Design of Cutting Depth of Artificial Dam of Underground Reservoir in Wulanmulun Mine

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Abstract. Rich in coal and lack of water is a remarkable characteristic of mining area in western China. The water storage technology of underground reservoir has become an important means of water resources protection in mining area of western China, and the cutting depth of artificial dam plays an important role in the design of underground reservoir. In order to study the influence of cutting depth of artificial dam on the stability of underground reservoir, the MB-1 dam of No. 2 reservoir in Wulanmulun mine is selected as the research object. The 3D calculation model is established by using FLAC³D, and several calculation schemes are made by changing the cutting depth of side, roof and floor, respectively. Then the influence of cutting depth of artificial dam on the stability of mine underground reservoir is deeply analyzed from the aspects of displacement field and stress field. The results show that the optimum cutting depths of MB-1 artificial dam in side, roof and floor are 0.6m, 0.5m and 0.4m, respectively.

1. Introduction

The large-scale development of coal makes the limited water resources in western China even poorer, and the shortage of water resources has become the main restricting factor to the development of western China[1-3]. In order to ensure underground safety in production, a large amount of mine water is discharged to the surface, the discharged mine water will soon be evaporated, resulting in serious waste to water resources[4-5]. In order to make full use of mine water, pay equal attention to the protection of water resources and safe mining, Gu et al. have put forward the concept of using coal mine goaf to construct mine underground reservoir to store mine water[6-7].

The dam of mine underground reservoir is connected by the boundary coal pillar dam of goaf and artificial dam which is an important part of mine underground reservoir[8]. Yao et al. [9] carried out non-destructive immersion experiment of coal sample and uniaxial compression test under different moisture content and repeated immersion condition, and obtained the strength weakening law of coal pillar dam under the action of water and designed the width of coal pillar dam. Gu[10] developed the cutting connection technology between the coal pillar dam and the artificial dam, that is, cutting on the coal pillar first, then anchoring, and last pouring concrete to form the artificial dam.

It can be seen that the cutting depth of the artificial dam has a great influence on the stability of the dam. It is particularly important to design different cutting depth according to different geological
conditions. Therefore, author takes the MB-1 artificial dam of Wulanmulun mine No. 2 reservoir as the research object, and studies its influence on the stability of the dam by changing the cutting depth of side, roof and floor respectively, to get the optimal cutting depth, which is expected to provide useful suggestions for the design of artificial dam of mine underground reservoir.

2. Numerical calculation model

2.1 Establishment of 3D Model

On the premise of ensuring the accuracy of the calculation results, considering the calculation time and boundary effect of FLAC3D, the width, depth and height of roadway model are 20m, 12m and 16m, respectively. The grid is divided according to the distribution of surrounding rock, and a dense area is set up around the roadway in order to simulate a variety of cutting depth schemes. The model has a total of 96000 units and 102459 nodes, as shown in figure 2. The roadway is arranged in the middle of the model, the cross section is rectangular, and the roadway width and height are 5.0m and 3.6m.

![Figure 1. The three-dimensional calculation model](image)

2.2 Constitutive model and boundary conditions

The Mohr-Coulomb model is used to simulate the rock strata, coal pillars and artificial dams after excavation. The fixed boundary condition is used at the bottom of the model, stress boundary conditions is applied to the upper surface, fixed normal displacement boundary conditions are adopted on all four sides. The uniform vertical compressive stress is applied to the upper surface, and the horizontal compressive stress increasing with depth is applied to the side.

2.3 Application of water pressure and arrangement of monitoring points

The water pressure acts on the side of the dam in contact with water. At the same time, a total of 21 monitoring points are arranged on the surface of the artificial dam facing the water surface and at the cutting place. The mode of action of water pressure and the location of the monitoring point are shown in figure 2.

![Figure 2. Schematic diagram of water pressure and monitoring points](image)
3. Numerical simulation results and analysis

The actual cutting depth of MB-1 dam of No. 2 reservoir in Wulanmulin mine is as follows: side 0.5m, roof 0.3m, floor 0.2m. The type of artificial dam is plate, the concrete strength grade is C25, the thickness is 1m, and the water height is 21m. In below, several schemes are made by changing the cutting depth of side, roof and floor trough by the method of control variables, and their effects on the stability of the dam are studied respectively.

In order to study the influence of the side cutting depth on the stability of artificial dam and cutting position, keep the cutting depth of roof and floor unchanged and change the side depth to develop 9 schemes. The side cutting depth was set as 0.1m, 0.2m, 0.3m, 0.4m, 0.5m, 0.6m, 0.6m, 0.7m, 0.8m and 0.9m respectively. In the same way, when studying the influence of the cutting depth of roof and floor, 9 schemes are also made.

3.1 Displacement analysis

According to each scheme, several groups of numerical simulation calculations are carried out. Taking changing the side cutting depth as an example, the contour of Y-displacement of artificial dam under several schemes are obtained. As shown in figure 3.

![Displacement figures](image)

Figure 3. The contour of Y-displacement of artificial dam under different side cutting depth

As can be seen from figure 3, under different side cutting depths, the maximum displacement in the Y direction occurs in the center of the artificial dam, and gradually decreases outward, especially the displacement at the four corners of the dam is the smallest. And the displacement distribution trend of the dam is roughly in same, but with the increase of the cutting depth of the dam, the displacement variation of both the whole and the part along the Y direction decreases obviously. Therefore, the displacement of the central part of the dam should be one of the key points to be considered.

Moreover, according to the numerical simulation results of each scheme, the curve of the maximum displacement in the Y direction of the artificial dam varying with the cutting depth is drawn, as shown in figure 4. As can be seen from figure 4, with the continuous increase of the cutting depth, the Y-displacement curve of the artificial dam gradually slows down and finally tends to remain unchanged. Specifically, taking changing the side cutting depth as an example, the change rate of trend curve is 1.6%, 0.58%, 0.68%, 0.78%, 0.29%, 0.20%, 0.01% and 0%, and the displacement value in Y direction is reduced from $1.060 \times 10^{-4}$m to $1.016 \times 10^{-4}$m. It can be seen that increasing the side cutting depth has a certain influence on reducing the displacement of the artificial dam in the Y direction. And when the side cutting depth of is more than 0.6m, the roof cutting depth is more than 0.5m, and the floor cutting depth is more than 0.4m, the decreasing trend of displacement is obviously lower than that before. Therefore, if the peak displacement of the dam body is taken as the only criterion, it can be
considered that the optimum depths of the side cutting depth, the roof cutting depth and the floor cutting depth are 0.6m, 0.5m and 0.4m, respectively.

In order to explore the influence of cutting depth on the displacement of different positions of dam, taking the change of the floor cutting depth as an example, the displacement variation curve of each monitoring point of the dam under different floor cutting depth is drawn, as shown in figure 5.

**Figure 4. Maximum displacement in Y direction of artificial dam with cutting depth**

It can be seen from figure 5 that with the increase of the depth of floor, the changing of Y-displacement in the middle and lower position of the artificial dam(for example monitoring point 45, 49 and 48) is relatively large, while the changing of Y-displacement in the upper position of the dam(for example monitoring point 32, 40 and 47) is relatively small, and the displacement variation trend of the monitoring points is basically the same.

At the same time, among all the monitoring points, the Y-displacement of monitoring point 48 at the center of the dam is the largest, but the displacement of 47 and 49, which are both 1 m away from 48 monitoring point, is not the same, and the displacement of 49 monitoring point is larger than that of 47 monitoring point. It can be seen that the Y direction displacement of the lower part of the dam is generally larger than that of the upper part, so it can be inferred that the maximum Y-displacement of the dam occurs in the lower position of the center of the dam, and the contour of Y-displacement also confirms this phenomenon.
Because the strength of the surrounding rock at the cut is lower than that of the artificial dam, and it is also an important factor to limit the stability of the artificial dam, the following analysis is made on the changing trend of the displacement of the cutting part with the cutting depth. The calculated contour of Y-displacement cloud at the cut is shown in figure 6. As can be seen from figure 6, the displacement of the roof and floor is smaller than that of the side, because the strength of the roof and floor is stronger than that of the side coal pillar dam, so the displacement of the side cutting should be studied properly.

It can be seen from figure 7 that the Y direction displacement at the cutting place decreases with the increase of the cutting depth. Moreover, the decrease of displacement caused by increasing the side cutting depth is obviously greater than that caused by the increase of the roof and floor cutting depth. Specifically, when the side cutting depth increases from 0.2 to 1.0m, the displacement at the cutting decreases by 0.901×10^{-5}m. While the roof and floor cutting depth increases from 0.1 to 0.9m, the displacement at the cutting decreases by 0.228×10^{-5}mm and 0.128×10^{-5}mm respectively. Therefore, it can be seen that the effect of increasing the side cutting depth is more obvious.

At the same time, the decreasing trend of displacement at the cutting place gradually slows down and finally tends to remain unchanged. When the side cutting depth is more than 0.6m, the roof cutting depth is more than 0.5m, and the floor cutting depth is more than 0.4m, the decreasing trend of displacement is obviously lower than that before.

### 3.2 Stress analysis

Figure 8 shows the contour of the tensile stress of the dam under the actual cutting depth. In order to explore the influence of changing the cutting depth on the tensile stress of the dam, taking the change of the side cutting depth as an example, the relationship table between the tensile stress and the side cutting depth are shown in Table 1.
It can be seen from Table 1 that increasing the cutting depth has almost no effect on the tensile stress of the dam. When the cutting depth increases from 0.2m to 0.8m, the tensile stress decreases from 1.135MPa to 1.132MPa, and the change rate is 0.3%, which can be ignored.

**Figure 8. Contour of tensile stress of artificial dam**

**Table 1. Relationship between the tensile stress of dam and the side cutting depth**

| The side cutting depth/m | 0.2  | 0.3  | 0.4  | 0.5  | 0.6  | 0.7  | 0.8  |
|--------------------------|------|------|------|------|------|------|------|
| The tensile stress of dam/MPa | 1.135 | 1.135 | 1.133 | 1.133 | 1.133 | 1.135 | 1.132 |

Figure 9 shows contour of the tensile stress of the side coal pillar. As can be seen from figure 9, the maximum tensile stress is concentrated at the edge of the cutting of the side. In order to study the variation of the tensile stress with the cutting depth, the variation curve of the tensile stress with the cutting depth is drawn, as shown in figure 10.

**Figure 10. Relationship between the tensile stress of side and the cutting depth**

Figure 10 shows that the tensile stress at the cutting part decreases with the increase of the cutting depth, and the decrease of the tensile stress caused by the side cutting depth is obviously greater than.
that caused by the roof and floor depth. Specifically, when the side cutting depth is increased from 0.2 to 1.0 m, the tensile stress at the cutting is reduced by 0.0583 MPa, while the roof and floor cutting depth is increased from 0.1 to 0.9, and the tensile stress is only reduced by 0.0171MPa and 0.0047 MPa, respectively. Therefore, the effect of increasing the side cutting depth is more obvious. At the same time, it can be seen that the stress reduction trend at the cutting gradually slows down, and finally tends to remain unchanged.

4. Conclusion
(1) Through several groups of numerical simulation calculation, it is found that with the continuous increase of cutting depth, the displacement along the water pressure direction of the artificial dam and the cut gradually decrease, and the tensile stress at the cut gradually decrease too. And the decreasing trend gradually slows down and finally tends to remain unchanged. On the basis of the constant point of the change curve, it is determined that the suitable cutting depth of the side, roof and floor are 0.6m, 0.5m and 0.4m, respectively.

(2) The decrease of displacement and tensile stress at the cut caused by increasing the cutting depth of side is obviously larger than that caused by increasing the cutting depth of roof and floor. Therefore, it can be obtained that the effect of increasing the side depth is more effective.

(3) In the two points of equal distance from the center of the artificial dam between the upper and lower side, the displacement of the lower side point is generally larger than that of the upper side point. The maximum displacement point of the artificial dam appears below the center of the dam.

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