Study on Controlling Technology for Surrounding Rock in Withdrawal Channel of Full-Mechanized Caving Mining with Large Mining Height Face of Super High Seam

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Abstract. In order to solve the problems such as serious damage of the withdrawal channel and wall caving of tunnel side at end mining stage of 21604 fully-mechanized caving mining face of Huangyuchuan coal mine, study the deformation of surrounding rock of the withdrawal channel in 21604 working face and the law of destruction based on a large number of measured field data; the results show that when the working face is 10 m away from the withdrawal channel, the maximum roof subsidence is 300 mm, and the axial force of roof anchor rod reaches 52 kN, exceeding the anchoring force of anchor rod (50 kN); when it is 5 m away from the withdrawal channel, the maximum roof subsidence is 610 mm, and the axial force of side anchor rod reaches the peak value of 48 kN; when the working face passes through the withdrawal channel, the borehole stress meter reaches the peak value of 22 MPa, the withdrawal channel is seriously damaged, and the depth of tunnel side wall caving reaches 700 mm at maximum. According to the deformation characteristics of the surrounding rock of withdrawal channel, it is proposed to adopt the grouting reinforcement for the mining side and the anchor mesh cable combined with reinforced support for the non mining side and roof on the basis of the original support. It has been successfully applied in 21605 working face, and the support effect is remarkable.

1. Introduction
Along with the gradual increase of coal mining intensity, the general application of the coal mining methods of fully-mechanized caving mining, large mining height, and fully-mechanized caving mining with large mining height, the working face replacement is an integral part in the actual production process of the mine, and moving the inverted face is the first task of the working face replacement, which is also a necessary link for high efficiency and high yield of the working face [1-3]. However, since the fully-mechanized caving equipment is heavy and huge, the withdrawal cycle of working face equipment has become an important factor restricting the working face replacement [4-5]. In addition, the withdrawal channel is an important channel for the withdrawal of fully-mechanized caving mining equipment. After the fully-mechanized caving mining working face enters the end mining stage, the extension of plastic zone of surrounding rock is large, the advanced bearing pressure is remarkable, the phenomenon of roof breakage, floor heave, wall caving, etc. occur frequently, and the withdrawal channels of some mines even have the phenomenon of roof falling, which not only threatens the safety of underground workers, but also harm the safe withdrawal of equipment [6-8].
For the stability control of surrounding rock in the withdrawal channel of working face, many experts and scholars have conducted in-depth study on this issue. Zhuo Junyong [9] proposed the scheme of single withdrawal for the problem that the time of equipment withdrawal is long for the withdrawal channel of stop line near the fault of fully-mechanized caving face with large mining height; for the problems that the roof stability of large mining height working face is poor and the deformation of surrounding rock is serious, Xie Fuxing [10] studied the stability of surrounding rock structure by establishing the mechanical model and other research methods; for the problem that the deformation of withdrawal channel of fully-mechanized caving face in shallow coal seam is large, Yang Shang [11] analyzed the stability of surrounding rock of the withdrawal channel by establishing the mechanical model of anchor beam structure; Zhou Huizhen [12] studied the asymmetric deformation of withdrawal channel in the large mining height working face to conclude that the interval coal pillar should not be less than 4.1 m; for the influence of high stress dynamic load effect produced at end mining stage of Yunnan Dali deep well, Wang Yuequan [13] adopts the hydraulic pressure relief technology for withdrawal channel to weaken the roof rock stratum of working face, reduce the roof overhanging area of the end mining stage, and delay the surrounding rock deformation of the withdrawal channel.

In summary, most researches on withdrawal channels are based on the theoretical analysis, physical experiment, establishment of mechanical models, and numerical simulation to study the deformation and instability mechanism of surrounding rock of withdrawal channel. The feasible support scheme is put forward, which improves the stability of the withdrawal channel. However, the geological conditions are different and their deformation laws are different, so the specific deformation laws can be determined only from the actual measurement to carry out targeted support design. Therefore, the author takes 21604 working face of Huangyuchuan coal mine as the engineering background, uses the methods of field monitoring analysis and field investigation to analyze the stability of surrounding rock in the withdrawal channel of 21604 working face, and puts forward the reinforced support technology of anchor mesh cable for the withdrawal channel, which has been successfully applied in 21605 working face and effectively controlled the surrounding rock deformation of the withdrawal channel.

2. General situation of working face

The 21604 fully-mechanized caving face in the Huangyuchuan coal mine is located in the second level and the first panel. The inclined length of working face is 250 m and the average propulsion length is 1186.5 m. The design mining height of working face is 3.7 m, the average coal thickness is 11.2 m, the thickness of caving coal is 7.5 m, the mining and drawing ratio is 1:2.02, the volume weight is 1.4 t/m³, and the average buried depth of coal seam is 269 m; the main withdrawal channel of 21604 working face adopts pseudo oblique arrangement, in which the tail is 13 m ahead of the nose. Pre-excavate the double withdrawal channel, and the interval between the main and auxiliary withdrawal channels is 20 m. The tunnel height of main withdrawal channel is 3.8-4.2 m, and there are few undulating slope change points in the tunnel, making the tunnel smooth generally. Being affected by mining, the wall caving of side wall of tunnel mining is serious. The roof consists of fine sandstone, coarse sandstone, medium-grained sandstone, and coarse sandstone, The floor is composed of mudstone and siltstone.

3. Study on deformation law of surrounding rock of withdrawal channel under the influence of dynamic pressure at end mining stage

3.1. Layout of surrounding rock stress monitoring of withdrawal channel

The field mine pressure monitoring items at end mining stage of 21604 working face mainly include: monitoring on the roof and tunnel side anchor rod and anchor cable force; monitoring on the tunnel side coal stress; monitoring on the working resistance of fully-mechanized caving support in working face at the end mining stage; racking support pressure statistics and column settlement in the
withdrawal channel.

3.1.1 Layout of anchor rod axial force monitoring station.
Set up seven anchor stress monitoring stations in the target tunnel of 21604 working face, and arrange four monitoring substations in the main withdrawal channel, which are Stations 1, 2, 3 and 4; arrange two monitoring substations in the auxiliary withdrawal channel, which are Station 5 and 6 (Figure 1 shows the layout of the station); Station 7 is arranged in the return air duct; each monitoring station is a tunnel section, and each anchor rod dynamometer needs to be re-installed with a new anchor rod. The anchor rod drilling, anchor rod parameters, and installation mode are the same as the original tunnel support scheme.

3.1.2 Layout of borehole stress sensor monitoring station.
Set up four borehole stress monitoring stations near the main and auxiliary withdrawal channels in front of the stop line in 21604 working face, and arrange two monitoring substations in the main withdrawal channel, which are Station 9 and 10; Station 8 is arranged in the return air duct near the withdrawal channel; Station 11 is arranged in the auxiliary withdrawal channel. Station 8, 9, 10 and 11 monitoring stations are all installed on the tunnel mining side, which are used to monitor the coal pillar stress state (the width of protective coal pillar in the withdrawal channel is 20 m). Figure 2 shows the layout of borehole stress monitoring.

Drilling parameters: each stress monitoring substation connects two borehole stress meters, and the buried depths of stress meters are 4 m and 6 m respectively. The interval of borehole stress meters in the station is 2 m and the borehole diameter is 42 mm.

3.2 Monitoring and analysis of surrounding rock stress in withdrawal channel

3.2.1 Analysis of anchor rod stress change
Figure 3 Variation curve of anchor rod axial force in main withdrawal channel of 21604 face

Figure 3 shows the axial force variation curve of anchor rod in the main withdrawal channel of 21604 working face; the analysis of the Figure shows that: the distance between the working face and the main withdrawal channel becomes smaller, and the axial force of anchor rod in the main withdrawal channel presents a gradual increasing trend; when the working face is 30 m away from the main withdrawal channel, the axial force of the roof and tunnel side anchor rod begins to increase slowly; when the working face is 20 m away from the main withdrawal channel, the increasing rate of the anchor rod axial force increases remarkably; when the working face is 10 m away from the main withdrawal channel, the axial force of roof anchor rod reaches 52 kN, exceeding the design value (50 kN) of roof anchor rod anchoring force in the Huangyuchuan coal mine. The axial force of working face anchor rod reaches the peak value of 48 kN when the working face is 5 m away from the main withdrawal channel, which is close to the design value of anchoring force (50 kN). The anchoring force of coal pillar side anchor rod shows an increasing trend as the distance between the working face and the main withdrawal channel decreases. However, the increasing range is always low, and the maximum anchoring force is 29 kN.

Figure 4 shows the variation curve of anchor rod axial force in the auxiliary withdrawal channel of 21604 working face; analysis of the Figure shows that the maximum axial force of the roof and side anchor rods in the auxiliary withdrawal channel is distributed about 30 m away from the auxiliary withdrawal channel, which are 14 kN and 23 kN respectively. As the working face gradually approaches the auxiliary withdrawal channel, the anchor rod axial force has an increasing trend.
3.2.2 Analysis of borehole stress variation

Figure 5 shows the variation curve of borehole stress monitoring of return air duct; analysis of the Figure shows that the stress value at 6 m of the borehole stress meter in 21604 working face is larger than that at 4 m. As the distance between the working face and the main withdrawal channel decreases, the mining side stress of the return air gateway gradually increases. When the distance between the working face and the monitoring point is 50-20 m, the stress value presents a slow increasing trend; when the distance between the working face and the monitoring point is 20-5 m, the mining side stress of return air gateway increases remarkably, from 5 to 14 MPa.

Figure 6 shows the variation curve of borehole stress monitoring in the main withdrawal channel;
analysis of the Figure shows that when the distance between the working face and the monitoring point is more than 20 m, the side stress value of the working face in the main withdrawal channel presents an slow increasing trend as the distance decreases, but the increasing rate is always low. When the working face is 20-0 m away from the main withdrawal channel, the monitored pressure value in the stress meter begins to increase remarkably. When the working face is about to connected with the main withdrawal channel, the pressure is the maximum, which is 22 Mpa.

3.2.3 Analysis on stability of surrounding rock in withdrawal channel at end mining stage

Set up an observation point at a distance of 50 m within 200 m in the main withdrawal channel of 21604 face. Start recording data when the working face is 50 m away from the withdrawal channel. Observe it twice a day. Analyze the surrounding rock pressure and deformation by manually observing the racking column table data.

Figure 7 shows the statistics of column subsidence in 21604 main withdrawal channel; analysis of the Figure shows that the working face is basically not affected by mining when it is 50 m away from the withdrawal channel; the working face begins to be affected by mining when it is 30 m away from the withdrawal channel. As the working face gradually advances, the distance to the withdrawal channel becomes closer and closer, and the settlement of racking column gradually increases, from the initial 32 mm to 610 mm when the working face is 5 m away from the withdrawal channel, indicating that now the withdrawal channel is strongly affected by mining.

The field monitoring and field investigation shows that: when the working face is pushed to 10-5 m away from the withdrawal channel, the pressure of withdrawal channel increases remarkably, the column sinks relatively rapid, the overall subsidence of the withdrawal channel roof is large, the roof anchor cable (rod) collapses, and the wall caving of the mining side of withdrawal channel is serious. The maximum depth of wall caving reaches 700 mm. Parts of the support side thread steel anchor tray collapses, and the tunnel deformation is serious.

Figure 8 is the variation curve of tunnel side convergence of the main withdrawal channel; the Figure shows that before the working face is 30 m away from the main withdrawal channel, the tunnel side deformations of the withdrawal channel are less affected by mining, which are kept within 50 mm; when the working face is 20 m away from the withdrawal channel, the affection from mining on tunnel side begins to increase; when the working face is 5-0 m away from the withdrawal channel, the increase of deformation of the surrounding rock in the withdrawal channel is most remarkable; when the working face is connected with the withdrawal channel, the tunnel side convergences of each monitoring point are 200 mm, 345 mm, 300 mm and 430 mm respectively.

In the auxiliary withdrawal channel, there is no obvious roof subsidence, the floor is partially cracked, and both sides have no obvious bulge. The floor heaves of the combined tunnel between the main and auxiliary withdrawal channels are 50-200 mm, and there is no obvious roof subsidence and bulge.

![Figure 7 Statistics of racking column settlement in main withdrawal channel](image_url)
4. Optimal design of surrounding rock support for withdrawal channel of 21605 working face

4.1 Original support scheme of withdrawal channel

In order to ensure the safe withdrawal of equipment in the working face, it is very important to control the stability of surrounding rock in the withdrawal stage. The field monitoring shows that the closer the working face is to the withdrawal channel, the more serious the surrounding rock damage is. The surrounding rock damage of the channel roof, especially near the coal wall, is most serious. The plastic zone range of the channel surrounding rock continuously expands, which intensifies the deformation of withdrawal channel. Therefore, it is an urgent need for a reinforcement technology to maintain the stability of the tunnel. In this case, the withdrawal channel roof adopts the support with anchor rod + double wire mesh + cable + π steel belt, the mining side adopts the glass fiber reinforced plastic anchor rod + double high strength polyester mesh, and the non mining side adopts the support with thread steel anchor rod + double wire mesh.

The layout of the withdrawal channel section support. The top part adopts the steel strand cable with φ 22×8000 mm and a row spacing of 1.6 m and the thread steel anchor rod with φ 20×2200 mm and a row spacing of 800 mm; the side part adopts the thread steel anchor rod with φ 20×2200 mm and a row spacing of 800 mm and φ 27 × 2400 mm and a row spacing of 800 mm.

4.2 Design of reinforced support for withdrawal channel

The field monitoring and analysis show that the problems that the roof settlement of main withdrawal channel 21604 working face is large, the convergence of two sides is large, the racking column settlement is large, the wall caving of mining side is serious, and the convergence of top and bottom plate of return air duct near the main withdrawal channel is large are outstanding. In order to strengthen the stability of surrounding rock, the design of reinforced support for the withdrawal channel is proposed. The scheme is as follows:

4.2.1 Grouting reinforcement of mining side

As the mining side of withdrawal channel is significantly affected by mining, start drilling to the mining side when 21604 working face is pushed to 140 m away from the withdrawal channel. The drilling parameters are: the hole depth is 8 m, the row spacing is 6 m and 1.5 m respectively. When drilling, tilt up 5-12 ° to allow the drilling water to flow out of the hole, and then start grouting. The main material of slurry is Marithan.

4.2.2 Reinforced support of non mining side

Add two rows of side cable + W steel belt for the non mining side, adopting the φ 22×5000 mm cable with row spacing of 2.2 m and adopting the φ 22×2400 mm thread steel anchor rod with design
anchoring force of 70 kN, with anchoring end of 500 mm, four sets per row, row spacing 1100 × 1100 mm, and lay the double-layer wire mesh. 4.2.3 Roof reinforced support

On the basis of the original support, add one φ 28 × 8000 mm anchor cable in the middle of anchor cables on the roof of the main withdrawal channel to reinforce the support for the roof of the withdrawal channel. Select the φ 22 × 2400 mm thread steel anchor rod with design anchoring force of 70 kN for the roof anchor rod, with anchor end of 500 mm, three sets per row, and row spacing of 1100 mm × 1600 mm.

5. Field application

5.1 Application of optimized support design in withdrawal channel of 21605 face

Figure 9 shows the statistics of racking support subsidence of 21605 working face; it can be found: when the working face is 5 m away from the main withdrawal channel, the subsidence of the column begins to decrease remarkably (the maximum subsidence is 320 mm), compared with the subsidence of 610 mm in the withdrawal channel of 21604 face, the support effect is significant.
Figure 10 shows the convergence of the tunnel side of withdrawal channel, it can be found: before 21605 extraction working face is 50 m away from the withdrawal channel, the deformation of tunnel side is within 15 mm; when the working face is 20 m away from the withdrawal channel, the deformation of the surrounding rock of tunnel side increases remarkably. Obviously, the mining stress has begun to affect the tunnel side; when the working face is 5-0 m away from the withdrawal channel, the deformation of the surrounding rock of withdrawal channel increases most remarkably; after the working face is connected with the withdrawal channel, the convergence of the tunnel side of withdrawal channel at each monitoring point is 42 mm, 125 mm, 150 mm and 63 mm respectively.

5.2 Analysis and evaluation of support effect

![Figure 11 Comparison of maximum reduction of racking support in main withdrawal channel](image1)

![Figure 12 Comparison of roof subsidence of main withdrawal channel](image2)
Figure 13 Comparison of convergence of tunnel side of main withdrawal channel

Figure 11 shows the comparison of the maximum settlement of racking support in the main withdrawal channel, Figure 12 shows the comparison of the roof subsidence of main withdrawal channel, and Figure 13 shows the comparison of the convergence of tunnel side in the main withdrawal channel.

After the support optimization measures are implemented for the main withdrawal channel of 21605 working face, the racking support settlement, roof subsidence and tunnel side convergence are significantly reduced compared with 21604 working face, and the effect of surrounding rock control is obviously better than the support scheme for the withdrawal channel of 21604 working face; the results show that the surrounding rock grouting reinforcement, reinforced roof support, reinforced tunnel side support, advanced support of crossheading near the main withdrawal channel and other technical measures for optimization of surrounding rock control can ensure the stability of the surrounding rock of withdrawal channel and the safe and rapid withdrawal of equipment in the working face.

6. Conclusion

Through the field monitoring technology of stress meter, the deformation law of surrounding rock of withdrawal channel is obtained. When the working face is 20 m away from the withdrawal channel, the increasing rate of axial force of anchor rod increases remarkably, and the influence strength of advance bearing pressure increases; at 10 m, the maximum subsidence of roof is 300 mm, the axial force of roof anchor rod exceeds the anchor force, which is 52 kN, and the influence of mining force on the withdrawal channel is intensified; at 5-0 m, the maximum subsidence of roof is 610 mm, the axial force of anchor rod on the side reaches 48 kN, and the withdrawal channel is significantly affected by mining.

The on-site monitoring analysis and field investigation show that when 21604 working face is pushed to 10-5 m away from the withdrawal channel, the racking column sinks rapidly and the subsidence is large, the roof anchor cable (rod) part collapses, and the wall caving on the mining side of withdrawal channel is serious, the maximum wall caving depth reaches 700 mm, parts of the side support thread steel anchor tray collapses, and the deformation of tunnel is serious; when the working face is connected with the withdrawal channel, the convergence of tunnel side at each monitoring point is 200 mm, 345 mm, 300 mm and 430 mm respectively.

In view of the deformation characteristics of surrounding rock of withdrawal channel in 21604 working face, follow the support principle of "roof and coal column side", author of the article proposes the reinforcement technology for the surrounding rock of withdrawal channel at end mining stage based on the original support, which has been applied in 21605 working face. Through the comparative evaluation of surrounding rock support effect of 21604 and 21605 working faces, the
feasibility of surrounding rock reinforcement technology is fully verified.

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