Study on Optimization of Face Length of Fully Mechanized Caving Face in Extra-thick Coal Seams

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Abstract

The working face inclined length critically affects production efficiency in fully mechanized top-coal caving mining. Theoretical analysis and numerical simulation determined the optimal face length for Coal Seam 2302 in Zhaoxian Mine. Key parameters included key stratum behavior, roof subsidence, and plastic zone development. Simulation results reveal accelerated stope roof deformation growth rates beyond 250 m face length. For face lengths of 160-250 m, plastic zone development increases gradually without affecting the water-bearing conglomerate layer. These findings support a 250 m optimal face length for Working Face 2302.

Keywords

Extra-thick Coal Seam; Fully Mechanized Top-coal Caving Mining; Optimization of the Face Length; Numerical Simulation.

1. Introduction

In Chinese coal-resource occurrence, extremely thick coal seams are crucial, with rich reserves and wide distribution, ensuring national energy supply. Their efficient mining is vital for the coal industry's sustainability and national energy security. The face length of fully mechanized caving working faces, a key mining-efficiency and safety parameter, is a research focus in mining engineering. Mine pressure manifestation includes roof subsidence, coal-wall spalling, and support-stress changes due to overlying rock movement and stress redistribution during mining. A reasonable face length optimizes stope-rock stress, controls mine pressure, and ensures safety. An unreasonable one may cause strong pressure manifestations, roof accidents, and affect production and safety.

Recent studies have extensively investigated optimal working face length configurations. Yanxia Fan[1] aimed to explore the reasonable length of the working face in the shallow coal seam. Theoretical modeling was employed to analyze working face length optimization in Bulianta Mine's Face 12416, with particular focus on production output, economic performance, and ventilation needs. Finally, it was concluded that the reasonable range of the length of this working face was between 215 and 287 m. Previous research by Qingxu Lv[2] focused on the fully mechanized top-coal caving operations at Buertai Mine's Panel 42108. By comprehensively considering the differences in the coal cutting and coal caving recovery rates, he derived the formula for checking the ventilation capacity and determined that the reasonable length of the working face was 310 m. Chang Liu[3] with the help of similar simulation experiments, confirmed that the overlying rock could break into the shape of a trapezoidal platform, clearly expounded the formation mechanism of the trapezoidal platform and the calculation principles of its param. Based on the trapezoidal platform structure, they deeply explored the influence of the working face length on the breaking law of the overlying rock, and clarified the relationship between the trapezoidal platform and the key stratum theory. Ze Wang[4] adopted means such as theoretical analysis, on-site monitoring and numerical simulation to conduct research on the mine pressure characteristics of the working face with a shallow buried depth and the variation law

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of the working face length. Results indicated a direct relationship between stress arch elevation and face length, stabilizing beyond 240 m.

Existing research has yet to establish a consistent theoretical model for the variable effects of working face length on rock pressure behavior in different geological contexts. Analysis of face length impacts in thick-seam top-coal caving systems is essential for pressure regulation, design optimization, and operational safety improvement. This study systematically investigates the impact of working face length on strata pressure behavior in extra-thick coal seams using combined theoretical and numerical approaches, aiming to establish a foundation for safe and efficient top-coal caving operations.

2. Project Overview

The No. 2 mining area of Zhaoxian Mine contains Middle Jurassic Yan'an Formation coal-bearing strata, with Coal Seam 3 being the primary recoverable reserve. In Mining Area No. 2, the exposed coal seam dips westward with angles ranging from 5° to 20°. The average buried depth of the No.2302 working face is 420 m, and the average coal thickness is 11.6 m. Most of the roof of the No.2302 working face is hard sandstone. Among them, the main roof is fine sandstone, medium sandstone and coarse sandstone, with an average thickness of 27.7 m; the immediate roof is mudstone or carbonaceous mudstone, with an average thickness of 3.27 m. Borehole logs indicate a 20.83-m thick fine sandstone immediate roof, overlying a 2.9-m mudstone immediate floor and 21.1-m fine sandstone main floor.

3. Analysis of the Influence of the Working Face Length on the Failure Height of the Overlying Rock

Within a certain limit, there is a positive correlation between the length of the working face and the failure height of the overlying rock, that is, the greater the length of the working face, the higher the height reached by the failure of the overlying rock. In mines with hard sandstone overburden, key stratum fracturing significantly influences overlying rock stability. Therefore, key stratum identification was conducted for Face 2302 to determine overburden failure heights at varying face lengths.

Borehole logs from Face 2302 indicate predominantly hard sandstone and conglomerate overburden strata. Applying the methodology from Reference [5], key strata were identified in Coal Seam 3's overburden, with results summarized in Table 1.

Table 1. Distribution of Key Strata in the No.2302 Working Face

Item number	Rock stratum name	Thickness/ (m)	Type	Distance from the roof of 3 coal seam/ (m)
41	Medium-grained conglomerate	132.6	Main key stratum	184.4
25	Argillaceous siltstone	14.17	Sub-key stratum	88
24	Mudstone	14.33	Sub-key stratum	88
6	Siltstone	18.11	Sub-key stratum	3.15

Reference [6] establishes correlations between water-conducting fracture zone height and key parameters: coal seam thickness, face length, and mining depth:

$$H=16.812b-0.125h+0.193l+56.187 \tag{1}$$

Where H is the development height of the water-conducting fissure zone; b is the mining thickness of the coal seam, taking 7.5 m; h is the buried depth of the working face, taking 420 m; l is the length of the working face. Then the relationship between the development height of the water-conducting fissure zone and the length of the working face can be expressed as:

$$H=129.78+0.193l \tag{2}$$

To maintain main key stratum integrity, the water-conducting fracture zone height must remain below the key stratum elevation. Equation (2) accordingly constrains the working face length to <283 m.

4. Numerical Simulation Analysis of the Working Face Length

4.1 Construction of the Numerical Model

Using geological data from Face 2302 (Zhaoxian Mine), we constructed a 3D numerical model of the fully mechanized caving operation. During numerical calculation, the working face is set to be arranged along the dip direction (X-axis), and advanced along the strike direction (Y-axis). The gravity direction is the Z-axis, with the upward direction being positive. 150-m boundary coal pillars were maintained along both strike and dip directions of Face 2302 to minimize edge effects. The total advancing length is set to 450 m to achieve the “square effect”. The 3D model dimensions measure 773 m (strike) × 450 m (dip) × 500 m (vertical). The model is shown in Figure 1.

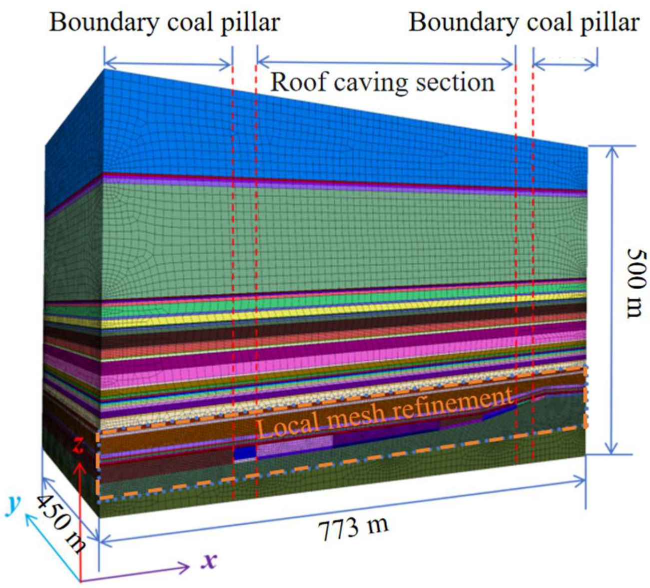

Figure 1. Numerical model

During the process of model establishment, the layers of the overlying rock are divided according to the columnar section of the No.2302 fully-mechanized caving face. The weak rock layers with small thickness that have little influence on the calculation results are merged. Considering that the average buried depth of the No.2302 working face ranges from 351 m to 490.7 m, the bulk density of the overlying rock is assumed to be 25 kN/m³, and the thickness of the overlying rock for simulation is set as 400 m. An equivalent compressive stress of 1.51 MPa is applied to the upper end-face of the model. When meshing the model, the mesh size within the research area should be as small as possible, and the mesh elements should be regular in shape without any distorted elements. At the same time, it is necessary to ensure that the total number of elements does not exceed the computing capacity of the computer hardware. Local refinement is carried out in the coal seam area of the model, with the mesh width set to 2 m. A total of 4.494 million elements and 3.134 million nodes are divided.

4.2 Analysis of the Deformation of Overlying Strata for Working Faces with Different Lengths

After mining, surrounding rock stress changes, pressuring the working face to deform (displace). In simulation, roof vertical displacement equals roof subsidence, a key part of stope mine-pressure manifestation. Analyzing simulated roof vertical displacement reveals macroscopic mine-pressure patterns at different working face lengths, enabling optimization of face length by roof deformation. Figure 2 shows max roof subsidence at different mining lengths for various face lengths.

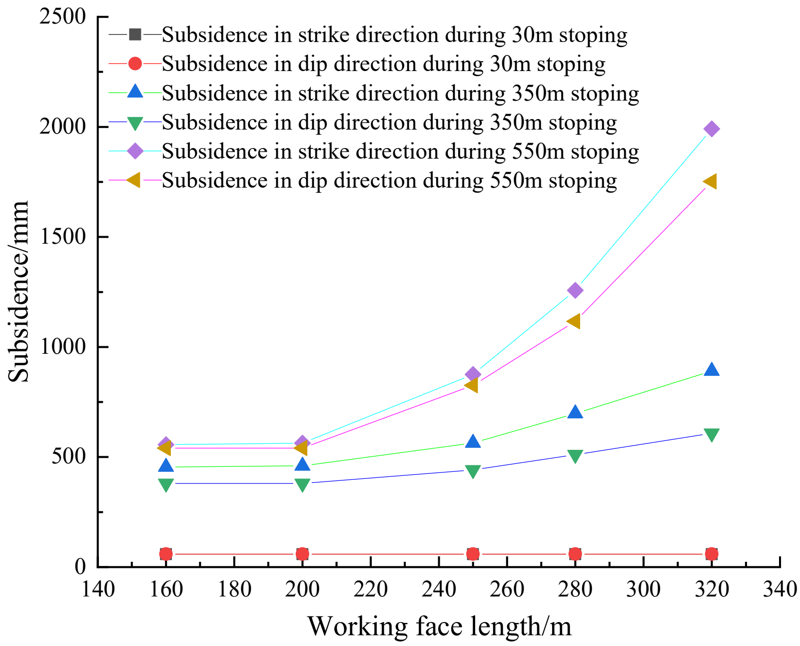

Figure 2. Maximum roof subsidence amount under different working face lengths

As shown in Figure 2, when the advancement reaches 30 m, the roof subsidence in both the strike and dip directions of working faces at different sites is around 59 mm, indicating that the working face length has no significant impact on roof deformation at this stage. When the advancement reaches 350 m, all working faces of various lengths have achieved the “square-effect” state. The roof deformation in the dip direction increases to 455.3-890.8 mm, and that in the strike direction to 380.1-607.8 mm. Roof displacement increases proportionally with working face length. When the advancement reaches 550 m, the influence of the working face length on stope roof deformation becomes more pronounced. When the face length ranges from 160 to 200 m, the impact on roof deformation is relatively small; when it is between 200 to 250 m, the roof deformation begins to increase, and when it exceeds 250 m, the growth rate of stope roof deformation accelerates significantly.

4.3 Analysis of the Failure of Overlying Strata for Working Faces with Different Lengths

The working faces with different lengths have a significant impact on the development height of the plastic zone in the stope. The cloud diagrams of the plastic zone in the stope under different working face lengths are shown in Figure 3.

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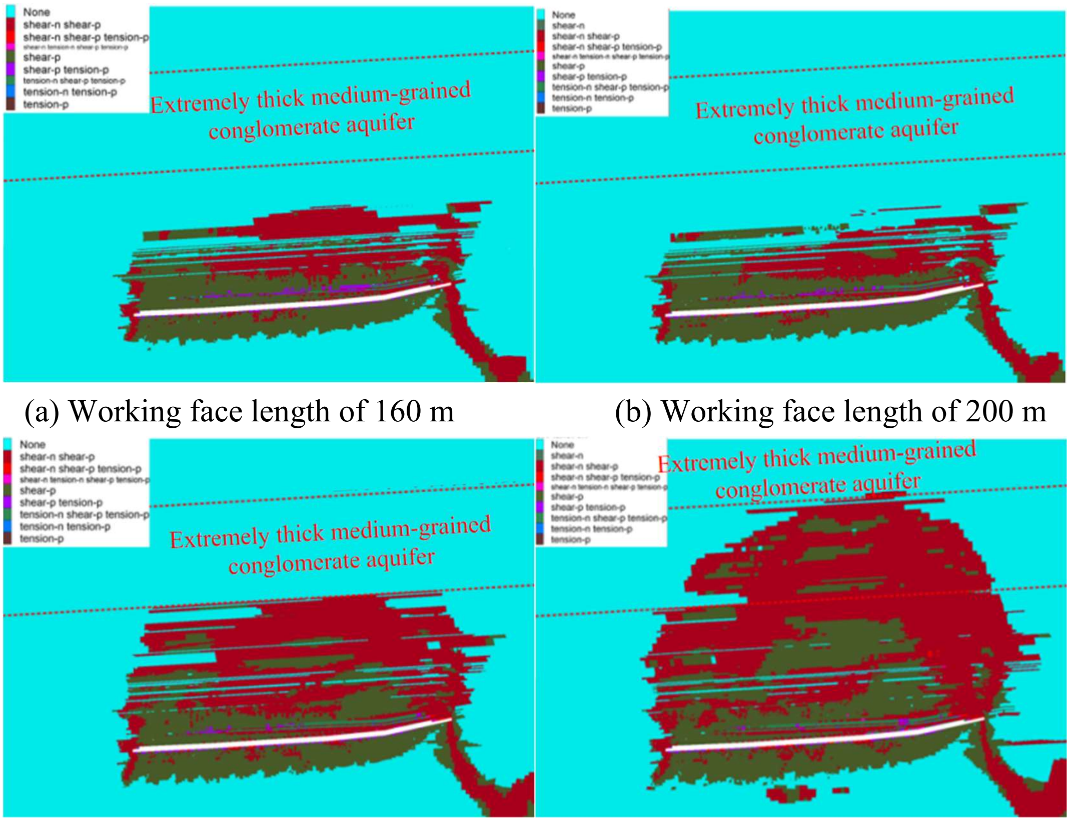

(a) Working face length of 160 m (b) Working face length of 200 m

(c) Working face length of 250 m (d) Working face length of 320 m

Figure 3. Cloud diagrams of the plastic zone in the stope under different working face lengths

Figure 3 clearly demonstrates that the length of the working face exerts a pronounced influence on the development height of the stope's plastic zone. Specifically, when the working face length spans from 160m to 250m, the height of the stope's plastic zone development gradually escalates. Notably, throughout the mining phase, this development does not encroach upon the extremely thick water-bearing medium gravel layer. Once the working face length extends to 280m, the plastic zone development height surpasses the thickness of this gravel layer, initiating a progression towards the overlying loess rock layer. Consequently, water-conducting fissures commence their propagation towards the surface. Meanwhile, the stope floor's failure depth remains consistent within the 160m to 250 m range, but begins to increase once the working face length exceeds 250 m.

Zhaoxian Coal Mine benefits from its high management standards. The 2302 working face's mining area is devoid of faults, featuring merely a single syncline, and the coal seam's roof and floor conditions are favorable, justifying an increase in the working face length. Additionally, the working face lengths of neighboring mines fall within the 200m to 267m range, signifying that current equipment and techniques are fully capable of facilitating ultra-long working face mining. Considering all these findings, it is concluded that the optimal length for the 2302 working face at Zhaoxian Coal Mine should be set at 250m.

5. Conclusion

This study investigates the fully mechanized top-coal caving system in Zhaoxian Mine's ultra-thick Coal Seam 2302. Theoretical analysis establishes 283 m as the maximum allowable face length. Roof deformation exhibits increasing trends at face lengths between 200-250 m. Beyond 250 m, stope roof deformation rates accelerate significantly. Plastic zone development increases gradually at 160-250 m face lengths without compromising the water-bearing conglomerate layer. The optimal face length for Panel 2302 was determined as 250 m.

Acknowledgments

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