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Research on Anti-Leakage Measures for Fully Mechanized Mining Faces in Gently Inclined Thin Coal Seams

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Abstract: Aiming at the rock fragment leakage caused by small dip angle of coal seam, limited mining height, and poor stability of roof and floor in gently inclined thin coal seams of fully mechanized mining faces, this study systematically analyzed the causes of leakage and proposed comprehensive prevention measures based on the engineering background of the 31101 working face in Lu Ning Coal Industry. The research revealed that the leakage primarily resulted from stress imbalance between the upper and lower parts of the working face, misalignment between the end support and transition support (1.0m), and concentrated pressure at the tail end. By optimizing roadway layout (avoiding overlying coal pillars), ensuring the flatness of roof and floor, enhancing the initial support force of hydraulic supports, strictly controlling mining height, and designing a novel anti-leakage device (including components such as sliding channels, sliders, and high-elasticity rubber plates), the adaptability issues of traditional rock-blocking devices in thin coal seams were effectively resolved. Field tests demonstrated that the leakage rate decreased from 95% to 10% after improvements, significantly improving mining efficiency and ensuring personnel safety. The findings provide technical support for the safe and efficient mining of gently inclined thin coal seams, offering significant engineering application value.

Keywords: Gently inclined thin coal seam; fully mechanized mining face; rock fragment leakage prevention; hydraulic support; anti-leakage device.

1. Introductory

With the gradual extension of coal resource mining in China to areas with complex geological conditions, gently inclined thin coal seams have become one of the challenges for efficient coal mining due to their unique occurrence conditions. During the advancement of fully mechanized mining faces, factors such as the dip angle of the coal seam, limited mining height, and poor stability of the roof and floor often lead to the leakage of rock fragments. The intrusion of these fragments into the operating space of the shearer and the transportation system not only accelerates equipment wear and reduces mining efficiency but may also cause safety hazards such as chain jams and bunker blockages, even endangering workers' safety. Therefore, researching rock fragment prevention measures suitable for inclined thin coal seams is of great significance for ensuring safe and efficient mining.

Currently, scholars both domestically and internationally have conducted extensive research on rock fragment prevention measures for fully mechanized mining faces. For instance, Liu et al. analyzed the influencing factors, motion trajectories, and interactions between flying rock fragments and the working face caused by roof water leakage based on the actual conditions of a specific working face[1]. Lei et al. investigated the current situation and influencing factors of rock fragment spalling in fully mechanized mining faces with soft and unstable coal seams, adopting comprehensive prevention measures to reduce the probability of spalling[2]. Wang et al. addressed potential issues such as inter-support rock fragment leakage and coal dust dispersion in ultra-high mining height faces by developing a rock fragment prevention device, which was applied on-site and significantly reduced the risk of leakage[3]. In summary, research on rock fragment prevention measures for medium-thick coal seams is relatively mature. However, these technologies are less effective when directly applied to inclined thin coal seams. On one hand, the narrow space in thin coal seams makes it difficult to adapt the structural dimensions of traditional rock-blocking devices. On the other hand, the variability in roof and floor lithology and the randomness of rock fragment leakage volume and motion trajectories further increase the difficulty of prevention and control. Therefore, there is an urgent need to design rock fragment prevention measures suitable for gently inclined thin coal seams, which is crucial for ensuring the safe and efficient recovery of such coal seams.

2. Mine Overview

2.1. Working Face Overview

The 31101 working face of Lu Ning Coal Industry Co., Ltd. has a strike length of 750 meters and a dip length of 159 meters (net coal wall). The average thickness of the minable coal seam is 1.6 meters, with a bulk density of 1.33 t/m³, and the minable reserves are approximately 190,800 tons. The mine employs the fully mechanized mining method to extract the entire seam height in a single pass. Above the working face, there are six goaf areas: 21104, 21102, 21103, 21101, 21303, and 21303. The layout is illustrated in Figure 1.

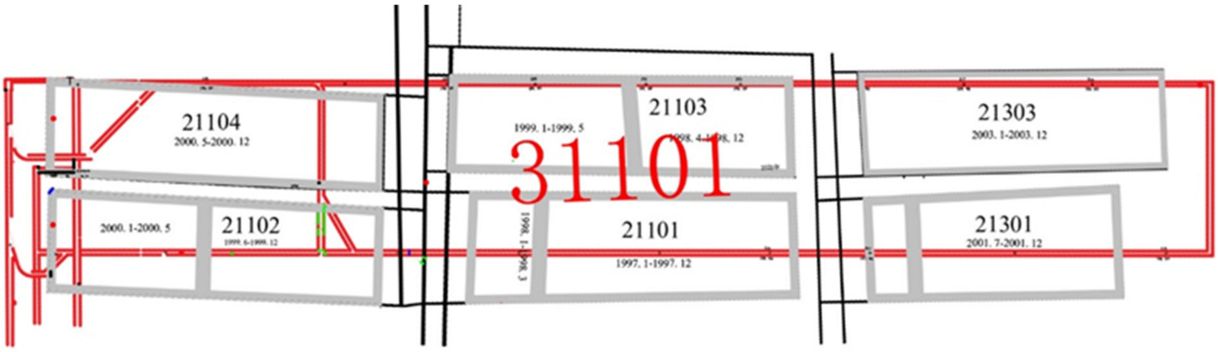

Figure 1. Correspondence Diagram of the 31101 Working Face and the No. 2 Coal Seam

When the working face roadway is excavated along the floor of the coal seam, there is a significant misalignment between the tail-end support and the transition support. During the advancement of the working face, this misalignment leads to severe leakage of coal and rock fragments from the roof. Such leakage not only hinders the normal progress of the working face but also poses a threat to the safety of personnel. Therefore, there is an urgent need for a rock fragment control device suitable for the large misalignment of hydraulic supports at the ends of fully mechanized mining faces in thin coal seams to ensure the safety and efficiency of the working face.

2.2. Causes of Rock Fragment Leakage

The locations of rock fragment leakage in the 31101 working face are shown in Figure 2. The causes of leakage are analyzed as follows:

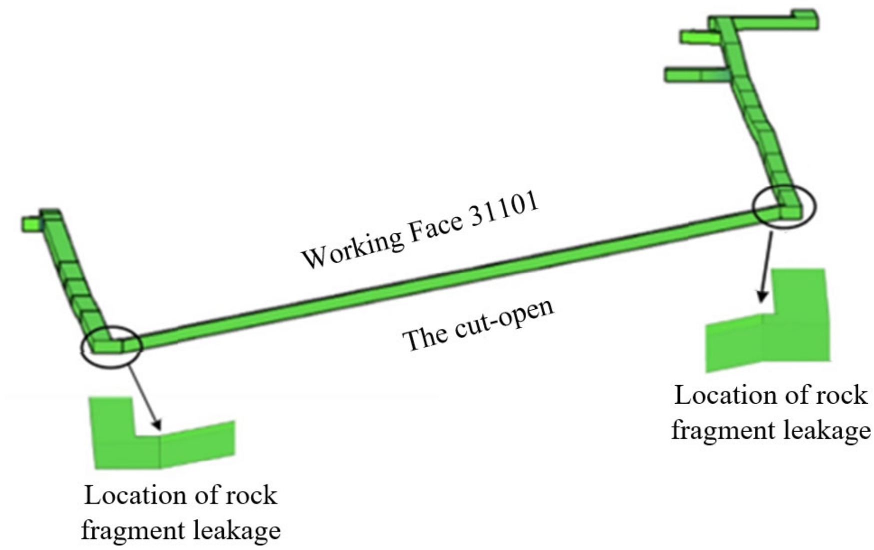

Figure 2. Schematic Diagram of Rock Fragment Leakage in the 31101 Working Face

(1) Loss of Stress Balance Between Upper and Lower Strata: Before being disturbed by mining activities, the coal body is in a state of triaxial stress, with equal and opposite forces acting on it. As a result, the coal body and the surrounding rock strata remain relatively stable. However, as the longwall face advances, the integrity of the coal body is disrupted by the shearer, leaving the roof of the coal seam in a suspended state. Depending on the lithology of the roof and the conditions of the coal seam, varying degrees of roof displacement and failure occur.

(2) Misalignment of Hydraulic Supports: The ventilation roadway of the working face is excavated along the floor of the coal seam, with a height of 2.3 meters. There is a 1.0-meter misalignment between the tail-end support and the transition support, as shown in Figure 3. During the advancement of the working face, this significant misalignment leads to severe roof leakage of rock fragments, hindering normal progress.

(3) Concentration of Pressure at the Tail End: The tail end of the 31101 working face is located near the coal pillar of the No. 2 coal seam, as shown in Figure 4. Analysis of mine pressure distribution indicates that the central rear section of the working face is a prominent pressure center, where the pressure is the highest. The pressure on other supports decreases radially from this central support.

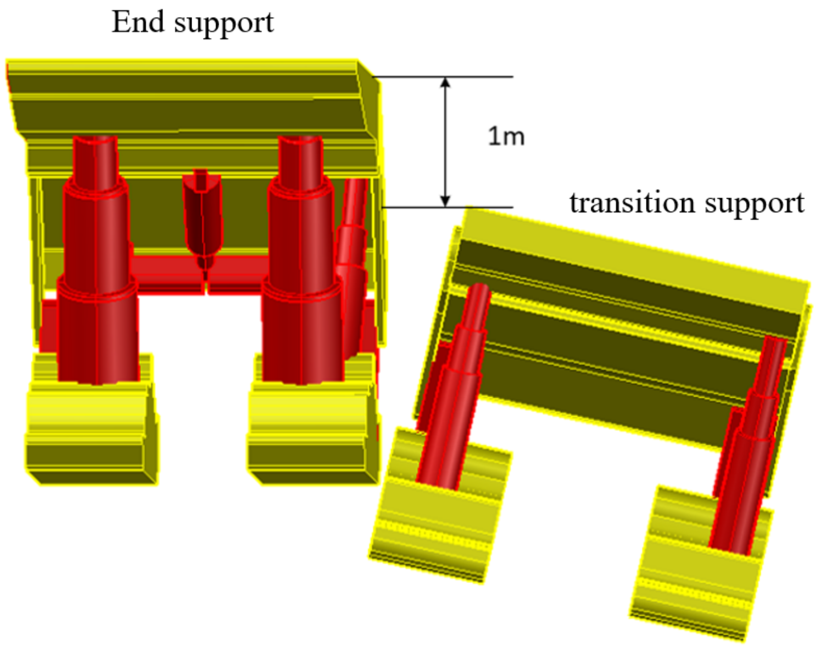

Figure 3. Schematic Diagram of Support Misalignment

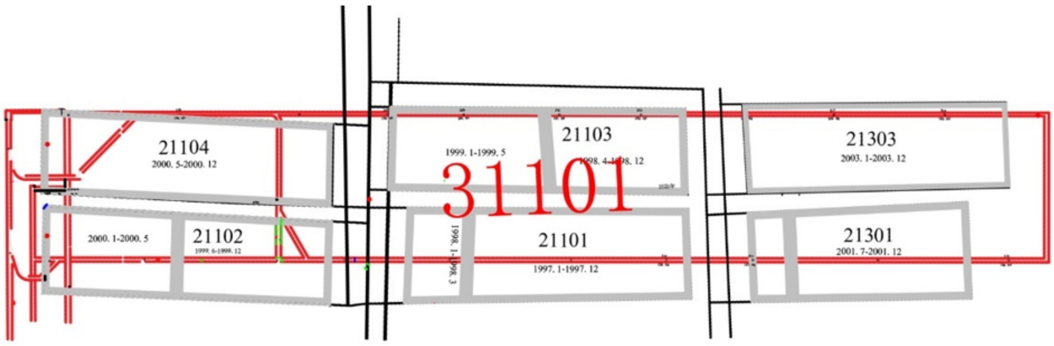

Figure 4. Stratigraphic Relationship Between the 31101 Working Face and the No. 2 Coal Seam

3. Research on Rock Fragment Leakage Prevention Measures for Gently Inclined Thin Coal Seams

3.1. Preventive Measures

(1) Roadway Layout:

From a preventive perspective, the method of roadway layout is proposed. Compared to other areas, the pressure concentrated at the roof is relatively higher[4]. If uncontrolled, roof collapse may occur. In contrast to the pressure-bearing capacity of other regions, the pressure at the roof concentration point will significantly increase, potentially leading to uncontrolled roof collapse.

The locations of the goaf areas in the No. 3 and No. 2 coal seams are shown in Figure 5. Considering the relationship between the mining of the upper and lower coal seams, in the subsequent roadway layout of the working face, the roadways of the lower coal seam should ideally be positioned at the center of the upper coal seam working face and should avoid being placed directly below the coal pillars of the upper seam. The advantage of this approach is that it reduces the roof pressure on the working face, significantly improving the issue of rock fragment leakage at the tail end.

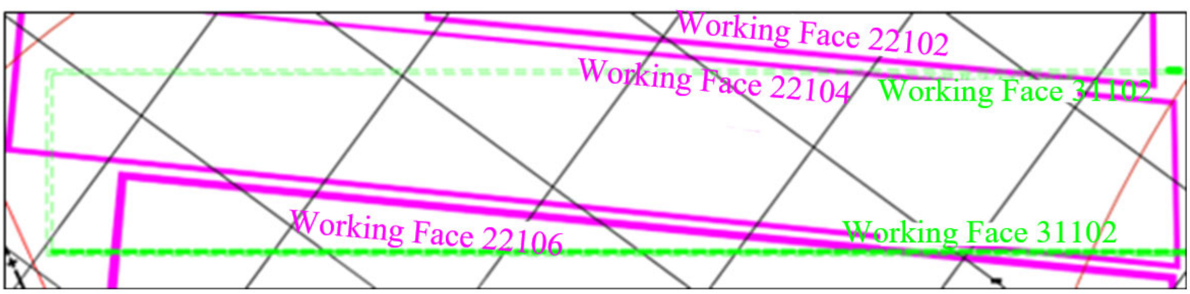

Figure 5. Stratigraphic Relationship Between the No. 3 and No. 2 Coal Seams

(2) Ensure the Flatness of the Roof and Floor at the Tail End:

The flatness of the roof and floor significantly affects the stability of hydraulic supports. If the roof and floor are uneven, it may lead to uneven force distribution and unstable support, resulting in rock fragment leakage under high roof pressure. Therefore, it is essential to maintain the flatness and levelness of the roof and floor in the working face, especially at the junctions of cutting marks. Steps and significant undulations should be minimized. Additionally, the effectiveness of hydraulic support is influenced by its structural design. Supports with poor roof contact or tilting should be adjusted promptly to prevent tilting or collapse. This measure is equally necessary to address roof leakage caused by insufficient support strength.

(3) Ensure the Initial Support Force of Hydraulic Supports:

Sufficient initial support force and rated working resistance of hydraulic supports are critical measures to ensure roof stability and prevent rock fragment leakage, and they should be given due attention. At the same time, the rationality of the support structure and the condition of the roof contact with the support canopy must be continuously monitored to ensure effective support. The hydraulic support is illustrated in Figure 6.

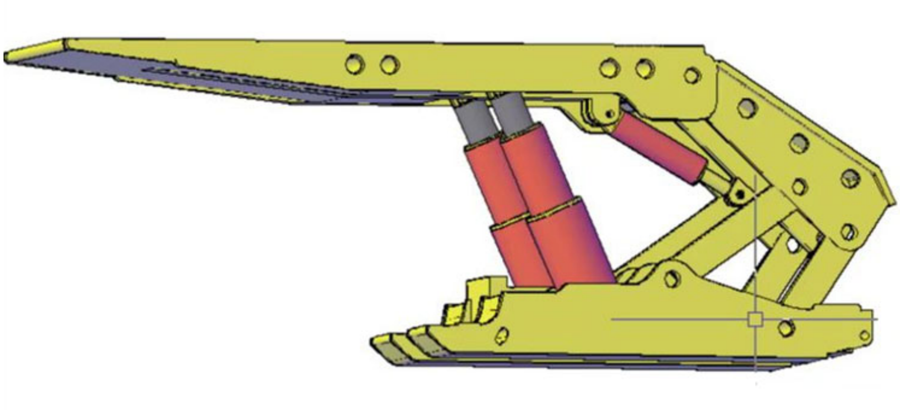

Figure 6. Schematic Diagram of Hydraulic Support

Strengthening ground pressure monitoring and hydraulic system management is crucial, as the stability of the roof in fully mechanized mining faces largely depends on the initial support force and rated working resistance of the hydraulic supports. Insufficient initial support force and working resistance can lead to roof displacement due to lack of stable support under mining disturbances. During this process, the immediate roof may separate under the influence of its own weight and disturbance forces. As this effect intensifies, it can eventually cause the roof bedrock to shear along its full thickness, resulting in dynamic loads and subsidence at the roof steps of the working face. Therefore, during coal seam mining, it is essential to ensure the initial support force of the hydraulic supports to provide reliable adjustment capabilities. Additionally, maintenance of the hydraulic system must be strengthened to prevent leaks and ensure the emulsion concentration is maintained within the range of 4% to 5%, guaranteeing the support strength of the hydraulic system.

(4) Strictly Control the Mining Height:

It has been observed in production that the canopy-to-face distance of hydraulic supports varies significantly across different mining height ranges, with smaller variations within a certain height range. Therefore, during production, the maximum mining height should be determined based on the optimal canopy-to-face distance of the hydraulic supports to ensure good support strength, enhance roof control, and prevent rock fragment leakage.

3.2. Design Measures

Use a Rock Fragment Control Device to Address Tail-End Leakage, as shown in Figures 7, 8, 9, and 10.

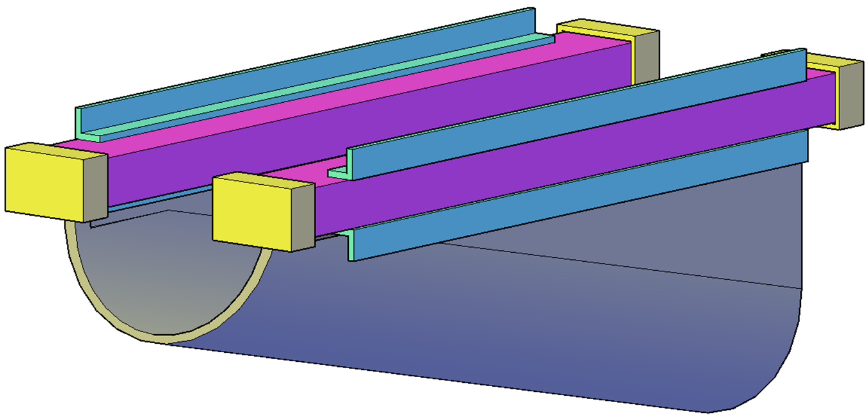

Figure 7. Installation Schematic of the Rock Fragment Control Device

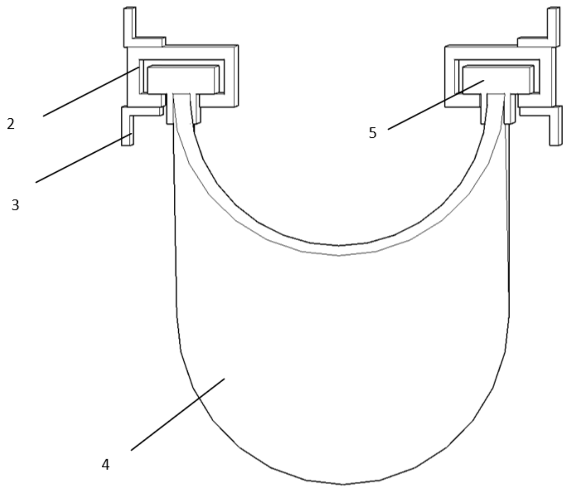

Figure 8. Front View of the Rock Fragment Control Device

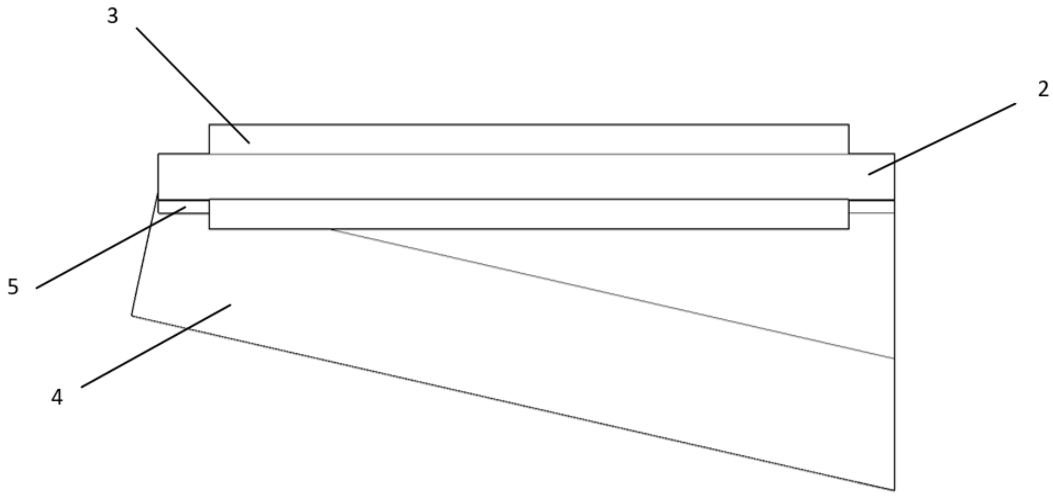

Figure 9. Side View of the Rock Fragment Control Device

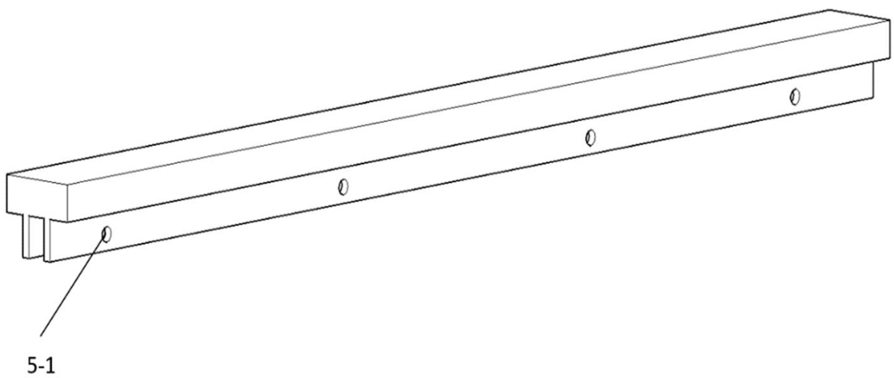

Figure 10. Structural Diagram of the Rock Fragment Control Device

As shown in the figures, Figure 7 illustrates the installation schematic of the rock fragment control device for the large misalignment of hydraulic supports at the ends of fully mechanized mining faces in thin coal seams. The device includes a cover, right-angle iron plates, sliding channels, sliders, high-elasticity rubber plates, and rubber covers. One end of the right-angle iron plate is welded to the sliding channel, while the other end is welded to the hydraulic support.

The length of the slider and the high-elasticity rubber plate is slightly shorter than that of the sliding channel. The rubber covers are tightly fitted to both ends of the sliding channel using rubber elasticity to prevent the slider from detaching during the movement of the hydraulic support.

As shown in Figure 8, the front view of the rock fragment control device, the width of the right-angle iron plate slightly exceeds that of the sliding channel, facilitating the sealing of the sliding channel by the rubber covers.

As shown in Figures 8 and 9, the side view of the rock fragment control device, the high-elasticity rubber plate has a "U"-shaped structure when viewed from the front and a trapezoidal structure when viewed from the side. The rear opening of the high-elasticity rubber plate is larger, and its inclination angle is greater than the angle of repose of coal and rock fragments. Due to this inclination, the coal and rock fragments can slide along the rubber plate to the rear of the hydraulic support, preventing long-term accumulation and extending the service life of the rubber plate.

As shown in Figure 10, the structural diagram of the slider in the rock fragment control device, the slider consists of upper and lower parts. The upper part is a rectangular block, while the lower part comprises two smaller rectangular blocks with a gap in between, equal to the width of the high-elasticity rubber plate. The lower part of the slider is equipped with multiple bolt holes for securing the rubber plate. When the rubber plate is damaged, it can be replaced by removing the bolts. The structure is simple, and the installation and removal are convenient.

4. Effectiveness Verification

The test was conducted at the 31101 working face of the No. 3 coal seam in Lu Ning Coal Industry. Anti-leakage measures were implemented on the hydraulic supports at the ends of the working face, and the results are shown in Table 1.

Table 1. Effectiveness of Anti-Leakage Measures

Problem Type	Before Improvement	After Improvement	Effect
Roof Rock Fragment Leakage	Steel plate device (leakage rate ~95%)	Anti-leakage device and measures (leakage rate ~10%)	Leakage rate reduced by ~85%

From the table, it can be seen that the leakage rate of rock fragments in the working face was as high as 95% when using the steel plate device. After adopting the independently developed anti-leakage device and measures, the leakage rate was reduced to 10%, effectively blocking roof rock fragments in the 31101 working face. This has played a significant role in improving the recovery efficiency of the working face and ensuring personnel safety.

5. Conclusions

(1) The causes of rock fragment leakage in the 31101 working face of Lu Ning Coal Industry Co., Ltd. were analyzed. The causes include: Stress imbalance between the upper and lower parts of the working face; A 1-meter misalignment between the tail-end support and the transition support; The return airway of the working face being located near the coal pillar of the No. 2 coal seam, where stress is concentrated.

(2) Anti-leakage measures were studied, including: Arranging the working face roadways to avoid overlying coal pillars; Ensuring the flatness of the roof and floor; Guaranteeing the initial support force of hydraulic supports; Strictly controlling the mining height; Implementing the anti-leakage device.

(3) An anti-leakage device was designed, which includes a cover, right-angle iron plates, sliding channels, sliders, high-elasticity rubber plates, and rubber covers. This device can effectively prevent rock fragments from sliding into the working face, ensuring worker safety and efficient recovery of the working face.

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