2016

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Publication Details

Hong-wei Zhang, Xing FU and Yu-zhi Shen, Study on Rib Spalling Mechanism and Spalling Depth in Large Mining Height Fully-Mechanized Face, in Naj Aziz and Bob Kininmonth (eds.), Proceedings of the 16th Coal Operators' Conference, Mining Engineering, University of Wollongong, 10-12 February 2016, 204-212.

STUDY ON RIB SPALLING MECHANISM AND SPALLING DEPTH IN LARGE MINING HEIGHT FULLY-MECHANIZED FACE

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Abstract: Due to the influence of the high intensity mining operation in the Shendong mining area located in Ordos City, Inner Mongolia Region of China, the problem of rib spalling in large mining height and fully-mechanized working face production is increasingly becoming more serious. The occurrence and location of the maximum depth of rib spalling is studied inthe 12301 working face of Shangwan coal mine in the Shendong mining area taken as an example. The comprehensive methods of theoretical analysis, numerical simulation and field studies are adopted in this study. The gradual deterioration characteristics of rib spalling was studied using the 'thin plate' mechanical model of the working face and the empirical equation. The study showed that the rib instability was generally located below the roof at the position of 0.578 times of the mining height. The theoretical calculation showed that the maximum depth of rib spalling was 0.98 m~1.61 m at the 12301 working face, and the initial rib spalling started 2.53 m below the roof, which is basically consistent with the results of the numerical simulation and the statistical analysis of data from the field. The study provides the foundation for the future control measures of rib spall.

INTRODUCTION

In recent years, with the trend of nationalization and heavy-industrialisation of fully-mechanized mining equipment, the fully-mechanized mining technology is widely applied in Shendong, Jincheng and Datong mining areas. The technology has achieved considerable economic and social benefits due to its high resource recovery rate and large production capacity. This technology is considered to be one of the best coal mining methods for safe and highly efficient mining of the thick coal seams in China (Gao Jin and He Hai-tao 2010). However, many engineering field practices show that accidents due to rib spall are more likely to occur in the working face due to the increase of mining height. Spalling could also contribute to the increase of unsupported roof span in front of the support line causing roof falls that can seriously affect the normal advancing speed and cyclic operations of the working face. Therefore the rib spall is one of the most serious problems that must be resolved. Only if the mechanism and the depth of rib spalling are fully understood and managed then the potential of large mining fully-mechanized working face can be fully achieved (Meng Chao 2013 and Zhu Yong-jian and Feng Tao 2012).

Many scholars have studied rib spalling using theoretical analysis, field tests and numerical simulations to determine the stress distribution in front of the working face. Jin Jun-heng and Meng Xiang-rui (2011) put forward the rib spalling model and stability condition and proved that coal parting in coal seam can effectively improve the overall stability of the rib. Yang Jing-xuan and Liu Chang-you(2013) simplified the rib spalling by using the single sliding model, and introduced a stability coefficient K. Fang Rui-hong and Liu Pan(2013) determined the critical relationship between the rib instability and the stability coefficient. Song Zhen-qi and Liang Sheng-kai (2011) studied the rib spalling laws with different condition of mining height and depth and obtained fitting formula of the rib spalling. Wang Jia-chen (2007) analyzed effective measures to control the rib spalling for top coal caving.

The average depth of 1-2# coal seam is 240 m in the Shangwan coal mine, Shendong mining area. The large mining height using a fully-mechanized mining technology was applied in the working faces of the 1-2# coal seam in the 3rd panel. The large area of face spall occurred repeatedly during the mining process, which seriously affected the normal production of the working face. The "thin plate" mechanical

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model and the deflection equation to predict the working face rib deformation was established by using fracture mechanics as the theoretical basis for the longwall working face LW12301. This work examined the opening and extension of coal fractures for the large mining height. Using theoretical analysis and numerical simulations, the position of rib instability and the mode of failure is researched here and the depth of rib spall and failure mode determined.

MINING CONDITION OF 12301 WORKING FACE

Shangwan coal mine is one of the main producing mines of the Shenhua Shendong Coal Mine Group Co, Ltd, which is located in the southeast of Erdos City, Inner Mongolia. There are five mineable seams (1-2 up, 1-2, 1-2 down, 2-2 and 3-1 seams). The total thickness of all seams is 16.50 m, of which the1-2 coal seam is divided into 4 panels. The 1-2 coal seam is nearly horizontal and about 6.2 m thick. The geographical position of Shangwan coal mine is shown in Figure 1.

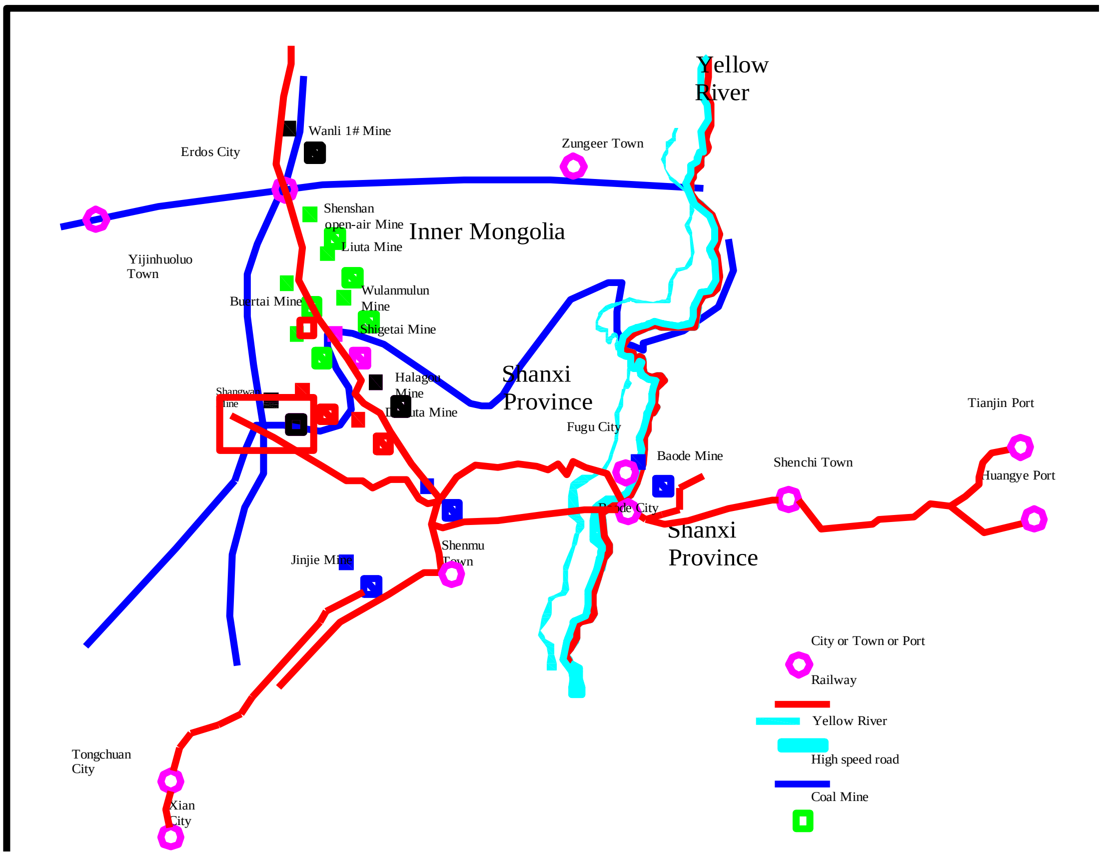

Figure 1: Geographical position of Shangwan coal mine

LW12301 is the first working face of panel 3 in 1-2 coal seam, which is operated using a fully-mechanized longwall mining method. The mining height is 6.0 m, the face length is 249 m and the mineable advancing panel is 4948 m long. The roadway arrangement of LW12301 is shown in Figure 2. The thickness of the sandy mudstone immediate roof ranges from 0.63 m to 3.87 m. The thickness of the fine-sandstone main roof is 1.3~4.2 m and is the main component of sandstone. The thickness of immediate bottom is 0.56~2.11 m with mudstone easily softened with water. The site investigations revealed that the large area of face spall exploded into the working area several times during the periodic weighting with the fish scale like face appearance. The maximum depth of rib spall was 1.7 m, which decreased the normal shearer and hydraulic support efficiency and posed a huge threat to the working face production and workers safety. The rib spalling scene of LW12301 during first weighting is shown in Figure 3.

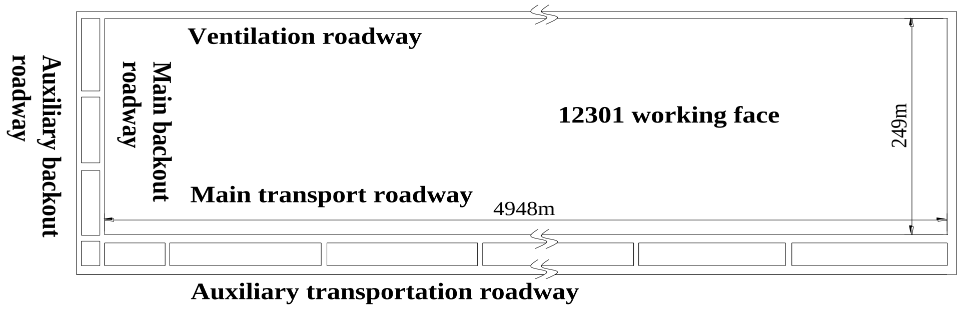

Figure 2: Roadway arrangement of LW 12301

Figure 3: Rib spalling of LW12301 during first weighting

GRADUAL DETERIORATION CHARACTERISTICS AND MECHANICAL CONDITION ANALYSIS OF RIB SPALLING DUE TO LARGE MINING HEIGHT AT FULLY-MECHANISED WORKING FACE

Gradual deterioration characteristics of longwall face spall

Rib deterioration due to the large mining height at the working face is a complex mechanical process. The coal rib is not only influenced by the mining induced and tectonic stress, but also affected by some constrained effects of the deeper coal mass. From the perspective of fracture mechanics, the delamination fracture will occur when the tension or relative displacement between rib and deep coal mass reaches a certain limit. The deformation of the inelastic rib bearing segment continues to grow and the internal fissure damage within the ribside will accumulate. If the delamination fractures develop within the rib to inter-permeation, it is easy to reach rib instability in a large area. The interior coal fractures, under compressive stress, can rapidly expand causing rib failure along the parallel or biased maximum principal stress α_1 direction as shown in Figure 4. Rib failure can be simplified using the 'thin plate' model as shown in Figure5. Rib gradual deterioration damage characteristics are shown in Figure 6.

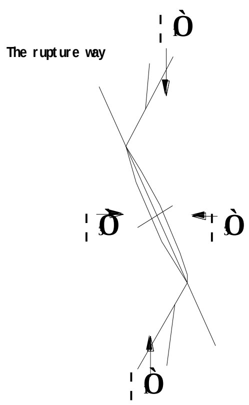

Figure 4: Rupture direction of crack tip under cyclic compressive load

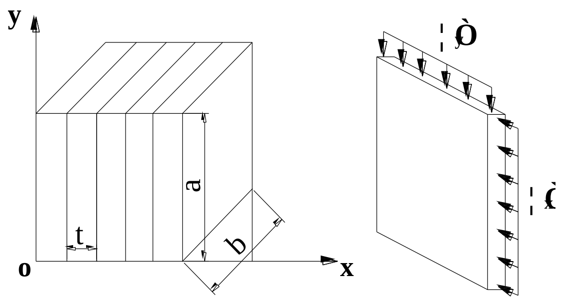

Figure 5: Thin plate force model of rib

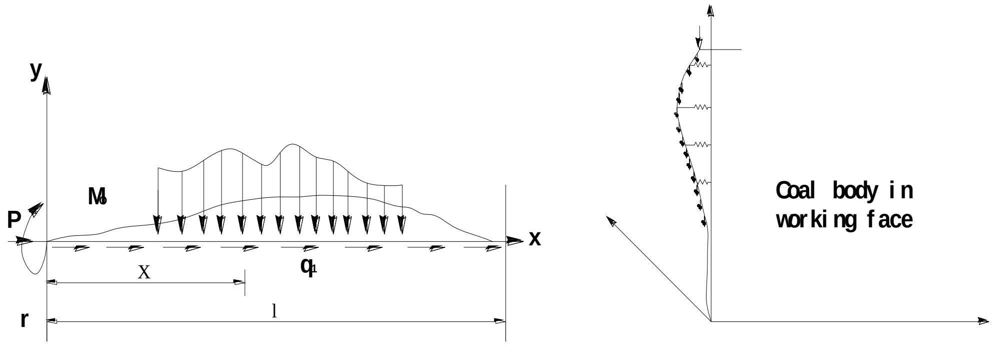

Figure 6: Rib progressive deterioration damage characteristic

Mechanical condition analysis of rib spalling in fully-mechanized working face

The rib of a large mining height working face bears the horizontal pressure from the front coal mass and the gravity stress of the overburden roof. The rib can be regarded as the statically indeterminate uniform beam (one end is clamped as support and the other end is simply supported). The rib geometry can be simplified to analyse the rib deflection produced in a horizontal direction. The gravity stress and the compression deformation in a vertical direction are ignored. The simplified model of the large mining working face rib is shown in Figure 7.

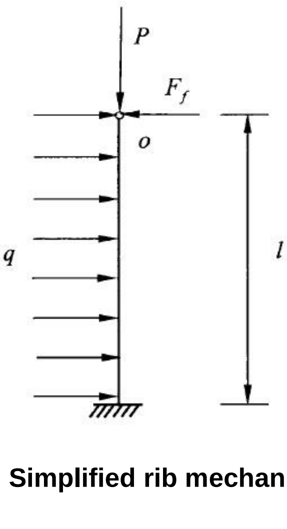

Figure 7: Simplified rib mechanical model

In Figure 7 q is the horizontal load, F_f is the friction resistance between coal seam and roof, P is the roof pressure, l is coal seam mining height, the rectangular coordinate system is built with the point o as the origin of coordinates, x is the vertical downward axis and y is the horizontal axis poositive to the right . The simplified model of the large mining height rib is mechanically analysed as follows:

For any cross section the centroid moment, the bending moment and deflection can be obtained by the following equations:

$$M = \frac{3qlx}{8} - \frac{qx^2}{2} \quad (1)$$

$$\omega = \frac{qx^2}{2EI} - \frac{3qlx}{8EI} \quad (2)$$

Integrating the equation (2), the following is obtained:

$$\omega' = \frac{qx^3}{6EI} - \frac{3qlx^2}{16EI} + c_1 \quad (3)$$

(3)

According to the characteristics of a cantilever beam, ω'=0 when $x = l$. Substituting it into equation (3), the following equation is obtained:

$$c_1 = \frac{ql^3}{48EI} \quad (4)$$

Integrating equation (3), the following equation is obtained:

$$\omega'' = \frac{qx^4}{24EI} - \frac{qlx^3}{16EI} + \frac{ql^3x}{48EI} + c_2 \quad (5)$$

According to the characteristics of auniform beam, ω''=0 when $x = l$. Substituting it into equation (5), the following equation is obtained:

$$c_2 = 0 \quad (6)$$

Then the deflection curve equation is as follows:

$$\omega'' = \frac{qx^4}{24EI} - \frac{qlx^3}{16EI} + \frac{ql^3x}{48EI} \quad (7)$$

The maximum rib deflection can be obtained from equation (7). Differentiating equation (7) with respect to x and setting the derivative to zero yields the following equation:

$$\frac{qx^3}{6EI} - \frac{3qlx^2}{16EI} + \frac{ql^3}{48EI} = 0 \quad (8)$$

The stagnation points are therefore achieved from equation (8) as follow:

$$x_1 = l \quad (9)$$

$$x_2 = \frac{1+\sqrt{33}}{16} l \quad (10)$$

$$x_3 = \frac{1-\sqrt{33}}{16} l \quad (11)$$

Both the equation (9) and (11) cannot achieve the maximum value of deflection due to $x_2 \subset [0,l]$, and finally the maximum is obtained when $x_2 = \frac{1+\sqrt{33}}{16} l$, at the position $0.422l$ from the roof and 0.578 times of the mining height, the maximum deflection is followed:

$$\omega_{\max} = \frac{13ql^4}{2400EI} \qquad (12)$$

THE RESEARCH OF LW 12301 RIB SPALLING DEPTH

Theoretical analysis of rib spalling depth

According to the statistical analysis of the damage form and depth of rib spalling of different working faces in the Shendong mining area (including the Shangwan coal mine, Bulianta coal mine, Daliuta coal mine andBuertai coal mine). The authors established the relationship between the depth of rib spalling and mining height under similar conditions, as shown in Table.1.

Table 1: Mining height and the depth of rib spalling of five fully-mechanized working faces in Shendong mining area

Name of working face	Mining height /m	Form of rib spalling	Depth of rib spalling /m
LW 12307 in Shangwan coal mine	3.5	tension crack failure	0.83
LW 12302 in Shangwan coal mine	4.5	tension crack failure	0.95
LW 22307 in Bulianta coal mine	6.8	tension crack failure	1.45
LW 52302 in Daliuta coal mine	6.6	tension crack failure	1.35
LW 42104 in Buertai coal mine	3.9	tension crack failure	0.45

The depth of rib spalling is associated with the rib spalling due to the tension cracking and direction of advance. Some researchers have determined the theoretical equation of rib spalling depth for tension crack failure in flat seams:

$$\Delta P = M \cdot \tan(90° - \varphi) \qquad (13)$$

Where, ΔP is the depth of rib spall, M is the mining height, α is the coal seam dip angle, φ is the coal seam friction angle.

Equation (13) is appropriately applied to working faces of which the mining height is below 3.0m.

Since Equation (13) is no longer adapted to the large mining height fully-mechanized working face in Shendong mining area, the correction coefficient K is introduced and a new equation which is suitable for large mining height working faces in Shendong mining area is obtained.

$$\Delta P = K \cdot M \cdot \tan(90° - \varphi) \qquad (14)$$

Substituting the data in Table. 1 into equation (14), the rib spalling correction coefficient K can be obtained. K ranges from 0.11 to 0.18, and thus the maximum depth of LW 12301 ranges from 0.98m to 1.61m.

Numerical simulation of rib spall in high working face

In order to analyse the rib spalling of LW12301, PFC^{2D} software was used to carry out the numerical simulation. The width of the model was 400 m and height is 80 m. The working coal face thickness was 6.0m and the dip angle was 0°. The geometric model as shown in Figure 8.

The stress constraint in front of LW12301 is shown in Figure 9. It is clearly observed that the peak abutment stress zone is 5.0m ahead of the working face. The scale of rib spalling is shown in Figure 10. With the working face advancing, the coal failure becomes tensile failure from shear failure and gradually develops inwards the rib which causes the instability of the coal wall, and the stable height is 4.5 m. In the comparatively stable area, the phenomenon of slight rib spalling occurs with the depth of rib spalling of 0.8 m. The more serious rib spall occurs 2.5 m below the roof level reaching 1.5 m in depth. The rib spall takes the shape of a triangle. The numerical simulation result is consistent with the theoretical result.

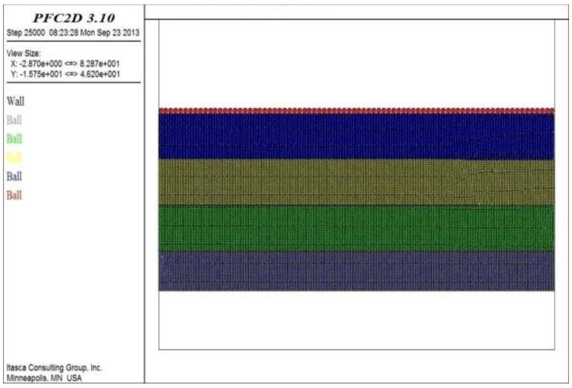

Figure 8: Graph of numerical analysis model

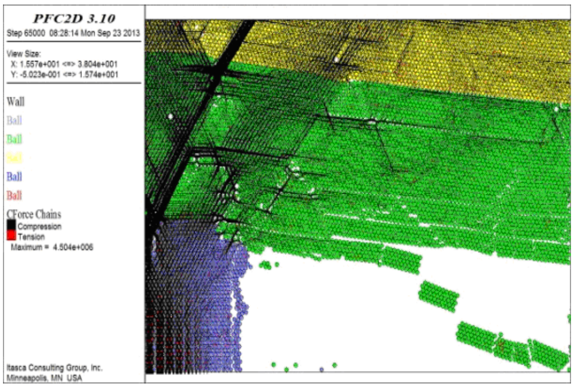

Figure 9: Peak abutment stress zone in front of LW12301

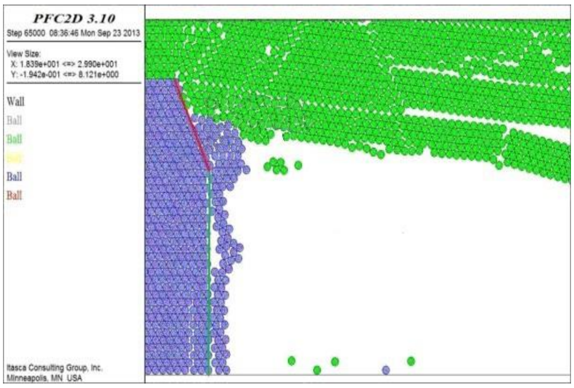

Figure 10: Rib spalling scale of LW 12301

OBSERVATION RESULTS ANALYSIS OF LW12301 RIB SPALLING

During the excavation process of LW12301 in the Shangwan mine, the observation results of the rib spalling depth were statistically summarised and are shown in Fig.11 and.12. According to the field statistics, it was found that the advancing speed of the working face influenced the rib spalling. During the normal mining of LW12301, the depth of rib spalling firstly increased and then decreased and finally reached a stable level of 1.0m to 1.2m. During the periodic weighting of LW12301, the peak stress in front of the working face inceased and moved forward, aggrevating the rib spalling. The average depth of rib spall was 1.55m, and the maximum was 1.7m. The observation results are consistent with both the numerical simulations and the theoretical results.

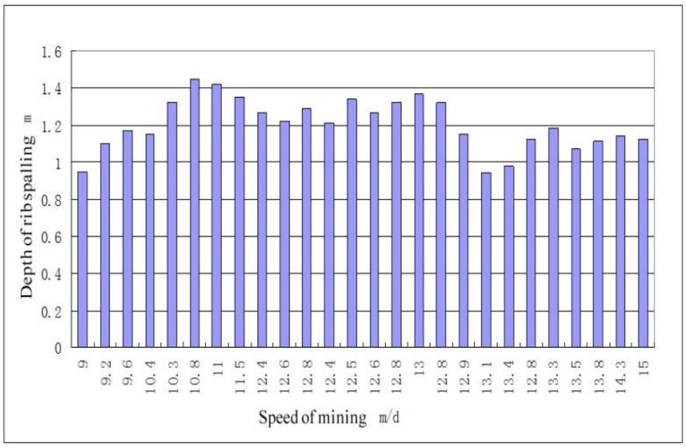

Figure 11: Depth of the working face rib spall (without periodic weighting)

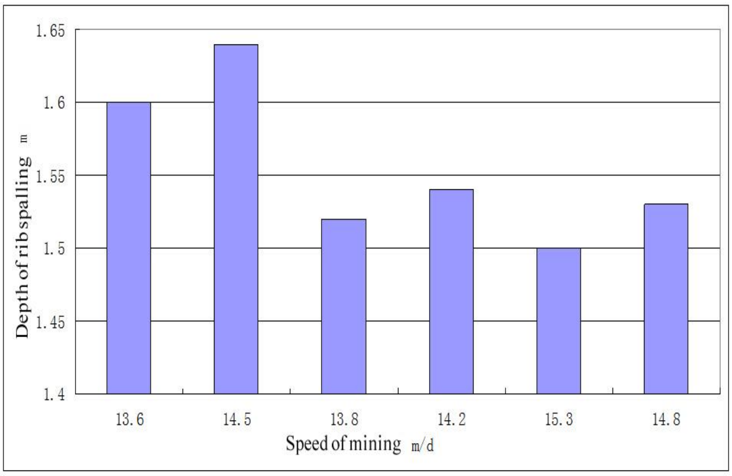

Figure 12: Depth of the working face rib spall (with periodic weighting)

CONCLUSIONS

The research reveals the gradual deterioration characteristics of the working longwall face. The thin plate mechanical model of working face and empirical equation of rib spalling were established. The deduced deflection equation of rib deformation is: $\omega = \frac{qx^3}{6EI} - \frac{3qlx^2}{16EI} + \frac{ql^3}{48EI}$, showing that the instability position is just above the mid seam (0.578 times of the mining height). According to the theoretical calculation, the maximum depth of rib spalling is between 0.98m and 1.61m, and the rib spalling initiates at 2.53m below the roof.

In numerical simulation, with the working face advancing, coal wall failure mechanism changed from the shear failure to tension failure. The coal wall stability decreased, the serious rib spall occurred at 2.5 m below the roof of the working face, and the total spalling depth extended to 1.5 m taking shape of a triangle.

The field statistical analysis of the rib spalling depth were consistent with both the theoretical analysis and numerical simulation, which verifies the reliability of this study.

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