Study on the reinforcement effect of bolt in the artificial dam of underground reservoir in Wulanmulun mine

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Abstract. With the exploitation of a large number of coal resources in Western China, the phenomenon of local water shortage has become increasingly prominent. In order to protect water resources, coal mine underground reservoir came into being. In the underground reservoir of coal mine, the stability of artificial dam is often the key to the water storage. In order to enhance its stability, steel structure is often arranged inside the artificial dam and connected with the bolt arranged in the cut, so that the artificial dam and the surrounding rock form a whole and play the role of water storage and blocking together. However, the effect of this reinforcement structure still needs to be further studied. Therefore, this paper takes Wulanmulun mine as the engineering background, mainly uses FLAC3D numerical simulation software to analyze the effect of reinforcement structure, and finds out the relatively reasonable bolt size. The results show that: the artificial dam and surrounding rock are more stable and safe under the reinforcement of bolt, increasing the size of bolt will reduce the displacement and plastic zone range of cut in the side, especially increasing the size of bolt at the top and bottom will have better effect.

1. Introduction

Affected by the climate and environment, the western region of China is dry and rainless all the year round, which leads to the lack of water resources. Due to the rich coal and other mineral resources, the water resources are further lost in the process of large-scale mining, which makes the water shortage problem more serious[1]. In order to solve this big problem involving people's livelihood, the concept of green mining and water conservation mining has been advocated[2-4], one of which is to protect the coal aquifer and improve the utilization rate of mine water[5-6]. Therefore, the coal mine underground reservoir came into being[7], its proposal and application has played a very important role in the protection of water resources and the utilization of mine water in the western region.

At present, Shendong mining area has built more than 30 underground coal reservoirs, with a total water storage capacity of 29 million m³[8]. However, as a new type of engineering application, coal mine underground reservoir is located in the underground goaf, and the environment is very complex. Therefore, many scholars have carried out a lot of research work on different aspects of coal mine underground reservoir, which has played an important role in guiding and promoting the improvement and maturity of engineering application[9-12].

In the underground reservoir of coal mine, the artificial dam and surrounding rock shoulder the task of water storage and retaining, and the joint is often a relatively weak link[13]. Anchor bolts are often laid for reinforcement, so as to strengthen the integration of artificial dam and surrounding rock. This technology has been used in the reinforcement of dam and retaining wall for a long time[14]. This paper
will start from the reinforcement structure, through the numerical simulation technology, analyze its application effect in the coal mine underground reservoir, as well as the influence on the stability of the artificial dam, and try to find a more reasonable anchor arrangement, in order to improve the stability of the artificial dam, reduce the risk of cracking.

2. Project overview
Wulanmulun coal mine is located in the north central part of Shenfu Dongsheng coalfield, with an area of about 44 km². The occurrence of strata in the mine field is gentle, without obvious fold structure and large fault structure, and only has weak wide and gentle undulation along the strike and tendency of strata, which is suitable for the construction of underground reservoir in coal mine. The annual precipitation in the area is 447.6 mm, the bedrock fissure is the main water filling channel, the actual normal water inflow of the mine is 936 m³/h, and the maximum water inflow is 997 m³/h. At present, there are two underground reservoirs 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 of the reservoir is 31# coal seam, with an average coal thickness of 3.64 m, and the occurrence of coal seam is stable. The roof of the reservoir is 10.2 m thick fine-grained sandstone, and the floor is 5.2 m thick silty mudstone. The roadway where the artificial dam is located is a rectangular roadway with a width of 5 m and a height of 3.6 m. At present, the water storage depth of the reservoir is 3.3 m, and the dam’s supporting arrangement is shown in figure 1.

3. Model design
The FLAC3D numerical simulation software is used to simulate the actual geological parameters of Wulanmulun mine. The Mohr Coulomb constitutive model is selected. From top to bottom, the fine-grained sandstone, coal seam, silty mudstone and argillaceous siltstone are successively selected. The specific parameters are shown in table 1.

| Rock Stratum          | Thickness (m) | Bulk Modulus (GPa) | Shear Modulus (GPa) | Tensile Strength (Mpa) | Compressive Strength (Mpa) |
|-----------------------|---------------|--------------------|---------------------|------------------------|----------------------------|
| Fine grained sandstone| 10.2          | 3.38               | 2.97                | 1.43                   | 51.89                      |
| 31# coal seam         | 3.6           | 2.2                | 0.9                 | 0.5                    | 17.8                       |
| Silty mudstone        | 5.2           | 3.16               | 3.45                | 1.79                   | 37.8                       |
| Argillaceous siltstone| 1             | 5.99               | 4.87                | 1.24                   | 36.9                       |
The overall width of the model is 20 m, the height is 16 m, and the depth is 12 m. It is composed of 96000 units and 102459 nodes. The excavation roadway is located in the middle of the coal seam, 5 m wide and 3.6 m high. The origin of the coordinate system is located in the center of the bottom of the model. The right origin is the positive direction of X-axis, the forward origin is the positive direction of Y-axis, and the upward origin is the positive direction of Z-axis. The null model is used to simulate the excavation. After excavation, cable structural unit is used to simulate the support form on site. After stabilization, the middle part of the tunnel is cut, and the bolt reinforcement and dam construction are carried out. After stabilization again, water pressure is applied on the Y-axis negative dam surface and tunnel wall.

4. Research on the influence of reinforced bolt on the stability of artificial dam

4.1 Displacement analysis

It can be seen from figure 2 (a) that the maximum Y-displacement of the artificial dam is 1.03e-4 m without bolt reinforcement, while the Y-displacement in the middle area of 2 m$^2$ is between 9.5e-5 m and 1.03e-4 m; it can be seen from figure 2 (b) that the maximum Y-displacement of the artificial dam is reduced to 7.38e-5 m after bolt reinforcement, which is 28.3% lower than that without bolt. And the same in the middle area of 2 m$^2$, the Y-displacement is between 6.5e-5 m and 7.38e-5 m, which is only $2/3$ of that without bolt.

Figure 3 shows the Y-displacement of the cut in the side of the artificial dam with and without reinforcement bolts. In order to facilitate the analysis, six displacement monitoring points are arranged along the horizontal direction in the side cut. The layout position is shown in figure 4, and the curve drawn by using the measured displacement is shown in figure 5.
It can be seen from figure 3 (a) that in the main dangerous area within 1 m of the junction between the dam body and the side coal wall, the Y-displacement is mainly between 4e-5 m and 5e-5 m, and the local maximum Y-displacement is 5.40e-5 m; in contrast, when there is reinforced bolt in figure 3 (b), the Y-displacement in the same area is basically within 3.75e-5 m, and the local maximum Y-displacement is only 3.83e-5 m, which is lower than the average value of the displacement in the dangerous area of the side cut without bolt. From the graph in figure 5, it can be more intuitive to find that the overall Y-displacement in the side cut with reinforced bolt is 1.1e-5 m to 1.5e-5 m lower than that without bolt, with a decrease of about 29%.

### 4.2 Stress analysis

It is obvious from figure 6 that the embedded part of the upstream face of the dam with or without bolt is the area with relatively high stress level, and the embedded part at the top is the distribution area of the maximum stress. In this area, the maximum stress without bolt is 1.13 MPa, and the stress of more than 1 MPa is also distributed within 2 m of the middle part; when there is bolt reinforcement, the maximum stress in this area is only 1 MPa.
Figure 7. Minimum principal stress contour of the side cut of the dam

Minimum principal stress contour of the side cut of the dam is shown in figure 7. It also can be seen that with bolt, the stress level of the side cut is lower and the range of high stress distribution is smaller.

5. Stability of artificial dam under different bolt sizes

Keep the layout unchanged, change the bolt size, followed by $\phi 14 \times 1400$ mm, $\phi 15 \times 1500$ mm, $\phi 16 \times 1600$ mm, $\phi 17 \times 1700$ mm and $\phi 18 \times 1800$ mm. The maximum displacement of the upstream face of the dam, the maximum stress of the side cut and the area of the plastic zone in the cut are obtained respectively. The specific data are shown in table 2.

It can be seen from the data in table 2 that the maximum Y-displacement on the surface of artificial dam decreases with the increase of the bolt size, and its change curve is shown in figure 8. During the increase of the bolt size from $\phi 14 \times 1400$ mm to $\phi 16 \times 1600$ mm, the maximum Y-displacement on the surface of dam basically decreases linearly, with a relatively large decrease. When it increases to $\phi 17 \times 1700$ mm, the decrease begins to decrease significantly, and the curve tends to be flat.

| Bolt Size       | $\phi 14 \times 1400$ | $\phi 15 \times 1500$ | $\phi 16 \times 1600$ | $\phi 17 \times 1700$ | $\phi 18 \times 1800$ |
|-----------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Maximum Y-displacement of artificial dam /m | 7.3943e-5 | 7.3889e-5 | 7.3832e-5 | 7.3796e-5 | 7.3789e-5 |
| Maximum stress of side cut /MPa | 0.3400 | 0.3398 | 0.3398 | 0.3400 | 0.3399 |
| Grid number of plastic zone in cut | 89 | 86 | 83 | 80 | 75 |

In the aspect the stress of the side cut, with the increase of bolt size, the maximum stress has no great change, which is nearly 0.34MPa. In the plastic zone, the increase of bolt size has a certain effect on reducing the area of the plastic zone in the cut.
6 Conclusion
(1) The reinforcement bolt connecting the artificial dam and the surrounding rock has a great effect on reducing the displacement of the artificial dam and its cut. Compared with no bolt, the maximum displacement of the artificial dam can be reduced by 28.3%, the displacement of the side cut can be reduced by 29%.

(2) When there is bolt reinforcement, the stress level on the surface of the artificial dam and its cut is lower, and the high stress area is less.

(3) Increasing the size of reinforcement bolt can reduce the displacement of artificial dam, but this trend gradually flattens with the increase of the bolt size.

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