Study on the strength of the artificial dam of underground reservoir in Wulanmulun mine

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Abstract. In recent years, to alleviate the problem of water loss and severe water shortages in the west of China, the concept of coal mine underground reservoir was put forward, and a series of related research were conducted. At present, it has achieved a large number of engineering applications, but the structure and the related parameters of the dam still remain to be studied and optimized. In order to explore the influence of the strength of the artificial dam on the stability of the artificial dam, FLAC3D numerical simulation was carried out based on the geological conditions of Wulanmulun mine and the actual working conditions of the artificial dam in its underground reservoir, and the displacement and stress were analyzed respectively. The results show that, with the increase of the dam strength grade, the displacement level of the dam and its cut decreases, but the stress level increases gradually. Overall, the proposed strength grade of the artificial dam should be C25.

1. Introduction

In the process of coal mining, artificial drainage often occurs and more cracks are often created, which lead to the loss of groundwater. However, the western region of China is short of water resources and rich in coal resources, which further deepens the contradiction between water conservation and coal mining [1-3]. At the same time, the Chinese government pay more and more attention to the protection and the utilization of mine water resources, green production has become the core of the modern coal mining [4]. Chinese scholars put forward the concept of "the coal mine underground reservoir" [5], and a large number of engineering applications have been implemented in Shendong mining area, more than 30 coal mine underground reservoir have been built, the water storage reached 29 million m³, large amounts of water are protected [6]. This not only alleviates the local water shortage, but also makes rational use of the goaf.

Since then, many scholars have carried out a lot of research work on problems related to underground reservoirs of coal mines, and obtained very valuable research results, which play an important role in guiding and improving specific engineering applications [7-10]. However, as a new large-scale engineering application, there are still many problems worthy of study, improvement and consideration, among which the stability of artificial dam is a key issue worthy of research [11]. How to choose the relevant parameters of artificial dam can make it more reasonable, on the basis of ensuring security and stability, is the main point of this study. The strength grade is an important...
parameter of the dam [12], in this paper, the field parameters of artificial dam in underground reservoir of Wulanmulun mine are taken as comparison, the numerical simulation is carried out. Then, by analyzing displacement and stress status of the dam and its cut with different dam strength grades, the optimal parameter is obtained.

2. Project overview

Wulanmulun mine is located in the central and northern part of Shendong coalfield. The occurrence of strata in the interior of the mine field is gentle, without obvious fold and large fault, which is suitable for the construction of underground reservoir of coal mine. The annual precipitation within the region is 447.6mm, and the bedrock crack is the main water-filling channel. The actual normal water inflow of the mine is 936m³/h, and the maximum water inflow is 997m³/h. At present, there are two underground reservoirs built in Wulanmulun mine, with a total water storage of 5.516 million m³. The research object of this paper is No. 2 underground reservoir with a water storage of 3.944 million m³. The coal seam where the reservoir is located is the 31# coal seam, with an average coal thickness of 3.64m and an average dip angle of 2°. The mining elevation is 1060m, and the occurrence of coal seam is stable. The reservoir roof is fine-grained sandstone with a thickness of 7.9m, and the lithological characteristics are grayish white, with fine-grained sand-like structure and blocky structure with partial horizontal bedding. The floor is mainly silty mudstone with a thickness of 5.2m and the lithologic characteristics are light gray. The roadway where the artificial dam is located is a rectangular roadway with a width of 5m and a height of 3.6m. The support method is combined support of bolt and cable. The current water storage depth is 3.3m, and the structure of the dam is a rectangular MB-1 waterproof closed wall.

3. Model design

In this simulation, FLAC3D numerical simulation software was used. According to the actual construction conditions, Mohr-Coulomb constitutive model was selected. The overall model was composed of fine-grained sandstone layer, coal seam, silty mudstone layer and argillaceous siltstone layer from top to bottom, with specific parameters as shown in table 1.

| Rock Stratum          | Thickness (m) | Tensile Strength(Mpa) | Compressive Strength(Mpa) |
|-----------------------|---------------|-----------------------|----------------------------|
| Fine grained sandstone| 10.2          | 1.43                  | 51.89                      |
| 31#coal seam          | 3.6           | 0.5                   | 17.8                       |
| Silty mudstone        | 5.2           | 1.79                  | 37.8                       |
| Argillaceous siltstone| 1             | 1.24                  | 36.9                       |

The overall width of the model is 20m, the height is 16m, and the depth is 12m. It contains a total of 96,000 units and 102459 nodes. The excavation roadway is located in the middle of coal seam, 5m wide and 3.6m high. The specific model is shown in figure 1. The origin of the coordinate axis is at the midpoint of the bottom of the model. The positive direction of the X-axis is when the origin goes to the right, the positive direction of the Y-axis is when the roadway enters the depth, and the positive direction of the Z-axis is when the origin goes up. The null model is used to simulate excavation. After excavation, cable structure element is adopted to simulate the supporting form in the field. After stabilization, channel is cut in the middle of the roadway to build a dam. When it stabilizes again, water pressure is applied to the negative Y-axis dam surface and roadway wall.
4. Research on the influence of dam strength on the stability of artificial dam

4.1 Design simulation scheme
Combined with the actual working conditions, the designed simulation scheme is as follows: the artificial dam body is in the form of plate, with the fixed depth of the upper part 0.5m, the fixed depth of the roof 0.3m, the fixed depth of the bottom plate 0.2m, and the water level is 21m. The concrete strength grade of the dam body is C15, C20, C25, C30, C35 and C40 respectively.

According to the code for design of concrete structures GB 50010-2010, the Poisson ratio of concrete is set at 0.2, and the other relevant parameters are shown in table 2.

| Strength grade | C15 | C20 | C25 | C30 | C35 | C40 |
|---------------|-----|-----|-----|-----|-----|-----|
| Elastic modulus (GPa) | 2.20 | 2.55 | 2.80 | 3.00 | 3.15 | 3.25 |
| Tensile strength (MPa) | 0.91 | 1.10 | 1.27 | 1.43 | 1.57 | 1.71 |

4.2 Displacement analysis
By comparing the displacements in each direction of the dam body, it is found that the displacement of the dam is mainly in the Y-direction (the displacement along the depth of the roadway). Therefore, this paper only takes the Y-displacement as an example for analysis. Figure 2 shows the Y-displacement contour of the dam body with different strength grades, taking C25 and C35 as examples.
Figure 3. Y-displacement contour of the cut when the dam strength grade is C25

As can be seen from the figure 2, the Y-displacement of the dam basically takes the center point of the dam as the center of a circle, and gradually decreases to the periphery in a circular manner, and is basically symmetric about the vertical and horizontal axes. The largest displacement appears near the dam body center, while the smallest displacement appears at the four corners around the dam body, which is tangent to the annular displacement contour and presents a 45-degree angle with the boundary.

According to the figure 3, it is found that the maximum Y-displacement at the cut occurs in the range of 1/3 of the edge length near the midpoint of each side, which is consistent with the results obtained from the theoretical analysis of related artificial dam [7]. Among them, the Y-displacement near the middle point of the cut edge of the side part is the largest, which is considered to be caused by the relatively low strength of the coal seam on the side part. It can be seen that this is one of the dangerous points of the cut. And it can also be concluded that the change of the dam body's own strength has little effect on the displacement distribution of the cut.

By comparing the Y-displacement contour of the dam and its cut under various schemes, it is found that the overall distribution state of the Y-displacement basically does not change significantly with the increase of the dam body's self-strength, indicating that the change of the dam body's self-strength has little influence on the displacement distribution of the dam along the water pressure direction.

According to the simulation results, the change rules of Y-displacement peak value of the dam and the cut are obtained, as shown in figure 4.

(a) The Y-displacement of the dam
(b) The Y-displacement of the cut

Figure 4. Curve chart of Y-displacement peak value of the dam and the cut with different strength grades

When the strength grade from C15 to C40, the change rate is 7.63%, 5.50%, 3.88%, 3.03%, 2.08%, respectively. It can be seen that the Y-displacement of the dam body decreases with the increase of the strength grade of the dam body, but the decrease is small. In the process of transition from C15 to C25, the Y-displacement change rate of the dam body is relatively large, which exceeds 5%. In the process of transition from C25 to C40, the change rate of dam body Y-displacement is lower than 4%, and the curve gradually flattens, indicating that the increase of dam body strength grade has no effect on the
decrease of dam body displacement.

When the strength grade translates from C15 to C40, the change rate of the Y-displacement of the cut is 5.10%, 3.23%, 2.41%, 1.55%, 1.54%, respectively. The overall displacement change rate is small. And it is basically consistent with the change trend of Y-displacement curve of the dam body.

4.3 Stress analysis

Figure 5 shows the contour of the minimum principal stress of the dam body, taking C25 as an example.

As can be seen from figure 5, the minimum principal stress peak on the water surface of the dam body is basically distributed at the middle point of the fixed edge of the top and bottom plate, while the minimum principal stress peak on the backwater surface is basically distributed at the top and near the center of the dam body. And the distribution law of the minimum principal stress contour under different dam strength grades is basically consistent.

In order to study the variation rule of the minimum principal stress peak value of the dam body and the band cut with different dam body strength grades, the change curve is drawn, as shown in figure 6.

![Minimum principal stress contour](image)

Figure 5. Minimum principal stress contour of the dam when the strength grade is C25

As can be seen from figure 5, the minimum principal stress peak shows an upward trend with the increase of the dam body strength grade. The increase rate from C15 to C20 is the largest, with a change rate of 2.79%. The change rate from C20 to C25 is 0.91%. After that, the rate of change remained between 0.2% and 0.3%, which basically showed a relatively gentle linear growth.

As can be seen from figure 6 (a), the peak minimum principal stress of the dam body shows an upward trend with the increase of the dam body strength grade. The increase rate from C15 to C20 is the largest, with a change rate of 2.79%. The change rate from C20 to C25 is 0.91%. After that, the rate of change remained between 0.2% and 0.3%, which basically showed a relatively gentle linear growth.

As can be seen from figure 6 (b), the overall change trend of the minimum principal stress peak value of the band cut is showing an increasing trend. When the dam body strength grade is lower than C25, the stress change is relatively large, with the change rate of 3.9% and 2.2%; when the strength...
grade is higher than C25, the change rate is lower than 1%, and gradually decreases.

5. Conclusion
(1) By combining the simulation and analysis results of displacement, increasing the strength grade of the dam can reduce the displacement of the dam body and its cut, but the displacement reduction rates are relatively low and are still decreasing.

(2) At the same time, increasing the strength grade of the dam will increase the level of stress, especially the tensile stress which is easy to damage the dam body and its cut. When the dam body strength grade reaches C40, the minimum principle stress peak value of the side is 0.498MPa, which is very close to the limit tensile strength of the coal wall of the side of 0.5MPa.

(3) In order to consider the safety and stability of the coal wall at the cut of the side, and to reduce the displacement of the dam body and the cut as far as possible, it is advisable to choose C25 as the dam body strength grade.

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