roof is injected. After low pressure grouting is performed on shallow hole to form shallow stop bearing layer, high pressure split grouting is performed on deep hole. The area with relatively large opening degree of surrounding rock cracks within 0 - 3 m is reinforced by ordinary Portland cement grouting. For the deep surrounding rock above 3 m, the crack opening is relatively small, and the superfine cement is used for grouting reinforcement to improve the strength and deformation resistance of the surrounding rock.

While the surrounding rock is modified by grouting, "anchor cable + double reinforced ladder beam + steel mesh + thin layer shotcrete anti-weathering and anti-rust" is adopted on the basis of making full use of the original anchor cable and roof. Since the floor of lane 1105 was not supported originally, the floor heave seriously affected the overall stability of the roadway surrounding rock, so the floor reinforcement support was carried out to form a combined surrounding rock support body.

1) Roof anchor cable layout: Each section is arranged 5 in the vault, 2 in the spinner, and the high-strength pressure anchor cable Φ22 is arranged 1000 × 1000 mm apart.

2) Two sets of anchor cable layout: each set of 3 high-strength pressure anchor cables, the row distance is 1000 × 1000 mm.

3) Preload force: Except for the bottom corner anchor cable, the other anchor cables are laid vertically on the roadway surface, and the Angle of the bottom corner anchor cable is 15˚; The exposed length of the anchor cable shall be ≤300 mm, and the preload of the anchor cable shall not be less than 300 kN.

4) The roof and the anchor cables of the two sides are connected by double steel joists (double steel ladder beams).

5) Thin layer shotcrete anti-weathering and anti-rust: After the roof and the long anchor cable of the two sides are installed, in order to prevent the weathering of surrounding rock and the corrosion of the supporting structure, 10mm thick layer of cement mortar is sprayed to just cover the supporting components.

6) On the basis of grouting reinforcement of the bottom plate, the anchor cable bundle and I-beam support of the bottom plate are implemented. The cable bundle is made of 3 × φ21.8 mm × L10,300 mm high-strength steel strand, with three-hole locks or three-hole trays and single locks, and the row distance between them is 1400 mm × 1500 mm. The bottom of the cable bundle is anchored with ordinary cement grouting, and the grouting depth is 4 m. The end of the anchor cable bundle is connected with I-beam and laid with double-layer steel mesh. The pretension force of the cable bundle is 450 kN, and the pretension

force of each steel strand is not less than 150 kN. After the cable bundle is tensioned, the cable bundle is reinforced by high pressure grouting. After the construction is completed, the bottom plate is poured with concrete and closed and hardened to improve the toughness and strength of the protective structure.

6. Surrounding Rock Control Effect

According to the technical parameters of strong dynamic pressure roadway support, the roadway in the disrepair section of 1105 roadway in Hudi Coal Industry was applied on site. In the later stage, the laser range finder and the borehole peeper were used to monitor the deformation of the roadway and the grouting effect.

6.1. Roadway Surface Displacement Monitoring

The layout of the station: a station is set up every 100 m, and a total of 4 stations are arranged in the test section; in each station, the cross point method is used to observe, that is, one measuring point is arranged in the middle of the roof, floor and two sides, which is used to observe the relative convergence and convergence speed of the roof, floor and two sides.

Observation method: using laser range finder to measure the distance between two relative measuring points; observation 3 times a week, when the roadway deformation speed is faster, the number of observations should be increased accordingly; after the roadway deformation is stable, it can be reduced to 1 - 2 times a week.

6.2. Grouting Effect Drilling Peep

In order to adjust the grouting pressure and other grouting parameters in time, the drilling peep instrument is mainly used to monitor the seepage and consolidation of the slurry. The peephole is arranged in the middle of the roof, two sides and the floor. The depth of the peephole is 10 m, and the peephole is peeped by the borehole peeper.

6.3. Observation Effect Analysis

The borehole peeping of the roof and side of the roadway is carried out. The results of the borehole peeping of the surrounding rock cracks are shown in **Figure 5**. The surrounding rock has slight deformation in the range of 0.5 m, and the integrity of the surrounding rock in the depth of 1m is good, and no obvious crack development is observed. Overall, the surrounding rock control effect is good.

According to the technical parameters of roadway support under strong dynamic pressure, the roadway of lane 1105 in disrepair section of Hudi Coal Industry is applied in the field and the deformation of the roadway is continuously monitored. The observation results show that the deformation of roadway surrounding rock has been effectively controlled after construction, the roof

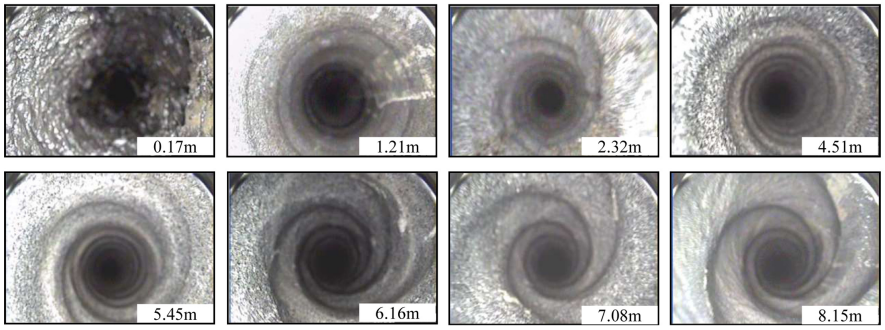


Figure 5. Surrounding rock fracture drilling peep.

Figure 6. Deformation control effect of lane 1105.

subsidence is less than 80 mm, the relative movement of two walls is less than 110 mm, and the stability of surrounding rock has been significantly improved (**Figure 6**).

7. Conclusions

1) Lane 1105 is mainly affected by multiple strong stresses, and the surrounding rock of the roadway has serious deformation and failure. a) Deep high ground stress: The buried depth of lane 1105 is about 700 m, which belongs to deep roadway, and the maximum formation principal stress reaches more than 20 MPa; b) Significant structural stress: Section 10# Hengchuan to 1306 bottom pumping roadway of Lane 1105 is located at the synclinal axis of Panjiazhuang. The synclinal structure causes the stress concentration in the surrounding rock of Lane 1105, and the structural stress has a great influence on the stability of the roadway. c) Influence of mining stress: When the distance between the 1309 (top) mining face and the stop-mining line remains 35 m, the influence of dynamic pressure is severe, resulting in serious deformation of the roadway in this section.

2) The structural characteristics and mechanical characteristics of the surrounding rock of the roadway lead to serious deformation and damage of the surrounding rock: a) The surrounding rock of the roadway is a "cross-layer" structure, which makes it easy to deformation and damage along the bedding plane, and the surrounding rock control is more difficult. b) The surrounding

rock of the roadway is weak. Under the action of deep high stress, the surrounding rock shows significant plastic flow deformation, resulting in a significant increase in the deformation of the roadway. c) Roadway surrounding rock cracks are developed, the strength is very low, and the deformation resistance is very poor.

3) In order to reduce the deformation of the surrounding rock of lane 1105, the bearing structure of the surrounding rock in the deep and shallow parts of the roadway with strong dynamic pressure is strengthened at multiple levels through the technologies of "roof collaborative support, layered grouting, anchor cable bundle floor support, and lane surface sealing and hardening", and the deformation and failure of the surrounding rock of the roadway are effectively controlled.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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