Numerical simulation of fluid-solid coupling of stress failure characteristics of floor in coal mining face

Weizheng Wu, ZHonghua Wang*

China Coal Technology Engineering Group Chongqing Research Institute, Chongqing 400037

* Corresponding author's e-mail: boaidajia2007@126.com

Abstract: In order to explore the characteristics of floor stress failure in the mining face under the action of non-uniform water pressure, a fluid-solid coupling model of non-uniform water-bearing area was established. FLAC-3D simulation software was used to simulate and analyze the changes in the initial mining stage, the sudden stress increase stage, the stress slow increase stage, and the stable stress stage during the mining process of the working face, and the failure characteristics of the floor were analyzed. It reveals the reasons why water inrush accidents are likely to occur at the front of the working face, which has a certain significance for understanding the mechanism of water inrush from the floor.

1. Introduction

The water hazard caused by coal mining is a serious threat to life and property safety. According to statistics, among the serious and serious accidents in my country's state-owned coal mines, water disasters rank second only to gas accidents in the number of deaths. Experts and scholars have conducted a lot of research on the mechanism of water inrush from the floor, and have achieved fruitful results. However, the research is mainly based on the water inrush of uniform water pressure. In fact, the coal floor aquifer is heterogeneous, and only a small part of the area is filled with water and the water pressure is evenly distributed. Water inrush exaggerates the danger of water inrush. In this paper, fluid-solid coupling numerical simulation is used to study the stress failure characteristics of the floor under the action of non-uniform water pressure on the working face, in order to deepen the understanding of the mechanism of water inrush from the floor.

2. Construction of fluid-solid coupling model for non-uniformly distributed water-bearing zone

2.1. Boundary conditions of the model

The bottom plate of the model adopts the bottom boundary condition, and the vertical displacement of the bottom of the model is taken as zero; the front, back, left, and right boundaries adopt lateral constraints, that is, the displacement in the x and y directions is taken as zero.

The seepage boundary is the first boundary condition, using a fixed water pressure boundary, the saturation of the aquifer rock mass is 1, the initial water pressure inside the floor changes according to the gradient water pressure, and the mined-out area after mining is the drainage boundary, so the mined-out area The boundary takes the fixed water pressure as zero.

2.2. Numerical model

This simulation uses FLAC-3D simulation software, Mohr-Coulomb (Mohr-Coulomb) mechanical
constitutive model, the length and width of the model is 300m×300m×150m, and the coal roof and water barrier adopts a rectangular grid of 10m×10m×5m. Carrying out dense subdivision of the bottom waterproof layer, using a rectangular grid of 10m×10m×2m, the model has 37,800 units and 41,323 nodes in total, and the three-dimensional numerical calculation model is shown in Figure 1.

![Three-dimensional numerical calculation model diagram](image1.png)

Figure 1 Three-dimensional numerical calculation model diagram

The water-rich area is located in two lanes with a size of 50m×300m along the strike, and the model is simulated when the water pressure is loaded with 4MPa. Each model is excavated at a step of 20m. After the calculation is cycled until the rock formation is stable, the excavation is continued. Until the working face advances to 200m, a total of 10 steps are excavated. Each rock layer is selected according to the actual thickness of a coal mine in Anhui, and the mechanical parameters are determined by the laboratory. With reference to the existing research results, according to the simulation results, the stress distribution and failure characteristics of the floor in the water-rich area during the pushing and mining process are studied.

3. The distribution law of floor mining stress

3.1. Initial stress distribution characteristics

Figure 2 is the initial equilibrium stress diagram of the model when the water-rich area is located in two lanes, the size is 50m×300m along the strike, and the water pressure is 4MPa.

![Initial equilibrium stress diagram](image2.png)

Figure 2 Initial equilibrium stress diagram

It can be seen from Figure 2 that the initial stress is basically distributed in layers under the combined action of gravity and water pressure, that is, the stress gradually increases from top to bottom; however, there is a stress increase zone at the water-rich area where the water pressure is applied. The enlarged area gradually decreases from the middle to the sides. It can be seen that the water pressure in the rich water area also has a certain destructive effect on the coal seam floor when it is not mined.

3.2. Mining stress distribution characteristics

During the process of advancing the working face 20~200m, the stress of the working face floor can be divided into the initial stage of mining, the stage of sudden stress increase, the stage of slow stress increase, and the stage of stable stress. Show in the Figure 3.
3.2.1. Early stage of mining
Figure 3(a) and Figure 3(b) are respectively the 20m trend and vertical stress diagrams of the working face. It can be seen from Figure 3(a) that due to the excavation of the coal seam, a stress reduction zone appears on the bottom of the goaf behind the working face. The depth of the reduction zone is about 10m, and the maximum supporting stress in front of the working face reaches 15MPa (the stress is compressive stress). It is a negative value, the same below), which is 1.37 times of the initial ground stress (11MPa), the pressure peak area is 10-11m away from the working front, and the leading influence range of the abutment pressure is about 25m.

It can be seen from Figure 3(b) that there is also a stress reduction zone with a depth of about 10m in the bottom of the goaf behind the working face. The deep stress contour of the bottom is bent due to the action of confined water, and the stress contour is directed towards the deep part. The trend of extension, that is, the stress is reduced in the depth of the bottom plate, and the effect is not obvious, and the main effect is in the lower part of the water barrier.

3.2.2. Stage of sudden stress increase
Fig. 3(c) and Fig. 3(d) are respectively the stress diagrams of the direction of the working face advancing 40m and the vertical inclination. It can be seen from Figure 3(c) that due to the excavation of the coal seam, there is a stress reduction zone with a depth of about 15m in the bottom of the goaf behind the
working face. The maximum supporting stress in front of the working face is up to 18MPa, which is 1.64 of the initial ground stress (11MPa). The peak pressure area is 10~12m away from the working front, and the leading influence range of the supporting pressure is about 28m.

From Figure 3(d), it can be seen that there is also a stress reduction zone with a depth of about 15m in the bottom of the goaf behind the working face. The deep stress contour of the bottom is bent due to the action of confined water, and the stress contour extends to the deep part. The trend is that the stress is reduced in the depth of the bottom plate. With the progress of pushing and mining, the influence range of the stress contour increases, but the main influence is in the lower part of the water barrier.

3.2.3. Stress slow-increasing stage
Fig. 3(e) and Fig. 3(f) are respectively the trend and inclined vertical stress diagrams when the working face advances 120m. It can be seen from Figure 3(e) that with the progress of pushing mining, the influence range and depth of the floor stress reduction zone in the goaf behind the working face gradually increase, and the maximum influence depth basically stabilizes, about 40m; the front support of the working face The maximum stress also gradually increased, reaching 28.1 MPa, which is 2.56 times the initial ground stress (11 MPa). The pressure peak area is 14-17m from the front of the work face, and the leading influence range of the supporting pressure is about 35m.

It can be seen from Figure 3(f) that with the progress of pushing mining, the change law of the floor stress reduction area and the strike direction in the goaf behind the working face is similar. The stress reduction area gradually increases with pushing mining, and the maximum impact depth is 42m; The degree of bending of the deep stress contour with the push mining slows down, that is, the influence range of the stress in the depth of the bottom plate increases, and it gradually affects the water barrier, and the influence range is mainly in the middle and lower parts of the water barrier.

3.2.4. Stable stress stage
Fig. 3(g) and Fig. 3(h) are respectively the trend and inclined vertical stress diagrams when the working face advances 200m. It can be seen from Figure 3(g) that when the working face is pushed to 200m, the influence range and depth of the floor stress reduction zone reach a maximum of 42m; the maximum bearing stress in front of the working face also reaches a maximum of 30.15MPa, which is the initial ground stress (11MPa) 2.74 times, the pressure peak area is 15~17m away from the working front, and the leading influence range of the supporting pressure is about 40m.

It can be seen from Figure 3(h) that the degree of bending of the deep stress contour of the bottom plate with the push mining slows down and basically tends to be smooth, which shows that the confined water has begun to affect the entire bottom plate.

4. Analysis of failure characteristics of floor mining
After the coal seam is mined, the plastic failure range of the surrounding rock is shown in Figure 4.
It can be seen from Figure 4 that with the recovery of the coal seam, the damage of the aquifer gradually increases (direct bottom and conduction zone), and the main form of damage is compression-shear damage. With the mining of the working face, the destruction of the floor water barrier gradually develops from top to bottom, and the damage zone is distributed in the direct bottom of the goaf. When the advancement is less than 40m, the failure zone is small, generally within 15m; when the working face advances to about 200m after two cycles of compression, under the action of the roof collapse load, the depth and extent of the plastic zone of the floor rock layer develop rapidly. It grows to the largest, reaching 20m.

5. Conclusion

Through simulation, it is found that as the working face advances, the range of the vertical stress concentration area of surrounding rock around the working face also expands, increasing from 25m to 40m. However, there is no obvious change in the peak stress concentration area, which is between 12 and 15m before the working face. When the working face advances less than 200m, the stress concentration factor increases with the mining of the working face, and the maximum stress concentration factor is 2.74.

Due to the continuous concentration and release of the advanced stress on the coal wall of the front floor of the working face, the leading damage of the front floor of the working face is caused. This is the cause of water inrush accidents at the front of the working face.

The fluid-solid numerical simulation is used to reproduce the characteristics of the floor stress failure during the advancement of the working face, and fully consider the effect of non-uniform water pressure. The simulation results are more in line with the actual project than the effect of uniform water pressure. The paper deeply understands the characteristics of stress failure of mining floor.

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