Parameters Optimization of Airtight Wall in Crossheading of Fully-Mechanized Caving Face using FLAC-3D Software

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Abstract — Airtight wall in cross-heading is the key ventilation between two neighboring working faces, it is also an effective barrier to ensure the safety of mining for the adjacent working face. In order to calculate the reasonable thickness and location of airtight wall filled with fly ash in cross-heading of 8617 working face in YunGang coal mine, different simulated working conditions were determined based on the pressure distribution of roof in cross-heading and model of minimum thickness. Mechanical parameters of strata and fly ash curing material as well as constitutive model were determined, then ANSYS software was adopted to establish numerical model of airtight wall in cross-heading of comprehensive face. It also determined: i) the corresponding boundary conditions, ii) different working conditions of airtight wall stress, and iii) deformation and damage, and all were simulated and analyzed combined with FLAC 3D. Furthermore, i) the distribution of stress field, ii) displacement field and iii) plastic zone under different conditions of airtight wall is substantially similar. As the length of cross-heading is 20m, the rational position of airtight wall is the distance to intersection which is 15m, and reasonable thickness is 4.9m.

Keywords - Fully-mechanized caving face; Crossheading; Airtight wall; Reasonable thickness; Constitutive model

I. INTRODUCTION

The coal mining technology has made considerable progress since the 2000s, the production capacity of mine has been greatly improved, new mining technologies springing like mushroom, which has brought new challenges to the fire prevention for mine[1], as has been generally manifested that vast majority of mine mining in the methods of dual lane tunnel, the number of crossheadings between the two lane has been increasing, the distance between the two lanes is quiet short, in order to ensure the smooth conduction of mining and safety in production, it is necessary to seal the crossheadings between two neighboring goaf timely, on the one hand, which can easily increase labor intensity for workers, increase the workload of coal mining and reduce the airtight in quality significantly, on the other hand, it will lead to a close collusion between mining empty area so that develop into a large area of air leakage easily, and then increase the probability of spontaneous combustion of working face and even the residual coal in goaf. Once the position and thickness of airtight wall were selected improperly, the airtight wall could be fractured easily, collapsed, produce a large amount of air leakage fissures, air leakage channels could be produced under the original negative pressure ventilation, it is likely to cause coal spontaneous combustion in two adjacent working face. In addition, it is easy to cause stress concentration of airtight wall in crossheading and will produce air leakage channels under the influence of mine pressure as well as dynamic mining pressure.

Numerous theoretical and experimental research on fill airtight wall has been done by coal science and technology workers domestic and international, Wangguang Hong [2] based on the spontaneous combustion and coal dust explosion hazard in acid thorn coal, combined with mechanical parameters of coal and rock physical and geological conditions, employed theoretical analysis and numerical simulation calculate the reasonable section of sealing wall. Lu Hai-choa and He Tao[3] established the numerical model of sealing wall in mechanized caving face by ANSYS. Then they studied the laws of stress-strain under different conditions, gained the reasonable parameters of sealing wall. Huang Jianjun and Qiao Dengpan [4] analyzed the mechanical properties of backfilling slurry and the special features of airtight wall, induced the calculation model of airtight walls. Lastly, the limit equilibrium conditions are built by combining Ken Lang theory with single-phase liquid and loose medium as carrier mediums. The changes about properties and physical state of slurry are analyzed to optimize the structure and force calculation of the wall. Zhang jie and Li yu[5] analyzed stress state of the sealing wall structure under the condition of air bursting stress and obtained the relations between the structure parameters and stress state for permanent sealing wall. Su Fu-peng and Zhou Xin-quan [6] adopted the comprehensive research method of theoretical analysis, field measurement, and numerical calculation, studied the influence law of the
periodical change of the atmospheric pressure on the airtight-wall leakage rate. Tang ZiBo and Zhao YongLiang [7] based on the theories and models related to the foamed concrete and blasting shock load, using the numerical analysis method, this study obtains the new material’s mechanical and destruction laws through analyzing its reaction to different conditions of load. Luo Zhenmin and Deng Jun[8] analyzed the effects of monomer, cross-linker, and accelerator content on the mechanical property of seal-filling hydrogel material for building hermetic wall through a series of single-direction compression experiments. Xu Liang-Ji and Xu Shan-Wen[9] investigated the optimum cover soil thickness of reclamation land, they found that the thickness of 55-70 cm is the optimum cover soil thickness, and the pH value is 8. 15. soil nutrient content of N, P, K are 6. 272, 26. 253, 143. 76 mg/KG, respectively. 

As to the airtight wall construction in Yungang Mine, ANSYS, FLAC 3D were used to simulate the stress, deformation and failure of airtight wall under different working conditions, interpret the reasonable parameters of the airtight wall from the perspective of numerical simulation.

II. GENERAL SITUATION OF WORKING FACE

The spontaneous combustion rank of coal in Datong Yungang Mine 8617 working face is the first order. The coal is compact and hard, with developed fissures, the average thickness is 5. 8m, the average thickness of sandstone and medium sandstone on the top of mudstone are 13. 2m and 28. 6m respectively. After completing coal mining the 8617 working face, at this moment, the distance from working face to stopping line is 20m. the neighbor working face 8612 is prepared to be mining, the initial mining location away from cores sheading is 40m.

To guarantee safe and efficient mining for neighbor working face 8612, it is very necessary to build an airtight wall in the crossheading between the two working face. Fly ash curing material was used to fill in airtight wall, since the complexity of airtight wall in crossheading and influenced by many factors, so it is indispensable to determine the reasonable position and thickness of airtight wall.

III. WORKING CONDITIONS AND NUMERICAL SIMULATION MODEL

A. Numerical Simulation Working Conditions

Before the crossheading was excavated, affected by the the neighbor working face, lead abutment pressure of the entire pillar present continuous increase in regular and decrease thereafter. After the tunnel excavation and coal mining, stress concentration produced in the edge of coal pillars, working face and the groove on both sides of pillar will generate its own plastic zone. Then the coal pillar excavate crossheading will be divided into two contact pillars, the internal pressure of original pillar has been released certainly, the abutment pressure of roof redistribution in stress affected by extractive activities. Vertical stress and subsidence of crossheading roof surface was simulated with FLAC 3D, were shown in Fig. 1 and Fig. 2, respectively.

As can be seen from Fig. 1, with the change of the distance from the intersection, the change of pressure on crossheading surface of is extremely complex, which can be divided into two phases: compressive stress phase and tensile stress phase, among which peak stress focused on the distance between the intersection 0m~3m and 9m. As can be seen from Fig. 2, the farther away from the intersection, the smaller the roof subsidence, and both varies linearly. Since airtight wall mainly support the roof, so choose the low-voltage stress phase (distance from intersection are 5m, 10m, 15m respectively).

Reference[10] deduced the minimum theoretical thickness formula of permanent sealing wall as follows:
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\begin{align*}
H_1 &= \frac{0.15qL_0}{2Pb} \\
H_2 &= \frac{3qL_0^2}{6f} \\
H &= \max\{H_1, H_2\}
\end{align*}
\]

Where,

\(P\) — The average compressive strength of sealing wall, \(\text{Pa}\);

\(b\) — width of sealing wall, \(\text{m}\);

\(H_1\) — thickness of sealing wall 1, \(\text{m}\);

\(H_2\) — thickness of sealing wall 2, \(\text{m}\);

\(L_0\) — height of sealing wall, \(\text{m}\).

By substitution of relevant parameters into the formula (1), the minimum theoretical thickness of sealing wall is 4.4 m.

In order to verify the reasonable thickness of sealing wall, different working conditions should be simulated and analyzed, the certain conditions were shown in table 1:

<table>
<thead>
<tr>
<th>Working conditions</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
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</thead>
<tbody>
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<td>5</td>
<td>10</td>
<td>10</td>
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<td>15</td>
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</tr>
<tr>
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<td>4.4</td>
<td>4.4</td>
<td>4.9</td>
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</table>

B. Numerical Models and Boundary Conditions

According to geological conditions of 8617 working face, numerical model was established with FLAC 3D. Based on modeling requirements and the actual situation, choosing the center of airtight wall in the return airway intersections as the coordinate axis, the direction of mining is the X positive direction. Crossheadings center to the 8617 working face is the Y positive direction, vertical upward is the Z positive axis. Numerical simulative range were selected as x direction 300 m, y direction 140 m, z direction 110 m, intake airflow roadway and return airway of 8617 working face are both rectangular roadway, width×height= 5.4 m×3.5 m. The crossheading: width×height= 3.8 m×3 m. Numerical models of original rock geology, working face excavation and airtight wall were shown in Fig. 3 to Fig. 5 below.
The two upper boundary conditions: the upper boundary is stress boundary, the load is simplified to a uniform load, the value is determined by simulating the thickness of strara. Exerting 7.5 MPa vertical stress to the upper model.

The two lower part of the boundary conditions: bottom boundary is displacement restriction, bottom clamped, the velocity in x, y direction of is zero.

Boundary conditions on both sides: both sides of the boundary are the displacement boundary, the velocity in x direction of is zero.

C Mechanical Parameters and Constitutive Model

In accordance with practical application, concrete curing materials was applied to filling in airtight wall, and Mole constitutive model is corresponding to the cement loose particles just as fly ash and other materials, it is also an engineering guidelines that the most commonly used in geotechnical, whose guidelines governing equation[11] is showed as follows:

$$f_s = \frac{\sigma_1 - \sigma_3}{1 - \sin \phi} = 2c \sqrt{\frac{1 + \sin \phi}{1 - \sin \phi}}$$  \hspace{1cm} (2)

where,

$\sigma_1$ --- the maximum and minimum principal stress.

$\sigma_3$ --- the minimum principal stress.

c --- the adhesion.

$\phi$ --- the friction angle.

If $f_s > 0$, the material will produce shear failure.

Mechanical parameters of strara and fly ash filling material are shown in table 2 and table 3 respectively.

IV. ANALYSIS OF SIMULATION RESULTS

According to the numerical models and constraints established above, FLAC 3D was used to simulate the distribution of stress, displacement and damage of airtight wall under different conditions.

A. The Maximum vertical Stress

According to the simulation results, the maximum vertical stress of each condition was extracted with fish...
function and then draw the relationship among stress, thickness and position, was shown in Fig. 6.

As can be seen from Fig. 6, the distance between airtight wall and intersection is 5m, with the increase of airtight wall thickness, the maximum vertical stress increases as well. With per 0.5m additional of thickness, the average increase of maximum vertical stress is $4 \times 10^5$ Pa. The distance between airtight wall and intersection is 10m, with the increase of airtight wall thickness, the maximum vertical stress increases as well. With each additional 0.5m of thickness, the average increase of maximum vertical stress is $4 \times 10^5$ Pa. The distance between airtight wall and intersection is 15m, with the increase of airtight wall thickness, the maximum vertical stress increases as well.

### B. The Maximum Vertical Displacement

According to the simulation results, the maximum vertical displacement of each condition was extracted with fish and then draw the relationship among stress, thickness and position, was shown in Fig. 7.

As can be seen from Fig. 7, the variation law of maximum deformation was similar to that of the maximum stress. The distance between airtight wall and intersection is 5m, with the increase of airtight wall thickness, the maximum vertical deformation increases. With each additional 0.5m of thickness, the average increase of maximum vertical deformation is 0.005m. The distance between airtight wall and intersection is 10m, with the increase of airtight wall thickness, the maximum vertical deformation increases. With each additional 0.5m of thickness, the average increase of maximum vertical deformation is 0.0051m. The distance between airtight wall and intersection is 15m, with the increase of airtight wall thickness, the maximum vertical deformation increases as well.

If the thickness of airtight wall is a constant, with the increase of distance to the intersection, the vertical deformation decreases, if the thickness exceed 10m, closed walls produce plasticity damage at different degrees, vertical deformation of the inner wall decreases as well. If the thickness exceed 15m, the average vertical deformation of the airtight wall was reduced to 0.067m. When the thickness is 4.9m, distance to the intersection is 15m, the maximum vertical deformation is reduced to 0.065m, therefore, there exist a reasonable thickness and location for airtight wall, it seems to be 15m away from the intersection, and the thickness of 4.4m or 4.9m.

### C. Characteristics of Plastic Zones

Figure 8 according to the simulation results, the damage volume and damage ratio of each condition was extracted with fish function and then draw the relationship among maximum vertical deformation.
damage volume and damage ratio, thickness and position, was shown in Fig. 8 and Fig. 9.

As can be seen from Fig. 8 and Fig. 9, the variation law of damage volume was similar to that of the damage ratio. The distance between airtight wall and intersection is 5m, with the increase of airtight wall thickness, the damage ratio increases. With each additional 0.5m of thickness, the average increase of damage ratio is 1.87%. The distance between airtight wall and intersection is 10m, with the increase of airtight wall thickness, the damage ratio increases. With each additional 0.5m of thickness, the average increase of maximum damage ratio is 1.88%. The distance between airtight wall and intersection is 15m, with the increase of airtight wall thickness, the damage ratio increases as well. If the thickness of airtight wall is constant, with the increase of distance to the intersection, the damage ratio decreases, if the thickness exceed 10m, closed walls produce plasticity damage at different degrees, damage ratio of the inner wall decreases as well. If the thickness exceed 15m, the average damage ratio of the airtight wall was reduced to 61.08%. When the thickness is 4.9m, distance to the intersection is 15m, the damage ratio is reduced to 55.63%.

Combining the numerical simulation results of the maximum vertical stress, the maximum vertical displacement and damage volume depends on the location and thickness of wall. Therefore, when the maximum vertical stress, maximum deformation and damage volume come up to the minimum, then the position and the thickness of the wall will be the best choice. According to the simulation results, if the length of the crossheading is 20m, the reasonable position for the airtight wall is 15m away from the intersection, the reasonable thickness is 4.9m.

V. CONCLUSIONS

As to the practical situation of YunGang Mine, the reasonable position and thickness of airtight wall in 8617 working face were studied with FLAC 3D, some conclusions are obtained as follows:

(1) To analysis the airtight wall in crossheading, the weight of the overburden and mining destruction caused by pressure on the airtight wall should be considered, study the reasonable arguments of airtight walls from the perspective of qualitative and quantitative. Set Shanxi Datong Yungang Coal Face in 8617 for an example, numerical models of the original rock geology, excavation crossheadings were established with FLAC 3D, got the distribution law of pressure and subsidence on roof surface in crossheading, results showed that: variation of pressure is rather complex, which can be divided into tensile phase and compressive stresses phase, the farther away from the roadway intersection, the smaller the roof subsidence.

(2) According to the distribution law of pressure and mechanism of airtight wall, a reasonable estimate of the airtight wall position as well as theoretical thickness formula, designed a variety of simulation working conditions and established the boundary and initial conditions for airtight wall.

(3) A three-dimensional numerical model of airtight wall in crossheading was build with FLAC 3D, stress field, displacement field and plastic zones and other related properties under different conditions has been obtained. Results shows that: the damage types of airtight wall in crossheading are tension-shear, tension and shear. The difference in the maximum stress, the maximum displacement, plastic zone under different conditions are obvious. Stress effect at the intersection on the airway can be superimposed and minimize the impact of mining face when distance to intersection is 15m, thus the stability of the airtight wall can be ensured. If wall thickness exceed 4.9m, the changes in deformation is not significant and the damage decreased to a minimum, therefore, according to the simulation results, if the length of the crossheading is 20m, the reasonable position for the airtight wall is 15m away from the intersection, the reasonable thickness is 4.9m.

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