Research on Adaptability of Full-mechanized Caving Mining with Large Mining-height

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Abstract

In order to solve the safety problem from methane concentration in mining face with high mining intensity, full-mechanized top-coal caving mining with large mining-height was put forward. In spite of its advantages in controlling methane, its main problems were pointed out. Higher mining height might reduce coal-wall stability and result in coal or roof fall. Top-coal caving difficulty degree might increase with larger top-coal thickness. Numerical simulation software applied, coal-seam thickness, strength and mining height were believed to be main factors of influencing the adaptability of full-mechanized caving mining with large mining height by orthogonal test. Relationship formula of meeting coal-wall stability and good top-coal caving degree were obtained. Based on this, adaptable conditions of full-mechanized caving mining with large mining-height were presented. This provided theoretical reference for methods selection of safe and high-efficient mining extremely thick coal-seam.

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Keywords: full-mechanized caving mining with large mining-height; adaptability; top-coal caving difficulty degree; stability of coal wall

1. Full-mechanized caving mining with large mining-height

Full-mechanized mining method originated from France, but only in China, it was developed fully and applied widely. It has been main mining method which brings high output and high efficiency in China.

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With application of large-power equipments in mines, mining intensity gradually increase but methane concentration problem seriously interfere with mining. Ability of discharging methane by ventilation is limited by ventilation section, so increasing ventilation section of mining face is an important approach of further improving output of full-mechanized caving mining face. There are two methods that may increase ventilation section. One is increasing horizontal dimension of mining face, namely, roof controlling length of supports. The other is increasing vertical height, namely, mining height.

The first method needs larger supporting resistance and supporting density because of extended roof controlling area. This will add difficulty in underground transportation, installation of powered support, and supporting open-off cut. So the extended roof controlling area is limited to some degree.

The second method may add mining height to above 3.5m on the basis of experience from large mining-height full-mechanized mining method. It may add ventilation section by increasing supports’ vertical height. This combines advantages of top-coal caving mining and large mining-height full-mechanized mining method and is another approach of realizing high output and high efficiency of mining extremely thick coal-seam\(^1\).[1-2]. Its advantages include:

1. Adding ventilation section without extending roof controlling length of support and reducing ventilation resistance.
2. Smoother supporting work-resistance vibration and simpler supports transportation, installation and open-off cut supporting.
3. Extending rare top-coal caving space by adding mining height is favorable for methane dilution near top-coal caving place and is convenient for layout of rare conveyor with large-power and large freight volume.
4. Smaller top-coal caving height and caving coal amount reduction will decrease the influence of top-coal caving on instantaneous output fluctuation. This is favorable for balanced mining and reducing instantaneous methane gushing.
5. Influence of top-coal caving is reduced, instantaneous output or methane gushing amount may be adjusted by coal cutter running velocity.

2. Main problems of full-mechanized caving mining with large mining-height

In full-mechanized top-coal caving mining with large mining-height, it is coal, not roof rock above powered support, so load bearing condition of top-coal caving powered support is different that of full-mechanized mining powered support. Compared with usual full-mechanized top-coal caving mining, its mining stress varies obviously and coal-wall stability reduces after the mining height increase. Mining height adding may make allowable top-coal caving height larger; this will add top-coal caving difficulty.

Numerical simulation software applied, influence factors of coal-wall stability and top-coal caving difficulty degree were analyzed by orthogonal test in this paper. Tension failure coefficient of coal-wall and top-coal were presented firstly.

Coal-wall tension failure coefficient was defined as ratio of coal tension failure area to coal body area in mining height per unit length along mining direction.

Top-coal tension failure coefficient was defined as ratio of coal tension failure area above powered support to that of top-coal area.

3. Influence factors of coal-wall stability

Coal mining will induce movement of overlying strata, concentrated vertical and horizontal stress form in coal with mining face advancing. Initially, compression and shear failure occur in coal affected by advanced abutment pressure and small horizontal displacement starts. With mining face further advancing,
coal loaded state starts to change from 3-dimensional stress to 2-dimensional stress. Fast reduction of horizontal pressure makes coal horizontal displacement to gob increase and coal loaded state is changed from compression to tension. Amounts of tension cracks occur and extend to be fissures in coal body, thus, coal-wall is easy to fall under outer disturbance. So coal-wall tension failure area and failure degree are the key to coal fall. In order to describe coal-wall failure by quantitatively, coal-wall tension failure coefficient was applied to evaluate coal-wall stability. 5-levels orthogonal test model was set up to researching influence of 4 factors including mining height, coal-seam thickness, and coal strength and supporting density on coal-wall tension failure coefficient.

Test results show that coal-wall tension failure coefficient is exponent related with mining height, coal-seam thickness, coal strength and supporting density. Their correlation coefficients are respectively 0.9904, 0.9750, 0.9652 and 0.9906, so similar linear relationship was set up between coal-wall tension failure coefficient and exponent form of 4 factors. Multiple linear regression equation is as follows.

\[ Y = A_0 + A_1 X_1 + A_2 X_2 + A_3 X_3 + A_4 X_4 \]  
\[ X_i = e^{T_i} \quad (i=1, 2, 3, 4) \]

Where \( Y \) is coal-wall tension failure coefficient; \( T_1, T_2, T_3, T_4 \) are respectively mining height \( h \), coal-seam thickness \( M \), Protoggyakonov’s coefficient of coal strength \( f \); supporting density \( p \), \( A_0, A_1, A_2, A_3, A_4 \) are unknown coefficient.

Test data are substituted into (1) and following equation is obtained by linearly regression.

\[ Y = 2.005664 + 0.0026e^h + 0.000043e^M - 0.0648e^f - 0.1283e^p \]  

Significance of regression equation show that the equation may be used to predict coal-wall stability of full-mechanized top-coal caving mining face.

By range analysis, influence degree of every factor is listed as follows: \( f > h > p > M \). \( f \) and \( h \) are main influence factors of coal-wall stability.

Simulation results from 25 simulation projections show that there are 13 projections in which coal-wall tension failure coefficient are larger than 1.5. In these projections, tension failure area of coal-wall cover all mining height. Coal-wall is unstable entirely, which result in coal-wall or roof fall. When coal-wall tension failure coefficient is smaller than 1.5, coal-wall tension failure area is not cover whole mining height. Coal-wall still have bearing capacity. So coal-wall tension failure coefficient 1.5 may be used as standard of judging coal-wall is stable or not.

For ensuring coal-wall stability, following expression must be met.

\[ Y = 2.005664 + 0.0026e^h + 0.000043e^M - 0.0648e^f - 0.1283e^p \leq 1.5 \]  

It may be transformed to be as follows.

\[-0.06934 + 0.0026e^h - 0.0648e^f + 0.000043e^M \leq 0 \]
4. Influence factors of top-coal caving difficulty degree

A 5-levels orthogonal test model was set up to research influence of factors including mining height, coal-seam thickness, and coal strength on top-coal tension failure coefficient. Test results show that top-coal tension failure coefficient is logarithmic related with mining height, coal-seam thickness and coal strength. Their correlation coefficients are respectively 0.9945, 0.9815 and 0.9938, so the similar linear relationship may be set up between top-coal tension failure coefficient and logarithmic form of every factor. Multiple linear regression equation is as follows.

\[ Y = A_0 + A_1 X_1 + A_2 X_2 + A_3 X_3 \]  \hspace{1cm} (5)

\[ X_i = \ln T_i \hspace{1cm} (i=1, 2, 3) \]

Where \( Y \) is top-coal tension failure coefficient; \( T_1, T_2, T_3 \) are respectively mining height \( h \), top-coal thickness \( \hat{h} \), Protogonov’s coefficient of coal strength \( f \), \( A_0, A_1, A_2, A_3 \) are unknown coefficients.

Test data are substituted into (5) and following equation is obtained by linearly regression.

\[ Y = 0.653873 + 0.192073 \ln h - 0.18703 \ln (M - h) - 0.21537 \ln f \]  \hspace{1cm} (6)

Significance of regression equation show that the equation may be used to predict top-coal caving difficulty degree of full-mechanized caving mining face.

By range analysis, influence degree of every factor is listed as follows: \( f > \hat{M_d} > h \). \( f \) and \( \hat{M_d} \) are main influence factors of top-coal caving difficulty degree.

Whether top-coal over caving place is broken or not is the key to caving it smoothly. Top-coal in compression state is not liable for caving. Only if there is no thick shear failure area over caving place, top-coal is liable for caving and higher mining ratio can be reached. Simulation results from 25 simulation projections show that there are 20 projections in which top-coal tension failure coefficient are larger than 0.3. In these projections, tension failure area of top-coal over powered support is near or even reaches immediate roof. When top-coal tension failure coefficient is smaller than 0.3, Over 2m thick top-coal is in shear failure state over caving place, top-coal loss is largest at this time. So top-coal tension failure coefficient 0.3 is be used as standard of judging top-coal is broken fully or not.

For ensuring top-coal is caved fully, following expression must be met.

\[ Y = 0.653873 + 0.192073 \ln h - 0.18703 \ln (M - h) - 0.21537 \ln f \geq 0.3 \]  \hspace{1cm} (7)

It may be transformed to be as follows.

\[ 0.353873 + 0.192073 \ln h - 0.21537 \ln f - 0.18703 \ln (M - h) \geq 0 \]  \hspace{1cm} (8)
5. Adaptability evaluation of full-mechanized caving mining with large mining-height

In order to make coal-wall stable and obtain higher top-coal mining ratio, mining height, coal thickness and Protogyakonov’s coefficient of coal strength must meet expression (4) and (8). When mining height is 2m, 2.5m, 3m, 3.5m, 4m, 4.5m, 5m, 5.5m and 6m, relationship of coal thickness and Protogyakonov’s coefficient is obtained under different mining height. They are showed in Table 1 and Figure 1.

Table 1 Requirement of coal strength and coal thickness under different coal mining height

<table>
<thead>
<tr>
<th>Mining height</th>
<th>Requirement for coal strength</th>
<th>Requirement for coal thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 m</td>
<td>&gt;0.5</td>
<td>&lt;10m</td>
</tr>
<tr>
<td>2.5 m</td>
<td>&gt;0.6</td>
<td>&lt;12 m</td>
</tr>
<tr>
<td>3 m</td>
<td>&gt;0.7</td>
<td>&lt;14 m</td>
</tr>
<tr>
<td>3.5 m</td>
<td>&gt;0.8</td>
<td>&lt;16 m</td>
</tr>
<tr>
<td>4 m</td>
<td>&gt;1.0</td>
<td>&lt;17 m</td>
</tr>
<tr>
<td>4.5 m</td>
<td>&gt;1.2</td>
<td>&lt;18 m</td>
</tr>
<tr>
<td>5 m</td>
<td>&gt;1.6</td>
<td>&lt;21 m</td>
</tr>
<tr>
<td>5.5 m</td>
<td>&gt;1.8</td>
<td>&lt;24 m</td>
</tr>
<tr>
<td>6 m</td>
<td>&gt;2.5</td>
<td>&lt;27 m</td>
</tr>
</tbody>
</table>

(a) Mining height is 2m
Figure 1 Relationship curves of coal strength and coal thickness under different mining height

(b) Mining height is 3.5m

(c) Mining height is 5m
Fig. 1 shows that in triangle area surrounded by 2 curves from expression (4) and (8), and horizontal line standing for mining height, top-coal thickness and coal strength are adaptable for full-mechanized caving mining with large mining-height. Y-axial coordination of two curves’ intersection point is upper limit of top-coal thickness. Intersection point of curve 1 from expression (8) and horizontal line is lower limit of coal strength. At this point, top-coal thickness is zero, that is, requirement of usual full-mechanized mining.

Fig. 1 also shows that with coal strength increasing, coal-wall stability improve and upper limit of mining height increase when coal strength is small. When coal strength is over some degree, upper limit of mining height decrease because of influence of top-coal mining ratio. This shows that in soft coal-seam, application of full-mechanized caving mining with large mining-height is dependant on whether coal-wall stability can be ensured or not; in hard coal-seam, it is dependant on whether top-coal caving degree is good or not. Adding mining height can obviously increase upper limit of single-mining coal-seam thickness, but adding mining height need improve lower limit of coal strength. When mining height is larger than 3.5m, for making coal-wall stable, Protogyakonov’s coefficient of coal strength shall be larger than 0.9, therefore, for full-mechanized caving mining with large mining height, Protogyakonov’s coefficient of coal must be larger than 0.9. When coal thickness is larger than 21m, mining height must be larger than 5m and Protogyakonov’s coefficient of coal must be larger than 1.6 for obtaining good top-coal caving degree and making coal-wall stable.

6. Conclusions

(1) Full-mechanized top-coal caving mining with large mining height is beneficial for solving methane concentration problem in mining face with high output and high efficiency.

(2) 2 main problems in full-mechanized caving mining with large mining-height include that higher mining height may reduce coal-wall stability and result in coal or roof fall, and that top-coal caving degree may be affected by larger top-coal height.

(3) Coal thickness, coal strength and mining height are main factors of influencing adaptability of full-mechanized caving mining with large mining-height. For ensuring coal-wall stability and obtaining good top-coal caving effect, relationship expressions of mining height, coal thickness and Protogyakonov’s coefficient of coal strength are put forward and corresponding requirement for lower limit of coal strength and upper limit of coal thickness are obtained.

References
