

Study on Sealing Depth Optimization of Gas Drainage Borehole in Coal Seam

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Abstract—To determine the reasonable sealing depth of the drainage borehole in the coal seam along lane W33011 of the Sihe coal mine and improve sealing quality based on the mine geological conditions, FLAC3D numerical simulation software was used to simulate the stress distribution and fracture development of coal body around the roadway after the roadway excavation. YFZ3 hole sealing quality detector was adopted to detect the hole sealing quality and leakage position. The reasonable drilling depth in the test area was determined to be 15m, effectively improving the gas drainage effect. This technology has important reference significance for improving the quality of hole sealing in other mines.

1 Introduction

In China, 95% of coal mines belong to underground mining, with complex production conditions and difficult gas control. For a long time, gas drainage in coal seams has been one of the important technologies for gas control, but according to statistics, about 65% of borehole gas drainage concentration along coal seams in China is lower than 30%, which affects the gas control effect [1-3]. The sealing quality affects the gas drainage effect of each borehole in the underground. Determining a reasonable sealing depth is the key to ensuring sealing quality. In the past, miners mostly relied on factors such as field experience and geological conditions to determine the sealing depth of the drainage borehole, which is somewhat blind and with big errors [4]. To determine the reasonable sealing depth of the drainage borehole, based on the on-site geological conditions in the test area, we used FLAC3D numerical simulation software to simulate the stress distribution and fracture development of the coal body around the roadway after the roadway excavation and used YFZ3 hole sealing quality detector to detect the gas and oxygen concentrations at different depths of the borehole. Thus, we determined the position of the gas leakage channel and the air tightness of the borehole, determined the reasonable sealing depth, and effectively improved the hole drainage effect.

2 Determination of Sealing Depth

After the roadway excavation affected the original coal body, the stress equilibrium state was destroyed. The coal body around the roadway changed from a three-dimensional stress to an approximate two-dimension stress state. The weight of the overlying coal body of the roadway is transferred to the sides of the roadway, which causes the

stress concentration phenomenon of the coal body around the roadway [5-6]. According to the different mechanical conditions, the stress distribution of the surrounding coal body can be divided into three areas after roadway excavation: stress reduction area, stress concentration area, and original stress area [7]. The tensile strength of the coal body in the stress reduction area is low. When the tensile stress exceeds the tensile strength of the coal body, cracks will appear in the coal body around the roadway, forming a fractured zone. In the stress concentration area, the stress value of the coal body is greater than the original stress. When the stress value is greater than the strength of the coal body, the coal body will undergo plastic deformation, and due to the large stress value, boreholes are prone to deformation, hole collapse, and hole blockage. The stress and permeability coefficient of the coal body in the original stress area is relatively stable, which has little influence on the gas drainage of the drainage borehole. Therefore, the sealing depth of the drainage borehole should avoid the fractured zone of the coal body around the roadway and exceed the stress concentration area to effectively prevent the problems of gas leakage, hole collapse, and hole blockage in the process of gas drainage, and thus improve the gas drainage amount of drainage boreholes[8-9]. The fractured zone and stress distribution of the coal body around the circular roadway is shown in Figure 1.

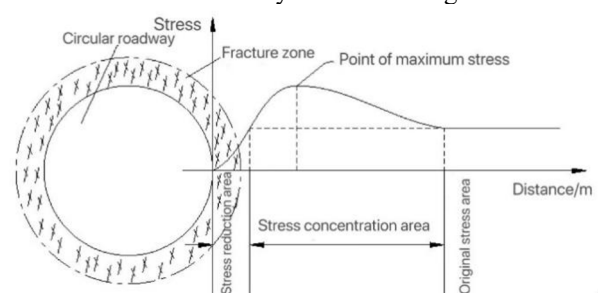


Figure 1. Schematic diagram of fracture zone and stress distribution of coal body around the circular roadway

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According to fluid mechanics, when the sealing effect of gas drainage borehole is good, the fluctuation of gas and oxygen concentration values with the change of borehole depth under negative pressure is small; when the hole sealing depth is insufficient, or the hole sealing quality is poor, the gas and oxygen concentration values in the borehole show a "benching" change from the bottom of the borehole to the hole mouth[10-11]. Therefore, by degerring the gas and oxygen concentration values at different depths of the drainage borehole, the sealing quality of the borehole and the location of gas leakage can

be accurately determined. Then the reasonable sealing depth can be determined. YFZ3 hole sealing quality detector is mainly used to determine the gas and oxygen concentration values at different depths in the drainage borehole under the pumping state and to determine the sealing quality of the drainage borehole and the location of the leakage channel in the borehole. The device mainly comprises a main unit, gas parameter detector, and quick tee. The device composition and connection method are shown in Figure 2.

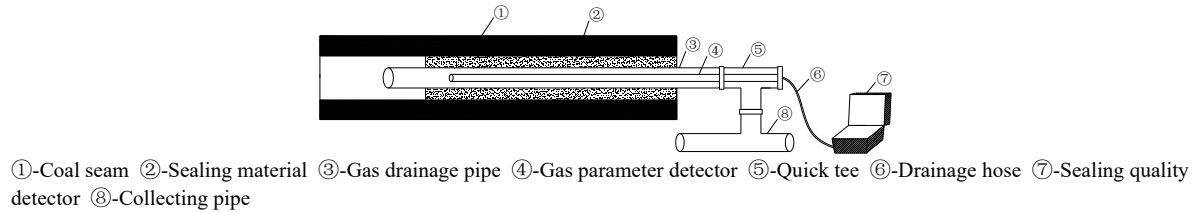


Figure 2. Schematic diagrams of the connection of the hole sealing quality detector

3 Numerical Simulation of Roadway Excavation

3.1 Roadway Overview

The working face along lane W33011 is a solid coal roadway with a coal-seam thickness of about 2.5 m. The roadway section is rectangular and has a section size of 5×3.8 m². The roadway is excavated along the floor, and rock bolts and anchor cables support the roof, and two sides;

the bolts are 1 m apart, the spacing is 0.9 m, each row of 6 pieces, and the anchorage stress is not less than 190 kN. The length of the anchor cable is 7.3 m, the anchor cable spacing is 1.8m, the row spacing is 2 m, and the pre-tightening force of the anchor cable is ≥ 250 kN. The roadway's rock stratum distribution and lithology parameters were determined based on the actual drilling data. The rock mechanics parameters were determined based on the actual measured data of mine exploration. The mechanical parameters of each rock stratum along lane W33011 are shown in Table 1.

Table 1 Physical and mechanical parameters of coal (in order of overlying strata of coal seam)

Coal or rock seams	Thickness/m	Elastic modulus/GPa	Poisson's ratio	Bulk modulus/GPa	Shear modulus/GPa	Frictional angle /°
Medium sandstone	8.89	7.02	0.352	7.91	2.6	33
Sandy mudstone	4.00	6.99	0.304	5.94	2.68	33
Carbon mudstone	0.30	6.9	0.34	7.19	2.57	30
3#coal seam	2.50	1.5	0.26	1.04	0.6	25
Fine siltstone	2.10	6.89	0.33	7.34	2.46	30
Medium sandstone	3.20	7.02	0.352	7.91	2.6	33

3.2 Modeling

We used the FLAC3D numerical simulation software to simulate numerical simulation of the stress distribution and fracture development of the coal body around the roadway during roadway excavation. The model adopts the Mohr-Coulomb model, which is established using a brick element with a model size of $50 \text{ m} \times 20 \text{ m} \times 50 \text{ m}$, the simulated roadway length is 20 m, and anchor bolts and cables are applied in the form of cables[12]. The bottom and sides of the model adopt zero displacement boundaries. The left and right boundaries of the model adopt a single constraint boundary, taking $u = 0, v \neq 0$, and u, v are the displacements of X and Y, respectively; the lower

boundary of the model is defined as a fully constrained boundary, taking $u = v = 0$; the upper boundary of the model is defined as a free boundary; the weight of the overlying rock layer of the model is applied to the upper boundary of the model as external load, and the model frame and the model roadway support are shown in Figure 3 and Figure 4.

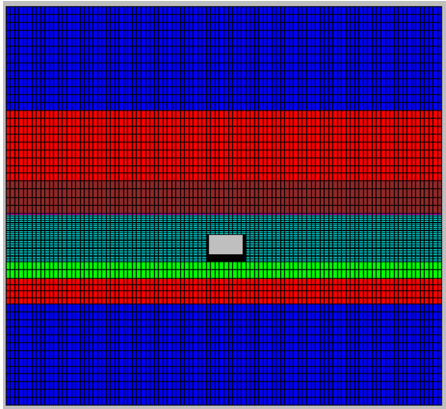


Figure 3. Model frame diagram

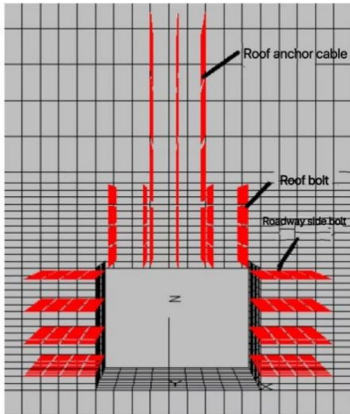


Figure 4. Model roadway support diagram

3.3 Simulation Analysis

The distribution characteristics of vertical stress after roadway excavation and support are shown in Figure 5, and the effect after being processed by Tecplot software is shown in Figure 6. It can be seen from the figure that the maximum vertical stress of roadway surrounding rock is 20.28 Mpa, 4 m away from the coal pillars, the stress concentration area is 3-14 m away from the coal pillars wall, and the vertical stress is less than the original vertical stress of coal body in the range of 0-3 m away from the coal pillars. The coal body in this area is severely damaged, the strength of the coal body is reduced, and the stress of surrounding rock is transferred to the depth of surrounding rock, which belongs to the range of fracture zone.

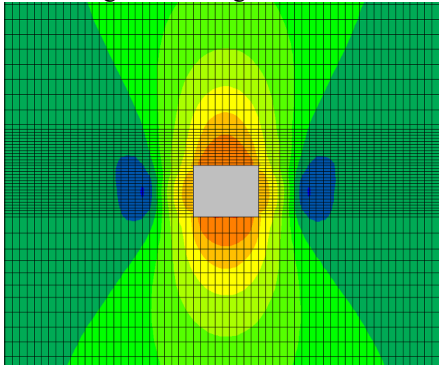


Figure 5. Cloud diagram of vertical stress distribution simulated by FLAC3D

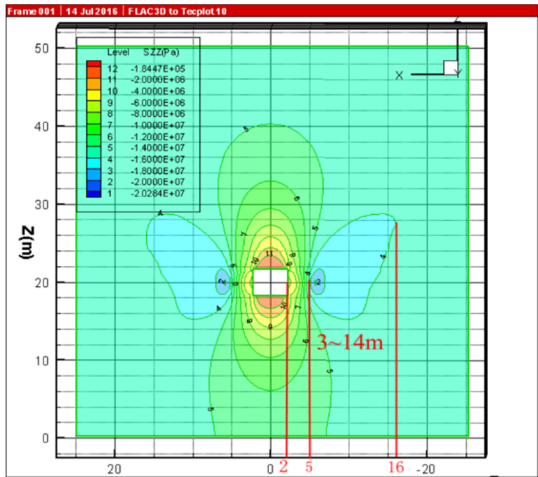


Figure 6. Isogram of vertical stress after Tecplot Post-processing

The distribution of the plastic zone, displacement vector, and change of displacement value of the surrounding coal body after the roadway excavation and support are shown in Figure 7, Figure 8, and Figure 9. It can be seen from the figure that the plastic zone and displacement of the roadway roof and roadway walls are obvious after the roadway excavation, the roof falls, and the compression fracture zone of the roadway walls also increased significantly, the displacement of the floor is small, but the surface surrounding rock underwent obvious compressive damage. The displacement value of the coal body tended to be stable at the position 14 m away from the roadway walls.

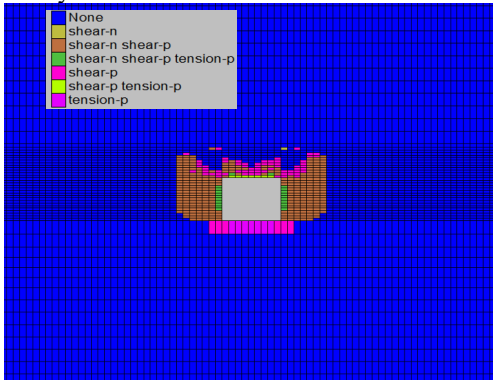


Figure 7. Distribution characteristics of plastic zone in roadway surrounding rock

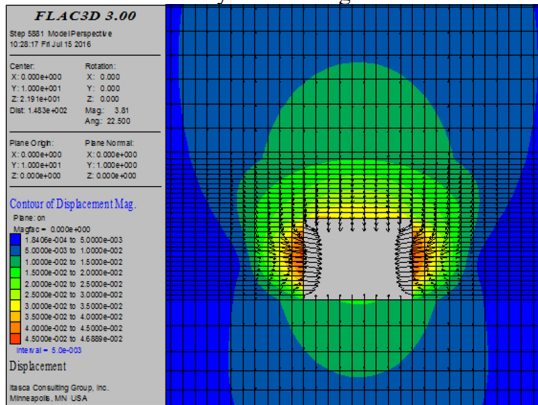


Figure 8. Vector diagram of roadway surrounding rock displacement

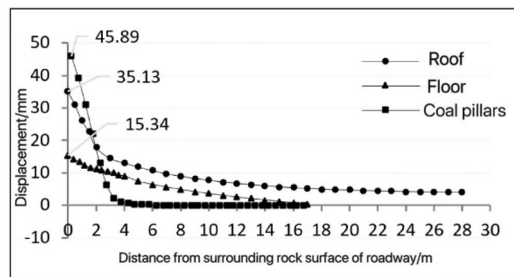


Figure 9. Displacement distribution of measuring points

4 Sealing Quality Inspection

YFZ3 hole sealing quality detector was used to detect the hole sealing quality of the drainage borehole in the coal seam along lane W33011 in the working face of the Sihe coal mine. By measuring the gas and oxygen concentration values at different depths in the drainage borehole under negative pressure, the hole sealing quality and the position of the leakage channel are determined to improve the parameters such as the hole sealing depth and sealing method, and thereby improve the gas extraction concentration of drainage borehole. The parameters of each borehole are shown in Table 2.

Table 2 Record table of drainage parameters

Borehole No.	Bore diameter/mm	Tilt angle/°	Bore depth/m	Hole sealing depth/m	Drainage negative pressure/kpa
3-1	113	5	108	12	22
3-2	113	3	96	12	22
3-3	113	5	100	14	22
3-4	113	4	112	14	22
3-5	113	5	108	16	22
3-6	113	3	98	16	22

The change of gas and oxygen concentration values with hole depth in each borehole is shown in Figure 10 below.

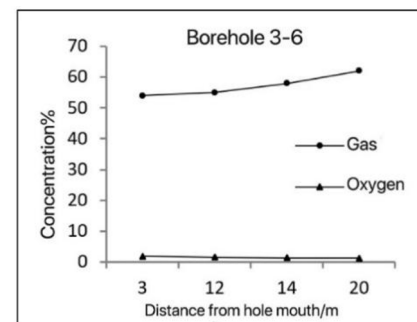
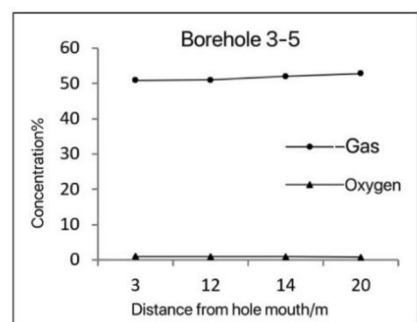
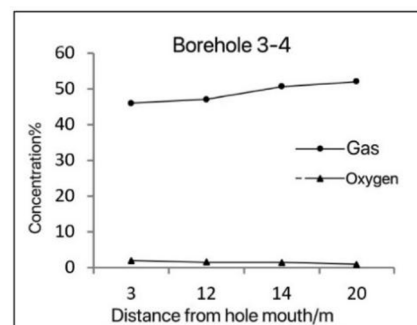
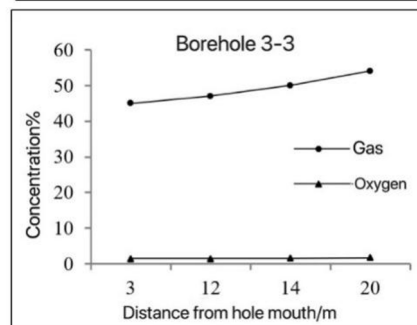
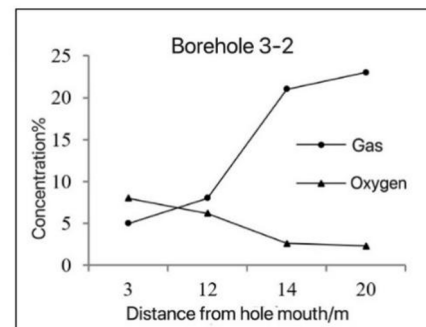
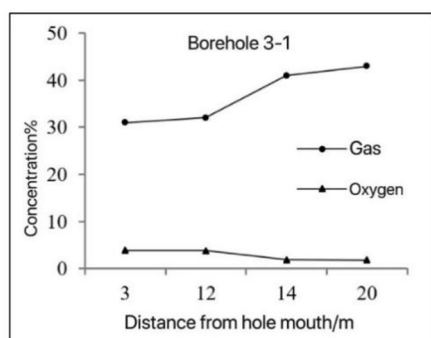


Figure 10. Line chart of gas and oxygen concentration values in boreholes changing with hole depth

It can be seen from the line chart that when the hole sealing depth is 12 m, the gas and oxygen concentration values fluctuate greatly with the increase of the hole depth in the range of 12-14m, and there are problems with gas leakage channels, insufficient hole sealing depth in this

range; when the hole sealing depth is 14m and 16m, the gas and oxygen concentration values in the hole did not show "steplike" sudden change with the increase of hole depth, and the hole sealing effect is good. To save sealing materials, the hole sealing depth should be 14 m.

5 Conclusion

According to the stress distribution of the surrounding coal body after roadway excavation, combined with FLAC3D numerical simulation and quality inspection of borehole sealing in the test area, it can be concluded that:

(1) After roadway excavation, there are a large number of cracks in the surrounding coal body in the stress reduction area, which can directly form gas diffusion channels with the main roadway; drilling in stress concentration areas is prone to problems such as deformation, hole collapse, and hole blockage. The depth of borehole sealing should avoid the coal body fracture zone around the roadway and exceed the stress concentration area to improve gas drainage more effectively.

(2) Using FLAC3D numerical simulation software to simulate the stress distribution and fracture development of coal body around the roadway after the roadway excavation, using YFZ3 hole sealing quality detector to detect borehole leakage position, then through comparative analysis, it is learned that the reasonable sealing depth in the test area along lane W33011 of Sihe coal mine was 14m.

(3) Due to the different geological conditions, burial depth, and gas content in different areas of the mine, the reasonable sealing depth of the drainage borehole is also different, so FLAC3D numerical simulation software shall be used to simulate the stress distribution and fracture development of coal body around the roadway after the roadway excavation, and YFZ3 hole sealing quality detector shall be used to detect the hole sealing quality and leakage position of the borehole, to determine the reasonable sealing depth in the area.

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