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Solving the Ultimate Water Accumulation Depth of Artificial Dam in Coal Mine Underground Reservoir Based on The Galerkin Method

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Abstract: In order to improve the problem of low utilization rate of groundwater in the process of coal mine production, some mining areas in northwest China use the goaf of the working face as a water storage space, and establish underground reservoirs to realize water retention mining. In order to solve the problem of the stability of the underground reservoir structure, this paper studies the ultimate water level height that the artificial dam can bear. The concrete wall of the artificial dam under the action of water pressure is simplified as the mechanical model of the four-sided solid support plate, and the expression of the strain deflection and the expression of the internal stress function of the dam are derived by using the Galerkin method. The ultimate head height that the dam can withstand is calculated to be 22m.

Keywords: Underground reservoirs; artificial dams; elastoplastic mechanics.

1. Introduction

China is a country with coal as the main energy source, and coal accounted for 57.7~63.8% of China's total energy consumption in 2015~2019. In the process of coal mining, the cracks of the roof gradually develop under the influence of mining, which conducts the aquifer and produces a large amount of mine water, resulting in a serious waste of groundwater resources. According to statistics, the amount of groundwater resources wasted in the coal mine production process in China reaches about 8 billion tons every year, and the effective utilization rate is only about 25%. [1]. With the gradual depletion of coal resources in the central and eastern parts of China, the focus of the development of China's coal resources has gradually shifted to the west. However, the climate in the western part of China is dry, the precipitation is small, and the evaporation is much greater than the precipitation, and the discharge of mine water to the surface will cause a large evaporation loss. This makes the contradiction between the development of coal resources and the shortage of water resources in the western region particularly prominent [2]. In this regard, Academician Gu Dazhao proposed a coal mine underground reservoir with "guiding and storing use" as the core, using the goaf to store groundwater resources [2,3]. After reviewing the relevant literature, it is found that there are few studies on the stability of artificial dams in underground reservoirs, and the stability of concrete structures is mostly focused on the stability analysis of surface reservoir dams [4–5]。Chen yang [6] The seepage field around the dam was simulated by a combination of numerical simulation and similar experiments, and the seepage flow around the dam was calculated. Fang Jie [7] Through the combination of theoretical derivation, similar model experiments and numerical simulation, the stress-strain law and failure mode of the artificial dam under the action of water pressure are studied, and the seepage law of the artificial dam and the trench site are summarized, and the comprehensive evaluation criteria for the stability of the artificial dam are summarized and analyzed according to the research results. Bai Dongyao et al [8] Through numerical model and theoretical analysis, the vulnerable position and maximum bearing capacity of the artificial dam of the underground reservoir of Lijiahao Coal Mine under the action of water pressure were studied. Fan Fan et al [9] The influence of confining pressure on the stability of artificial dam was studied by using FLAC3D numerical simulation software, and the results showed that low confining pressure could effectively improve the stability of the dam, but high confining pressure would promote the failure of the artificial dam. Zhi Guojun[10] Based on the shallow burial and large mining height working face in Shendong mining area, FLAC3D numerical simulation software was used to study the development and displacement of the plastic zone of the artificial dam excavation part, and the trenching parameters of the artificial dam in Shendong mining area were reasonably designed.

2. Establishment and Solution of Mechanical Model of Artificial Dam Mass

In order to prevent the reservoir water from entering the adjacent working face through the coal pillar roadway, the concrete wall is poured in the roadway, because the surrounding rock stress has been in a stable state at this time, the concrete wall structure of the artificial dam is less stressed by the surrounding rock after construction, and mainly bears the action of horizontal water pressure. In order to simplify the calculation, the water pressure is regarded as a uniform load, and the concrete wall can be regarded as a plate-like structure with four sides fixed support and one side applied uniform load, and its simplified model diagram and coordinates are shown in Figure 1.

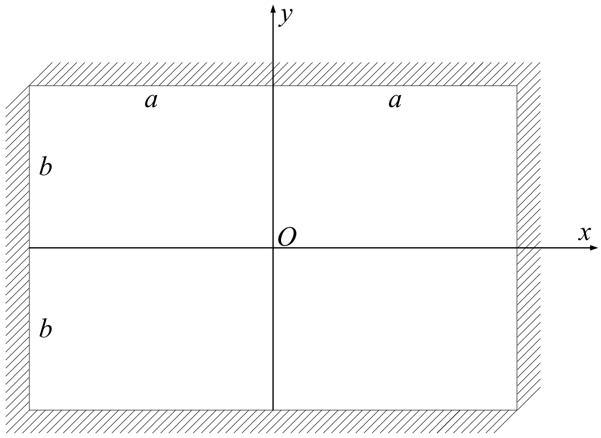

Figure 1. Simplified mechanical model of artificial dam

The Galerkin method in elastic mechanics is used to analyze the mechanical model, and the coordinates are set as shown in Figure 1, then the boundary conditions are as follows:

$$(\omega)_{x=\pm a}=0 \qquad (\frac{\partial\omega}{\partial x})_{x=\pm a}=0 \qquad (\omega)_{y=0,y=b}=0 \qquad (\frac{\partial\omega}{\partial y})_{y=b}=0$$

The expression for the deflection is:

$$\omega=\sum_{m=1}^{\infty}C_m\omega_m=(x^2-a^2)^2(y^2-b^2)^2(C_1+C_2x^2+C_3y^3+\cdots) \quad (1)$$

It can be seen that no matter how the value of the C_m is taken, the above equation can meet the boundary conditions of the model. Take only one item for calculation, i.e.:

$$\omega=C_1\omega_1=C_1(x^2-a^2)^2(y^2-b^2)^2 \quad (2)$$

The result is:

$$\omega_m=\omega_1=(x^2-a^2)^2(y^2-b^2)^2 \quad (3)$$

$$\nabla^4\omega=\frac{\partial^4\omega}{\partial x^4}+\frac{\partial^4\omega}{\partial y^4}+2\frac{\partial^4\omega}{\partial x^2\partial y^2} \quad (4)$$

$$=8[3(y^2-b^2)^2+3(x^2-a^2)^2+4(3x^2-a^2)(3y^2-b^2)]C_1$$

The uniform load on the surface of the thin plate is q, considering the symmetry of the model, which can be obtained by the Galerkin method:

$$4D\int_0^a\int_0^b 8[3(y^2-b^2)^2+3(x^2-a^2)^2+4(3x^2-a^2)(3y^2-b^2)]\times C_1(x^2-a^2)^2(y^2-b^2)^2\mathrm{d}x\mathrm{d}y=4q\int_0^a\int_0^b(x^2-a^2)^2(y^2-b^2)^2\mathrm{d}x\mathrm{d}y \quad (5)$$

After the points, the C_1 is obtained

$$C_1=\frac{7q}{128\left(a^4+b^4+\frac{4}{7}a^2b^2\right)D} \quad (6)$$

where D is the bending stiffness of the sheet, and the expression is:$D=\frac{E\delta^3}{12(1-\mu^2)}$

Substitution 2:

$$\omega=\frac{7q(x^2-a^2)^2(y^2-b^2)^2}{128\left(a^4+b^4+\frac{4}{7}a^2b^2\right)D} \quad (7)$$

Therefore, the stress component in the plate can be expressed as ω as follows:

$$\begin{aligned}\sigma_x&=-\frac{7qEz[(3x^2-a^2)(y^2-b^2)^2+\mu(x^2-a^2)^2(3y^2-b^2)]}{32D\left(a^4+b^4+\frac{4}{7}a^2b^2\right)(1-\mu^2)}\\ \sigma_y&=-\frac{7qEz[\mu(3x^2-a^2)(y^2-b^2)^2+(x^2-a^2)^2(3y^2-b^2)]}{32D\left(a^4+b^4+\frac{4}{7}a^2b^2\right)(1-\mu^2)}\\ \tau_{xy}&=-\frac{7qEz[x(x^2-a^2)(y^2-b^2)^2+y(x^2-a^2)^2(y^2-b^2)]}{32D\left(a^4+b^4+\frac{4}{7}a^2b^2\right)(1+\mu)}\end{aligned} \quad (8)$$

The formula for calculating the principal stress is:

$$\left.\begin{matrix}\sigma_1\\ \sigma_2\end{matrix}\right\} = \frac{\sigma_x+\sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x-\sigma_y}{2}\right)^2 + \tau_{xy}{}^2} \tag{9}$$

Equation 8 and Equation 9 can obtain the expression of principal stress at a certain point in the dam as follows:

$$\left.\begin{matrix}\sigma_1\\ \sigma_2\end{matrix}\right\} = -\frac{21qz(1+\mu)[\mu(3x^2-a^2)(y^2-b^2)^2+(x^2-a^2)^2(3y^2-b^2)]}{16\left(a^4+b^4+\frac{4}{7}a^2b^2\right)} \pm \sqrt{\left(-\frac{21qz(1-\mu)[\mu(3x^2-a^2)(y^2-b^2)^2-(x^2-a^2)^2(3y^2-b^2)]}{16\left(a^4+b^4+\frac{4}{7}a^2b^2\right)}\right)^2 + \left(-\frac{7qEz[x(x^2-a^2)(y^2-b^2)^2+y(x^2-a^2)^2(y^2-b^2)]}{32D\left(a^4+b^4+\frac{4}{7}a^2b^2\right)(1+\mu)}\right)^2} \tag{10}$$

The artificial dam is made of C25 concrete, and according to the Code for Concrete Structure Juice Design GB50010-2010, the design value of tensile strength of C25 concrete is 1.270MPa, and the design value of compressive strength is 11.900MPa. The size of the roadway is 5m wide, 3m high, and 1m thick. From equation 4-7, it can be seen that the maximum deflection of the dam occurs at the midpoint of the dam, and the maximum principal stress should also occur at the midpoint of the dam's backwater surface, which is calculated by substituting the dam parameters and the coordinates of the center point of the dam's backwater surface. When the head height is 21m, the water pressure q=0.21MPa, and the maximum tensile stress of the dam is 1.26MPa, which is less than the ultimate strength of the material. When the head height is 22m, the water pressure q=0.22MPa, and the maximum tensile stress of the dam is 1.32MPa, which is greater than the ultimate strength of the material.

Therefore, through theoretical calculation, 21m is taken as the limit head of the artificial dam.

3. Conclusion

A theoretical analysis model was established by using the elastic mechanics thin plate problem, combined with the elastic mechanics Galerkin method and the plane stress problem solving method, to establish the expression of the strain deflection of the concrete wall of the artificial dam under the action of water pressure in the goaf and the expression of the internal stress function. Through the calculation, the ultimate head height that the dam can withstand is 21m.

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