Journal of Civil Engineering and Urban Planning (2025) **DOI: 10.23977/jceup.2025.070105**
Clausius Scientific Press, Canada **ISSN 2616-3969 Vol. 7 Num. 1**

Deformation Characteristics and Control Technology of Surrounding Rock of Roof Cutting Retaining Roadway in Extremely Soft Thick Seam of Xinyi Coal Mine

Guang Yang[1,a,*], Mian Wang[2,b], Liuqun Du[3,c], Bing Yuan[3,d], Wei Chen[3,e]

[1]*College of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo, 454001, Henan, China*
[2]*Yimei Coal Industry Group, Xin'an County Yunding Coal Industry Co., Ltd., Luoyang, 471000, Henan, China*
[3]*Yimei Group Xinyi Mining Co., Ltd, Luoyang, 471000, Henan, China*
[a]*2963746597@qq.com*, [b]*Clumsy914@163.com.com*, [c]*2109793407@qq.com*, [d]*wanganxin2580@163.com*, [e]*2099938614@qq.com*
[*]*Corresponding author*

Keywords: Extremely Soft Thick Seam; Roof Cutting and Entry Retaining; Deformation Characteristics of Surrounding Rock; Control Technology of Retaining Roadway

Abstract: In this study, we address the challenges of high dynamic pressure and difficulties in roadway retention in extremely soft and thick coal seams with a Protodyakonov coefficient of 0.35. Taking the 12060 working face of Xinyi Mine as a case study, we employ FLAC3D numerical simulation software to analyze the deformation characteristics of surrounding rock during roof-cutting and roadway retention in extremely soft and thick coal seams. This analysis is based on the roof deflection formula for different regions, and we propose a surrounding rock control technology that integrates roof-cutting and pressure relief along the roof. The results indicate that the influence range of advanced mining on the roadway is approximately 30 m. The boundary of the limit equilibrium zone on both sides of the roadway extends more than 5 m into the coal body, which reduces the supporting effect of the shallow coal side on the roadway roof. This reduction leads to compressive deformation of the sidewalls due to roof pressure. Furthermore, the results demonstrate that the roof layer, after roof-cutting and roadway retention, forms a cantilever beam structure, resulting in significantly larger deformation on the goaf side compared to the solid coal side. Consequently, the roof bends horizontally toward the goaf direction. In this study, we implement directional blasting for roof-cutting and active advanced support technology. Anchor beams are utilized to enhance the support strength of the solid coal roadway side. In addition, dense long anchor cables and hydraulic lifting sheds are installed near the cutting seam on the goaf side to control lateral roof deformation and assist in roof-cutting. These measures effectively mitigate the lateral bending deformation of the roof.

1. Introduction

The directional pre-splitting and pressure relief technology for the roof can artificially shift the fracture zone of the basic roof in the gob-side roadway toward the goaf side, thereby optimizing the stress distribution in the surrounding rock and enhancing the structural integrity of the roof [1]. This approach not only improves the coal recovery rate but also alleviates the conflict between mining and excavation continuity, yielding significant economic and social benefits. Roadways in soft coal seams are characterized by low coal strength, rapid deformation of the surrounding rock, and extensive failure zones [2]. In major coal-producing provinces and regions in China, soft coal mines account for over 50% of the total number of mines, with mines in extremely soft coal seams comprising approximately 6% of the total [3]. Consequently, given the widespread adoption of the cutting-roof pressure relief gob-side roadway technology, there is an urgent need to investigate the deformation mechanisms and control technologies for surrounding rock in cutting-roof gob-side roadways under extremely soft geological conditions.

Coal can be classified into four categories based on the firmness coefficient: extremely soft, soft, medium-hard, and hard. Extremely soft coal, specifically, has a firmness coefficient of less than 0.5 [6]. The soft and low-strength nature of the coal body is the primary cause of severe deformation and structural failure in coal roadways. To address the challenges associated with gob-side roadway construction under such conditions, extensive theoretical and experimental research has been conducted by domestic and international experts. For instance, Wang Kai and Kang Zhipeng [7-8] investigated the deformation characteristics of surrounding rock in gob-side roadways and proposed key support technologies for controlling deformation during the mining of weak, thick coal seams. Ge Leisong [9] introduced a combined support cutting-roof roadway technology for 3.5 m-thick coal seams, which is particularly significant for mitigating coal scarcity in the southwestern region. Zhang Sheng [10], using the Liangbei Mine as a case study, established a mechanical model to analyze the stability of surrounding rock in advance sections before and after roof pre-splitting, subsequently proposing an active anchor-cable beam collaborative anchoring scheme. Wang Dongpan and Sha Xuan [11-12] focused on severe deformation and support challenges in thick coal seams. Through numerical simulations and structural-stress analysis of the surrounding rock, they redesigned the roadway support system and proposed a "support-relief" collaborative control strategy, coupled with a support scheme employing flexible concrete molds and high-strength materials. Additionally, Huang Qingxiang, Wang Pu, and Wang Yuyang [13-15] conducted comprehensive studies on the deformation characteristics of the roof, floor, and overall surrounding rock in soft coal roadways with thicknesses ranging from 1.5 m to 3 m.

In summary, existing research has predominantly addressed challenges related to gob-side roadways in weak coal seams with thicknesses below 3.5 m. However, the deformation characteristics of roof surrounding rock and corresponding support technologies for extremely soft and thick coal seams (≥3.5 m) remain underexplored, necessitating further in-depth investigation. This study focuses on the 12060 working face of the Xinyi Mine, analyzing the deformation characteristics of surrounding rock in gob-side roadways under cutting-roof pressure relief technology within extremely soft and thick coal seams. Furthermore, it proposes key support technologies for gob-side roadways, which has been successfully implemented in field applications.

2. Engineering Overview

Xinyi Mining Co., Ltd. is located approximately 7 km north of Xin'an County, Henan Province, within the administrative jurisdiction of Zhengcun Township and Tiemen Town, Xin'an County. The 12060 working face is situated in the western section of the mine's 12th mining area. The coal seam exhibits an inclination ranging from 2.5 ° to 14.5 °, with an average of 6 °, and a dip angle of 1 ° along the strike direction. The depth of the coal seam varies between 580 m and 720 m, with an average depth of 650 m, indicating deep mining conditions. The thickness of the coal seam demonstrates significant heterogeneity, ranging from 0.1 m to 10.6 m, with an average thickness of 4.2 m. The Pomeranz brittleness coefficient of the coal is 0.35. The original support design is illustrated in Figure 1.

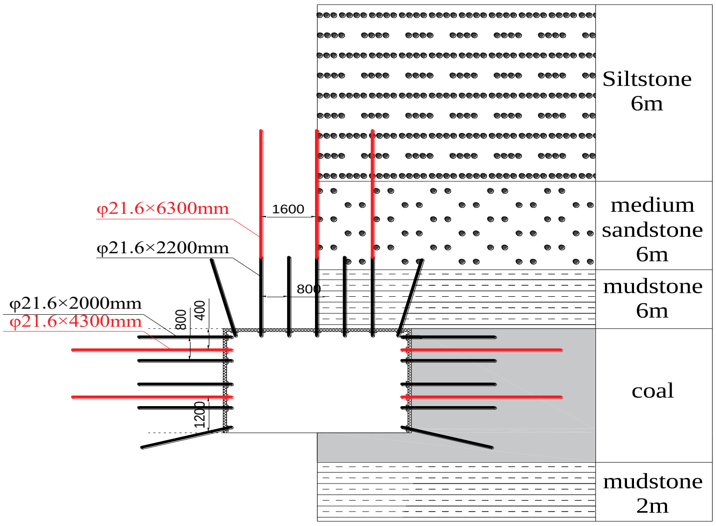


Fig.1 Rock stratum histogram and original support of roadway

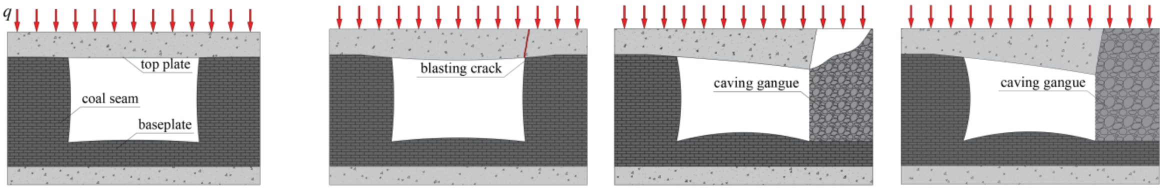
3. Evolution and Deformation Analysis of Surrounding Rock at Different Stages

To address mining-induced pressure issues during the roof cutting and pressure relief process, advanced strengthening support measures are implemented along the roadway within the "Advanced Strengthening Support Zone." This zone is located within the range of advanced support pressure but has not yet undergone blasting cutting operations. In this region, the roof structure remains intact, with solid coal pillars providing support on both sides, resulting in a two-end fixed support structure, as illustrated in Figure 2(a).

Once the strengthening support operation is completed and the working face progresses, the roadway construction enters the drilling and blasting cutting phase, referred to as the "Blasting Cutting Zone." After blasting, the roof transitions from a continuous state to a fractured state. Due to the inclined angle of the cutting seam, the solid coal pillars continue to support the roof, changing the roof structure from a fixed-fixed beam to a fixed-free structure, as shown in Figure 2(b).

As the working face continues to advance, the solid coal layer near the goaf is removed, and the roof in the goaf area gradually collapses under mining pressure. Owing to the time-dependent nature of the collapse, the roof does not immediately undergo complete collapse; only the shallow roof layers experience instability and collapse, forming a void near the roof. This results in a gradual loss of roof stability. During this phase, the roof structure transitions from a fixed-free beam to a cantilever beam structure, as depicted in Figure 2(c).

As the working face progresses further, the roof continues to collapse, and the caved gangue gradually fills the goaf. Simultaneously, the roadway exits the high-stress area, and the gangue begins to support the overlying roof, stabilizing the roof structure. Over time, the gangue's support role strengthens until it reaches a stable state. During this phase, the support strength can be gradually reduced. The roof structure is illustrated in Figure 2(d).



(a) Strengthened support area (b) Blasting slit area (c) Delayed support zone (d) Stable roadway zone

Fig.2 Roof structure in different stages of roof cutting pressure relief roadway retaining technology

4. Simulation Analysis of Deformation Characteristics of Surrounding Rock in Extremely Soft Thick Coal Seam

4.1 Numerical Model and Experimental Design

A numerical simulation model is constructed using FLAC3D software, based on the spatial distribution characteristics of the coal and rock layers in the 12060 working face. The model dimensions are set to 200 m × 100 m × 70 m, with fixed displacement boundary conditions applied to the sides and bottom of the model and stress boundary conditions applied to the top.

4.2 Simulation Results Analysis

4.2.1 Analysis of Surrounding Rock Deformation Characteristics

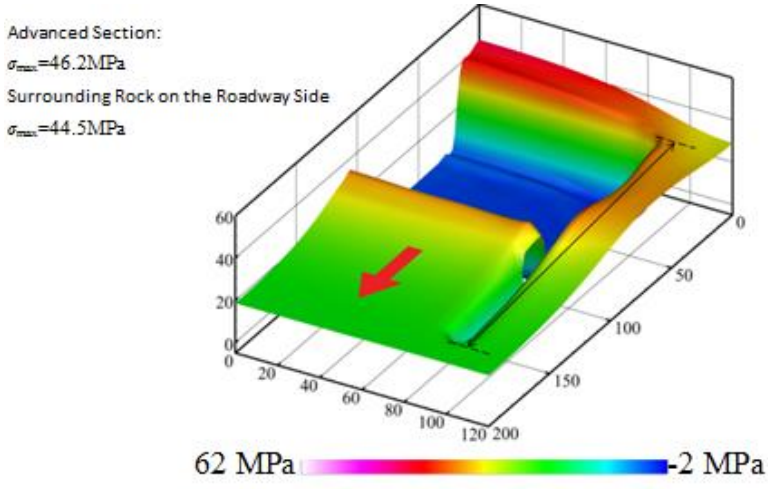


Fig.3 Stress distribution diagram of the roof of the working face

The stress distribution of the roof at the working face, obtained from numerical simulations, is shown in Figure 3. As can be seen, the shallow coal body on the upper side of the extremely soft coal roadway experiences nearly zero vertical stress, indicating that the shallow coal body has already undergone failure and is no longer providing adequate support to the roadway roof.

The deformation of the roof of the extremely soft coal roadway at different distances from the working face is shown in Figure 4. From Figure 4, it is observed that as the working face retreats, the peak vertical displacement of the roadway roof gradually shifts toward the cutting seam area. After the face retreats, the vertical displacement at the cutting seam increases sharply, and the subsequent peak displacement remains at the cutting seam. The displacement difference between the two ends of the roof continues to increase. When the face lags by 1 meter, the roof subsidence at the cutting seam side is 9 mm, while at the upper side, it is 4 mm, resulting in an overall bending of the roof of approximately 0°. After 20 meters of lag, the subsidence at the cutting seam side increases to 193 mm, while the upper side remains at 6 mm, and the overall bending of the roof reaches 2.21°. After 40 meters of lag, the subsidence at the cutting seam side increases to 329 mm, with an overall roof bending of 3.43°. The analysis shows that the roadway exhibits asymmetric deformation characteristics.

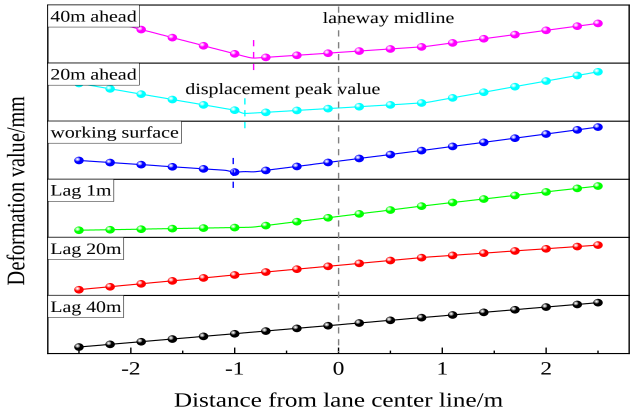


Fig.4 Vertical displacement of the roadway roof

4.2.2 Analysis of Surrounding Rock Deformation Mechanism

The deformation data of the roof in the delayed section of the roadway is shown in Figure 5. After the retreat of the working face, the roof in the delayed section of the roadway exhibits a non-linear subsidence trend along the width of the roadway. Under the conditions of extremely soft coal with a Pomeroy coefficient of 0.35, the critical deformation line of the roof is located 5.4 meters deep into the coal body on the side. This phenomenon occurs due to the low strength of the coal seam, which causes the stress to reach the peak strength of the coal body, resulting in plastic deformation and failure. Consequently, the plastic failure zone extends deeper into the side of the roadway, reducing the support effect of the shallow coal body on the roof and causing the critical deformation line of the roof to shift deeper into the coal body. As a result, the bending degree of the roof increases, making the surrounding rock more prone to bending and instability.

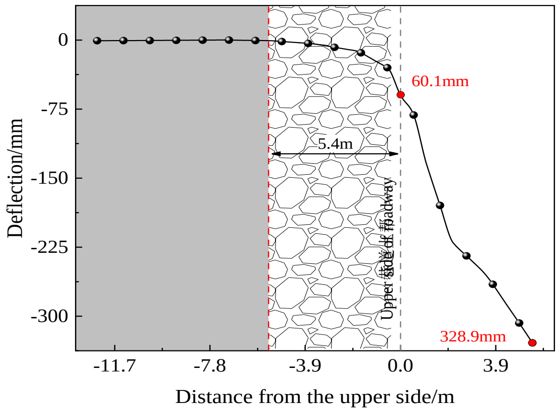


Fig.5 Vertical displacement of lagging section roof

In the roadway, the roof deformation on the upper side is 60.1 mm, while on the lower side, it is 328.9 mm. The maximum bending deformation of the roof near the goaf side in the retained roadway is 5.4 times greater than that near the solid coal side.

5. Application of Surrounding Rock Control Technology for Roadway Retaining in Extremely Soft Coal Seams

5.1 Design of Support Compensation Parameters in the Strengthening Support Zone

Both sides of the roadway in the strengthening support zone consist of intact coal. During this phase, the roof demonstrates a two-end fixed condition, representing the most stable state with minimal deformation in the roadway retention process. However, the shallow coal in the roadway sidewalls is susceptible to failure and support loss. The anchor bolt support extends to a depth of 2.2 m, whereas the anchor cable support reaches 6.3 m in depth. This configuration is inadequate for effectively anchoring the shallow unstable rock layers to the deeper, more stable strata. The initial support density of anchors and cables measures only 0.47 anchors/m^2, which proves insufficient to prevent plastic deformation of the roof during the advancement of the working face. Therefore, supplemental support is necessary to enhance the stability of the surrounding rock mass.

To ensure proper anchoring of the shallow rock layers to the deep, stable strata and to maintain the stability of the surrounding rock during construction, the anchoring end of the anchor cables must be secured within the deep, stable rock layers. According to the actual distribution of roof rock layers at the 12060 belt crossheading, the minimum effective length of the anchor cables should be 7.5 meters.

The required length of the reinforcing anchor cables can be calculated using the following equation:

$$l_s = l_{s1} + l_{s2} \tag{1}$$

Where:

$$l_{s1} = R_0\left[\frac{(\sigma_0 + C\cot\varphi)(1-\sin\varphi)}{C\cot\varphi}\right]^{\frac{1-\sin\varphi}{2\sin\varphi}} \tag{2}$$

The optimal spacing between anchor cables can be determined through the following theoretical formula:

$$\alpha\beta < \frac{F}{k l_{s1} \gamma} \tag{3}$$

In Equations (1)-(3), ls represents the design length of the anchor cable; ls1 denotes the effective length; ls2 indicates the anchoring length; k is the safety factor; α represents the spacing between anchor cables; β corresponds to the distance between cables; F stands for the designed prestress of the cable; γ is the unit weight of the rock mass; Rp refers to the surrounding rock loosened range; Ro indicates the radius of the external arc of the roadway; σ0 represents the self-weight stress of the rock mass; c denotes the cohesion of the rock mass; and φ signifies the internal friction angle of the rock mass.

The calculations yield ls = 8 m, which satisfies the objective of stabilizing the shallow roof strata by anchoring them into the deeper, stable strata. Since the maximum roof deformation in the delayed temporary support zone occurs at the cut-seam section of the roadway, an additional row of reinforcement anchor cables (Φ21.6 mm × 10,000 mm) has been installed near the cut-seam area to maintain roof stability and minimize vertical displacement. This reinforcement measure effectively supports the roadway roof. The observed roof bending and subsidence at 5.4 m from the coal body indicate that the support provided by the coal rib to the roof decreases within this range. Therefore, a row of anchor cables (Φ21.6 mm × 6,300 mm) has been installed on the upper rib of the roadway. No additional reinforcement is required for the lower rib, as it is located on the mining side.

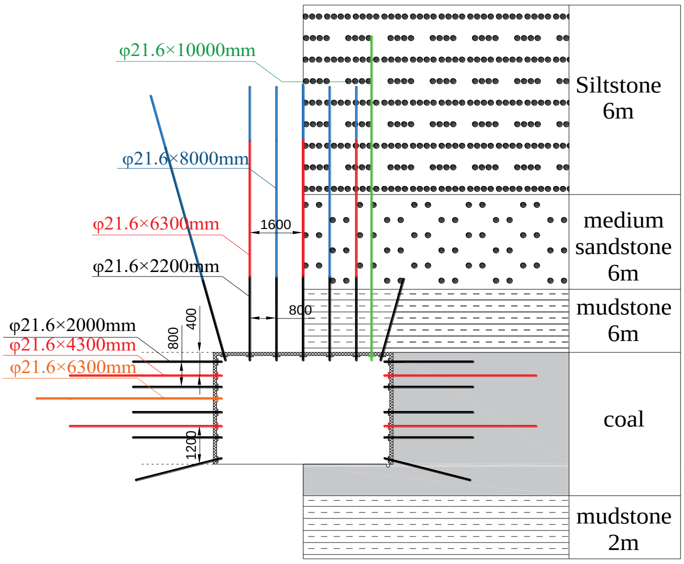


Fig.6 Roadway strengthening support diagram

The final reinforcement support plan incorporates a row of short anchor cables (Φ21.6 mm × 6,300 mm) installed on the upper rib, with a spacing of 800 mm and a row distance of 900 mm. In addition to the existing anchor cable support system for the roadway roof, supplementary anchor cables (Φ21.6 mm × 8,000 mm) are implemented. These reinforcement anchor cables, combined with the original support cables, create an array configuration with a spacing of 800 mm × 900 mm. In the vicinity of the cut-seam area, reinforcement anchor cables (Φ21.6 mm × 10,000 mm) are installed in conjunction with anchor cable beams, as depicted in Figure 6. Upon completion of the reinforcement anchor cable installation, the support density increases from 0.47 cables/m ^{2} to 2.22 cables/m ^{2}. The implemented reinforcement anchor cables effectively unify the shallow 2 m mudstone layer, the 3 m medium sandstone layer, and the deeper 6 m siltstone layer into an integrated structural system, thereby significantly improving the stability of the roof strata.

5.2 Support Parameters Design for the Blasting Cutting Zone

As the working face advances progressively, the solid coal pillars on the lower side undergo plastic deformation, culminating in structural failure and subsequent loss of their roof-supporting capacity. During this transitional phase, the roof structure transforms into a fixed-free beam configuration. Field monitoring data indicate that as the distance to the working face diminishes, the point of maximum vertical roof displacement shifts progressively from the roadway center toward the cutting seam. With ongoing face advancement, the roof stability exhibits progressive deterioration. To mitigate deformation in the roof-surrounding rock mass, passive support systems are deployed to preserve roadway roof integrity and maintain surrounding rock stability.

In the blasting cutting zone, hydraulic roof supports are employed for passive reinforcement. To ensure effective implementation of the roof cutting process, the temporary support zone is positioned within a 0–30 meter range ahead of the working face. Based on comprehensive geological assessments, the hydraulic roof support system is operated at an initial support pressure of 24 MPa to achieve optimal roof stability, as demonstrated in Figure 7.

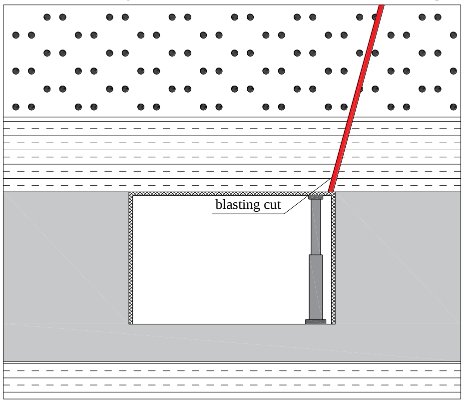


Fig.7 Temporary support design of blasting kerf area

5.3 Delayed Support Zone: Support Scheme and Parameter Design

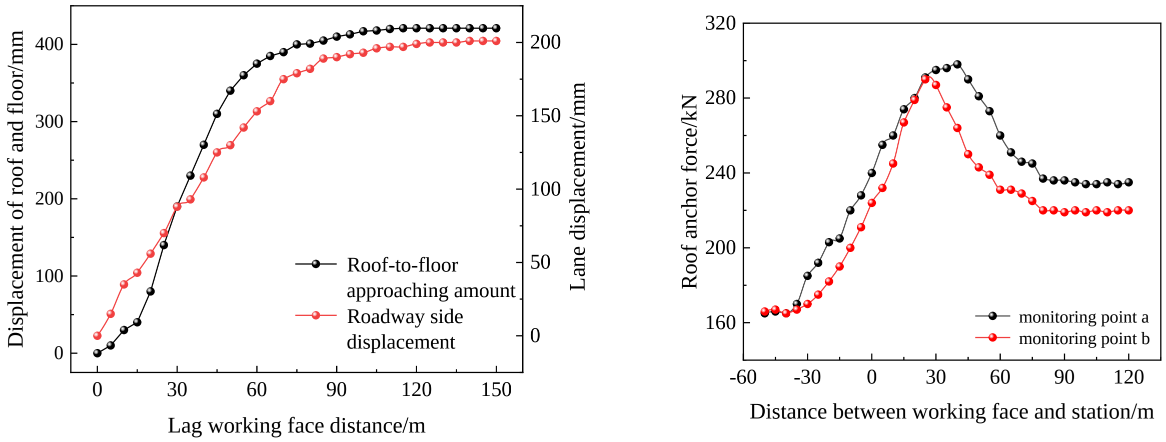
After the working face retreats, the solid coal pillars on the lower side disappear, and the roof structure completely transitions to a cantilever beam structure. During this phase, the roof is in its least stable and most deformable state. Therefore, to address roof deformation, hydraulic roof supports are installed for reinforcement. The design adopts the ZD2200/20/47 hydraulic lifting support, with a maximum lifting height of 4700 mm and a column diameter of 200 mm. Initially, a row of hydraulic supports is placed along the cutting seam, and two rows of hydraulic supports are installed when the roof begins to fracture, with an initial pressure of 24 MPa.

6. On-Site Application Results

On-site monitoring of the retaining section includes monitoring the anchor cable force, roof, and sidewall deformation. The monitoring data are shown in Figure 8. Figure 8(a) shows the deformation data of the surrounding rock in the retaining section. It is observed that when the delayed working face starts, the surrounding rock begins to deform. Between 0–30 meters, the deformation rate of the roof and sidewalls accelerates. The displacement of the roof increases from 0 mm to 200 mm, with a deformation rate of 6.67 mm/day. This indicates that the roof is moving significantly, and the roadway is subjected to the high-stress zone. Between 30–50 meters, the deformation rate of the roof and sidewalls stabilizes, and between 50–120 meters, the deformation rate slows down. This is because the collapsed roof in the goaf gradually fills the goaf and starts to support the roof, while the roadway exits the high-stress zone, causing the deformation rate to decrease.

Figure 8(b) shows the anchor cable stress data in the gob-side roadway. The data monitoring system uses the Uroca online monitoring system, with monitoring points set along the centerline of the roadway. The stress values of the roof anchor cables are monitored, starting from the self-stopping mining line. An anchor cable stress meter is installed every 100 meters. The data shown in the figure are obtained from the monitoring instruments at the 6th (monitoring point a) and 7th (monitoring point b) meters. From Figure 8(b), it can be seen that at approximately 30 m ahead of the working face, the anchor cable stress begins to increase from 160 kN. When the working face advances 30–40 m past the monitoring point, the anchor cable stress reaches its maximum value of 300 kN. This increase is due to roof fracture and collapse during this stage, causing a sharp increase in anchor cable stress. After the working face moves 40 m past the monitoring point, the anchor cable stress rapidly declines as the roof on the goaf side gradually collapses and consolidates. When the working face is about 100 m behind, the anchor cable stress stabilizes at around 230 kN, indicating that at this point, the roof on the goaf side has fully collapsed and compacted along the pre-split face.

After the cutting roof pressure relief and reinforcement support are implemented, the maximum convergence of the roadway roof is approximately 410 mm, and the maximum convergence of the rib is approximately 200 mm.



(a) Surrounding rock displacement curve (b) Anchor cable stress monitoring

Fig.8 Data curve of lagging section roadwa

From the analysis of the surrounding rock deformation curve, it can be seen that under the stress from the roof on the goaf side, the roof collapses along the blasting cut-seam, and the roof pressure is effectively relieved. During the cutting roof and gob-side roadway construction period, the surrounding rock deformation is maintained within an acceptable range.

After the cutting roof and gob-side roadway construction at the 12060 conveyor roadway, the final cross-sectional dimensions of the roadway are approximately 5,000 mm × 3,200 mm, indicating a 15.4% reduction in area compared to the original cross-section. This demonstrates that after the implementation of cutting roof gob-side roadway control technology and reinforcement support, the overall deformation of the surrounding rock is effectively managed, and the gob-side roadway is successfully retained, meeting the requirements for the next working face.

7. Conclusion

(1) When retaining the roadway in an extremely soft coal seam, the shallow coal body on the roadway side struggles to support the roof pressure under the influence of dynamic pressure. The boundary of the limit equilibrium zone shifts significantly toward the deeper part of the side, often exceeding the anchoring range of the side bolt (short anchor cable). This results in the bending and sinking critical line of the roof transferring to the deeper part of the solid coal. Consequently, the support effect of the shallow coal side on the roadway roof is reduced, and the side is subjected to squeezing deformation due to the roof pressure. The average displacement change rate of the roof in the lag range is 8.22 mm/m, indicating rapid deformation. The differential displacement between the two ends of the roof is large, and the deformation is highly asymmetric.

(2) Based on FLAC3D simulation software combined with field monitoring, the deformation characteristics of the surrounding rock in the extremely soft and thick coal roadway are obtained. The roof in the lagging area of the retained roadway exhibits a cantilever beam structure. Due to the reduced lateral restraint effect of the retained roadway, the roadway as a whole displays asymmetric

deformation characteristics, with the largest rotational deformation occurring near the roof of the goaf.

(3) A comprehensive support technology for soft thick coal seam roof cutting and roadway retention is proposed, which includes two-way directional pre-splitting blasting technology, active strengthening support in the roadway, adding a row of long anchor cables along the cutting line, inclined U-shaped steel roadway side support, hydraulic lifting shed temporary support, and roadway side support. This technology has been successfully applied in the 12060 working face of Xinyi Coal Mine, and the maximum shrinkage rate of the roadway section area is 15.4% after achieving roadway stability.

References

[1] He Manchao, Chen Shangyuan, Guo Zhibiao, et al. Control of surrounding rock structure for gob-side entry retaining by cutting roof to release pressure and its engineering application[J]. Journal of China University of Mining & Technology, 2017, 46(05): 959−969.

[2] Wang Xingkai, Xie Wenbing, Jing Shengguo, et al. Experimental study on large deformation control mechanism of surrounding rock of extremely loose coal roadway in gliding tectonics area[J]. Chinese Journal of Rock Mechanics and Engineering, 2018, 37(2):312-324.

[3] Lei Shun, Gao Fuqiang, Wang Xiaoqing. Research on statistics and classification of uniaxial compressive strength of coal bodies[J]. Coal Science and Technology, 2021, 49(3):64-70.

[4] CAO Qinghua, YANG Yuefei, CHEN Huiming, et al. Numerical simulation of advanced anchor cable active reinforcement and support in deep gob side entry retaining[J]. China Mining Magazine, 2023,32(4):133-139.

[5] Zhang Sheng, Wang Xiaoliang, Wu Ziqiang, et al. Status analysis of the key parameters of blasting borehole and the retaining effect for gobside entry retaining by the way of roof cutting and pressure releasing[J]. Journal of Henan Polytechnic University(Natural Science), 2019,38(6):1-9.

[6] Li Mingxuan. Analysis on Mechanical Property of Metal Mesh in Extremely Soft Coal Roadway[D]. Xuzhou: China University of Mining and Technology, 2022.

[7] Wang Kai, Yang Baogui, Wang Pengyu, et al. Deformation and failure characteristics of gob-side entry retaining in soft and thick coal seam and the control technology[J]. Rock and Soil Mechanics, 2022, 43 (07): 1913-1924+1960.

[8] Kang Zhipeng, Duan Changrui, Yu Guofeng, et al. Analysis on deformation characteristics of surrounding rock of gob-side entry retaining with soft bottom in thick coal seam and strengthening support technology of roof and side[J]. Journal of Mine Automation, 2022, 48(11):101-109.

[9] Ge Leisong, Liu Yanxiang, Chen Dachan, et al. Research and Application of Roof Cutting and Pressure Relief Along Goaf [J]. Mineral Engineering Research, 2020, 35(01):20-25.

[10] Zhang Sheng, Xu Ruize, Liu Jiawei, et al. Research on active advanced support technology for gob-side entry retaining with roof cutting and pressure relief in ultra-soft coal seam[J]. Journal of Henan Polytechnic University(Natural Science), 1-13 [2024-11-30].

[11] Wang Dongpan, Yang Hongzhi, Yuan Weiming, et al. A "support and pressure relief" ground control technology for double-used roadway with fully-mechanized caving method in thick coal seam[J]. Journal of Mining and Strata Control Engineering. 2022, 4(04): 32-42.

[12] Sha Xuan, Chu Xiaowei. Comprehensive control technology of surrounding rock for gob-side entry retaining in thick coal seam [J]. Coal Science and Technology, 2019, 47(11):76-83.

[13] Huang Qingheng, Dong Bolin, Chen Guohong et al. Failure Mechanism of Entry in Steep Soft Seam and Bolting Design[J]. Journal of Mining & Safety Engineering, 2006, (03):333-336.

[14] Wang Pu, Zhang Baisheng, Wang Lei, et al. Research on roof falling mechanism and support technology of mining roadway in expansive soft rock[J]. Journal of Mining and Strata Control Engineering, 2020, 2(02):57-65.

[15] Wang Yuyang, Liu Yong, Wang Chen, et al. Optimization and application research of soft rock roadway support scheme based on AHP[J]. Journal of Mining and Strata Control Engineering, 2020, 2(02):40-48.