Numerical Simulation Study and Analysis of Water Inrush from Floor Concealed Subsidence Column during Mining

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Abstract: In order to clarify the role of mining on the surrounding rock failure and water inrush of the karst collapse column in the working face floor, the concealed karst collapse column in the floor of Geting Coal Mine is taken as the research object, and the FLAC3D numerical simulation software is used to analyze the mining process. The stress field in the vertical direction, the plastic failure zone and the displacement change in the vertical direction are analyzed and studied, and the water inrush process of the hidden floor karst collapse column under different advancing distances is analyzed. The research results show that with the continuous increase of the advancing distance, the plastic failure range of the karst collapse column continues to increase, and the vertical displacement of the floor continues to increase. When the plastic failure zone of the coal floor and the plastic failure zone of the karst collapse column are connected, Water inrush accidents from the karst collapse column of the floor are prone to occur.

1. Introduction
Mine water inrush has become one of the major disasters affecting coal mine safety production. Among them, the water inrush caused by geological structures (faults, collapsed pillars) accounts for 80% [1], among which collapsed pillars are responsible for coal mine water inrush accidents. One of the main geological structures that occurred, due to the existence of the collapse column, not only changed the original coal seam structure, but also reduced the coal recovery rate, and seriously affected the safety production of coal mines. Among the collapsed columns that have been exposed in coal mines in my country, although most of the collapsed columns are not water-conducting or water-free, many mining areas force through the collapsed columns during the actual working face advancement process, and generally, water inrush accidents from the collapsed columns rarely occur. However, since the 1960s, my country’s Fengfeng Jiulong, Luotuoshan coal mines, and Taoyuan coal mines have experienced many karst collapse column water inrush accidents, which have gradually attracted people’s attention. For the water inrush problem of the collapse column, domestic and foreign experts Scholars have conducted research from different research perspectives and have achieved certain research results [2-4]. Comprehensive analysis of case data of water inrush accidents from karst collapse column shows that water inrush from karst collapse column has the characteristics of concealment, large amount of water inrush, suddenness, causing serious losses, and expensive treatment. Therefore, water inrush from concealed collapse column on floor Research and analysis of the main control factors are of great significance for preventing coal mine water inrush and ensuring coal mine safety production.
2. Theoretical model of stress and seepage coupling

2.1. Analysis of the influence of stress field on seepage field

Rocks and coal seams are porous media, and their mechanical characteristics are mainly composed of the micro-permeable voids in the rock body and the joints and cracks between the rock bodies. Experimental studies have shown that the change of pore water pressure firstly induces effective stress change, and then it is possible to significantly cause the distribution of fluid pressure in the fracture. The regular formula that the permeability coefficient of the rock mass changes with the stress of the rock mass \[5-6]\:

\[
\Delta K = \frac{\rho g b^3}{12S \mu} \left[1 + \Delta \varepsilon \left(\frac{K_b}{E} + \frac{b}{S}\right)\right]^{\frac{1}{3}}
\]

(1)

It can be seen from the above formula that the stress field affects the permeability coefficient of the rock mass through the volumetric strain in the rock mass, thereby affecting the seepage field in the rock mass.

2.2. Analysis of the influence of seepage field on stress field

In the seepage medium, the water load is expressed by the seepage stress and the seepage volume force. The distribution of the seepage field corresponds to the distribution of the water load one by one. The seepage field changes the stress field distribution by changing the volume strain of the rock mass in the floor. Assuming that the water head distribution in the floor rock body is \(H(x, y, z)\), the distribution of seepage pressure \(P\) on a certain acting surface is calculated as:

\[
P = \gamma(H-Z)
\]

(2)

From this, the distribution of the seepage volume force \(f\) is calculated as:

\[
\begin{bmatrix}
f_x \\
f_y \\
f_z \\
\end{bmatrix} = \begin{bmatrix}
\frac{\partial \rho}{\partial x} \\
\frac{\partial \rho}{\partial y} \\
\frac{\partial \rho}{\partial z}
\end{bmatrix} = \begin{bmatrix}
\gamma \frac{\partial H}{\partial x} \\
\gamma \frac{\partial H}{\partial y} \\
\gamma \left(\frac{\partial H}{\partial z} - 1\right)
\end{bmatrix}
\]

(3)

2.3. Plastic failure criterion of surrounding rock of coal roof and floor

When the rock mass undergoes shear failure \((f_s < 0)\), after the rock mass reaches the yield limit, if there is a relatively large pressure, the rock mass will undergo failure and deformation. The tensile stress yield conditions are:

\[
f_s = \sigma_t - \sigma_s \frac{1 + \sin \varphi}{1 - \sin \varphi} + 2C \frac{1 + \sin \varphi}{1 - \sin \varphi}
\]

(4)

\[
f_f = \sigma_f - \sigma_s
\]

(5)

At that time of \(f_s < 0\), the coal seam rock mass suffered shear failure; at that time of \(f_f > 0\), the coal seam rock mass suffered tensile stress failure.

3. Constructing a numerical model of concealed karst collapse column in the floor

3.1. Mining area engineering hydrogeological conditions

The stratigraphic groups developed in the mining area are: Middle-Lower Ordovician, Benxi Formation, Taiyuan Formation, Lower Permian Shanxi Formation and Quaternary Clay Layers. The mining coal seams are located in the 16th and 17th coal seams of the Taiyuan Formation. The coal seams are located 30~80m above the Ordovician ash aquifer. The 16th and 17th coals are threatened by the Ordovician ash aquifer to varying degrees. The top of the top plate is referred to as mudstone,
siltstone, fine sandstone and siltstone, and the bottom plate is referred to as siltstone, mudstone, and limestone. According to the three-dimensional seismic exploration of Geting Coal Mine, a total of 3 collapsed columns (SX1, SX2, SX3) were found. Except for the larger collapsed column of SX1, the other two are smaller. Located at the edge of the southwest corner of the survey area, it has fallen to the 13th and Ordovician ash, 30m under the 17th coal floor and 60m away from the 16th coal. It is elliptical in the area, with the long axis in the NW direction, with a length of 80m, and the short axis in the NE direction, with a length of 60m and an area of 2436m2. There are altogether 11 fault points, of which 10 are A-level and 1 are B-level. Figure 1 shows the SX1 collapse column.

![ SX1 collapse column ](a) time profile display (b) coherent display

**Figure 1.** Collapse column of SX1

### 3.2. Boundary conditions and scheme design of the numerical model

The model is as follows: set the model's front, rear, left, and right to be horizontal constraints, the bottom is a fixed boundary and the vertical orientation is zero; the direction of the working face is along the X axis; the top pressure of the model is replaced by an equivalent load of 10MPa; Using a fixed boundary water pressure, the ideal water pressure of the aquifer is set to 2.4MPa, and the rock saturation is 1, which changes trapezoidally with the initial water pressure of the karst collapse column. The water pressure of the working face boundary after mining is taken as zero. The size of the model is $300 \times 150 \times 250 m^3$ that the height of the karst collapse column is 40m and the diameter is 30m. The initial numerical calculation model is shown in Table 1.

**Table 1.** Mechanical parameters of rock strata.

| Parameter | Lithology     | Elastic GPa | Poisson's ratio of $\rho$ | Tensile MPa | $\rho$ kg/m$^3$ | porosity $\eta$ | Permeability coefficient K/10-3ms$^{-1}$ |
|-----------|---------------|-------------|---------------------------|-------------|----------------|----------------|---------------------------------|
| Fine sandstone | 3             | 0.30        | 1.6                       | 1600        | 0.09           | 0.250          |                                |
| siltsone  | 32            | 0.35        | 3.6                       | 2700        | 0.17           | 0.024          |                                |
| marl      | 15            | 0.26        | 2.2                       | 2500        | 0.16           | 0.043          |                                |
| Coal seam | 2             | 0.23        | 1.6                       | 1500        | 0.24           | 0.101          |                                |
| mudstone  | 3             | 0.30        | 1.6                       | 1600        | 0.18           | 0.028          |                                |
| Fine sandstone | 18        | 0.25        | 2.1                       | 2400        | 0.12           | 0.033          |                                |
| limestone | 17            | 0.34        | 2.0                       | 2000        | 0.13           | 0.050          |                                |
| aquifer   | 20            | 0.11        | 5.1                       | 3000        | 0.26           | 0.370          |                                |
| column    | 2.7           | 2.7         | 0.3                       | 1700        | 0.6            | 0.440          |                                |

### 4. Numerical simulation model results and analysis

#### 4.1. Stress analysis in the vertical direction of surrounding rock

1) From the analysis of Figure 2, it can be seen that the mining on the working face redistributes the stress, forming a stress concentration in front of the working face, and forming a pressure relief zone.
and a pressurizing zone on the roof and floor of the collapse column. When the working face advances 20m and the distance from the collapse column is about 60m, the advance distance of the working face has little effect on the stress distribution of the karst collapse column; when the advance distance reaches 80m, the stress area overlaps when it approaches the karst collapse column; At 100m, when pushing directly above the collapse column, a pressure relief zone appears in the collapse column. As a low-stress area, the collapse column is easily affected by mining and is prone to plastic failure. Then the floor collapse column serves as a communication between the working surface and the working surface. The preferred channel of the aquifer, therefore, should be paid attention to in the subsequent coal mining process.

![Figure 2. Vertical stress diagram of surrounding rock during advancing](image)

(A) Before mining  (b) Advance 40m  (c)Advance 80m  (d) Advance 100m

2) It can be seen from Figure 3 that the stress distribution of the surrounding rock at the working face before mining is clear. Stress concentration occurs around the collapsed column, and the concentrated stress reaches 16.4MPa, while the internal stress of the collapsed column is relatively small, and the vertical stress of the surrounding rock is only 9.5 MPa. Under the initial stress state of surrounding rock, the vertical stress in the collapsed column is less than the surrounding rock stress in the complete rock formation, indicating that the collapsed column is a natural low stress concentration area. Under the influence of mining, the stress concentration factor continues to increase. When the strength of the rock strata is exceeded, the surrounding rock around the collapsed column of the floor is easily damaged, and the confined water in the aquifer is extremely prone to seepage.

![Figure 3. Vertical stress change diagram of surrounding rock during the advancing process](image)

3) With the continuous increase of the advancing distance of the working face, when the mining distance of the working face is getting closer and closer to the collapse column, the stress
concentration factor increases continuously, and the stress concentration range is distributed on the side of the mining face close to the collapse column. When the working face is advanced for 80m, the stress failure zone of the surrounding rock of the working face and the stress zone of the surrounding rock of the collapsed column are superimposed; when the working face is advanced for 100m, the stress of the surrounding rock of the floor and the collapsed column is already completely coincident, the coal seam floor and the vertical stress failure zone of the surrounding rock of the collapse column coincide, and the possibility of plastic failure of the floor and the collapse column rock formation increases.

4.2. Analysis of plastic failure zone

![Diagram of the plastic failure zone during the advancing process](image)

**Figure 4.** Diagram of the plastic failure zone during the advancing process

1) When the mining face of the working face does not pass the collapse column, as the advancing distance of the working face continues to increase, the plastic failure depth of the coal seam floor continues to increase, from Figure 4 that the plastic failure depth of the floor reaches the maximum when it reaches the collapse column; when the working face passes the floor after the collapse column, as the working face is far away from the collapse column, the plastic failure depth of the floor gradually decreases. When the advancement distance of the working face reaches 80m, the plastic failure zone of the coal seam floor and the plastic failure zone of the collapse column will butt, and the floor is likely to occur. A water inrush accident occurred in the collapse column.

2) Before mining, a plastic failure zone of about 5m appeared at the junction of the collapse column and the Ordovician aquifer, and with the continuous increase of the distance of the working face, the plastic failure zone of the floor collapse column continued to increase, when the working face was advanced by 60m when left and right, the karst collapse column column communicates with the Ordovician aquifer. And with the continuous increase of the advancing distance of the working face, the water-resistant layer on the upper part of the collapse column is easily damaged under the action of mining and hydraulic fracturing, causing the water in the Ordovician aquifer to gush out.

4.3. Analysis of surrounding rock displacement field change

![Vertical displacement diagram during propulsion](image)

**Figure 5.** Vertical displacement diagram during propulsion

1) From Figure 5 that before the initial excavation, compared with the surrounding rock, the internal displacement of the collapsed column is relatively large, mainly in the vertical direction, and the
vertical displacement of the surrounding rock at the top of the collapsed column is smaller than the bottom of the collapsed column; When the excavation starts, the vertical displacement of the surrounding rock on the top of the working face is greater than the vertical displacement of the surrounding rock on the floor.

![Figure 6. Change of vertical displacement of surrounding rock of floor during advancing process](image)

2) With the continuous increase of the advancing distance of the working face, from Figure 6 that distance to the collapse column is getting closer and closer. When the mining of the working face advances to 80m, the vertical displacement field of the surrounding rock of the floor obviously shifts to the direction of the collapse column. The stress field in the vertical direction of the surrounding rock of the collapsed column is superimposed, and the plastic failure zone is connected.

3) With the continuous increase of the advancing distance of the working face, the vertical displacement of the top and bottom of the working face gradually increases, and the scope of influence continues to expand. Through comparison, it can be seen that the vertical displacement of the roof and floor is mainly concentrated on the newly excavated working face, while the vertical displacement of the surrounding rock of the roof and floor behind the goaf is relatively stable.

4) The vertical displacement value of the surrounding rock located below the goaf floor gradually decreases from top to bottom, and with the continuous increase of the advance distance of the working face, the vertical displacement value of the surrounding rock of the goaf floor gradually decreases. Increase. As for the surrounding rock above the mined-out area, its vertical displacement value gradually decreases from bottom to top.

5) The top rock layer of the goaf is dominated by marl, and its subsidence value gradually decreases from bottom to top, and the bottom rock layer is dominated by fine sandstone and mudstone, and the subsidence value gradually decreases from top to bottom. In addition to its location, the displacement of the rock layer is also related to the lithology and combination of the rock mass. Sandstone with stronger lithology deforms less than marl, and it is also reflected in the front plastic failure zone.

5. Conclusion
By numerically simulating the water inrush from the concealed collapse column of the floor, under the condition that the thickness of the water barrier is 30m, the mining of 17 coal is in danger of water inrush.

1) The surrounding rock on the floor of the mining area and the collapse column near the mining side is prone to shear and tensile failure.

2) Affected by mining, as the advancing distance continues to increase, the stress concentration and range of the surrounding rock gradually increase, the plastic failure range gradually increases, and the vertical displacement range gradually increases. The floor and collapse column should be adjusted before mining. Carry out grouting reinforcement transformation.
6. References

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