Study on discharge velocity of tailings mortar in dam break based on FLOW-3D

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Abstract. Tailings pond is used to store the tailings discharged from the mine after separation and mining. As a potential hazard source with high potential energy, the tailings mortar with high potential energy after dam break is transformed into high-speed dynamic energy sand flow to impact the downstream area through energy conversion. In this paper, through the establishment of a three-dimensional model of a tailings pond, the FLOW-3D software is used for numerical simulation, and the influence of correlation coefficient on the discharge speed of tailings mortar after dam break is analyzed, and the relevant migration law is obtained. The test in this paper can provide a reference for the corresponding disaster and protection engineering research.

1. Introduction

Tailings pond is a kind of dangerous source with high potential energy formed by tailings accumulation, and the tailings mortar is often accompanied with toxic chemical components (such as Pb, Cu, Mn and other heavy metal elements). Once dam break occurs, debris flow will occur, which may cause security threats and economic losses to downstream residents and public facilities.

In mining production, tailings dam break is still the main problem to be solved, many factors will affect the normal operation of tailings pond. Accidents caused by these factors will cause some differences in the properties of the discharged tailings mortar and the original tailings. The density and viscosity coefficient of the discharge body will change. Therefore, this paper selects the above parameters to explore its impact on the tailing mortar discharge process.

Recently, most scholars have carried out researches in the direction of tailing mortar and its toxic substances in the downstream channel diffusion range [1-3] and the influence of tailing mortar harmful substances on the downstream through underground dispersion [4-5] when tailing pond dam break occurs. If the number of tailings ponds is large, the study on the fluidity of tailings mortar can effectively solve the safety problem of domestic tailings ponds. The factors affecting the discharge of tailings mortar are multiple, so a more systematic study is still needed.

2. Calculation theory

The calculation method of the mortar movement after the dam break accident of tailings dam can refer to the calculation method of debris flow, and use the dynamic equation and continuity equation of fluid movement to express the movement state of dam break tailings mortar.
2.1 Basic governing equations of three-dimensional flow

In this paper, the mass conservation equation (continuity equation) and momentum conservation equation (N-S momentum equation) are used to describe the three-dimensional fluid motion[6], and the fluid phase interface is defined by Volume-of-Fluid (VOF) method.

Continuity equation:

\[ \frac{\partial}{\partial t} \iiint_{\text{vol}} \rho \, dx \, dy \, dz + \oint_{\partial \text{vol}} \rho \mathbf{v} \cdot d\mathbf{S} = 0 \]  

where Vol is the closed area in the flow field, A is the surface of the closed area; The first term is the increment of mass in the closed region, and the second term is the static flux through the surface of the closed region.

N-S momentum equation:

\[ \rho \frac{du_i}{dt} - \rho F_i - \frac{\partial}{\partial x_j} \left( \mu \frac{\partial u_i}{\partial x_j} \right) + \frac{\partial}{\partial x_j} \left( \mu \frac{\partial u_i}{\partial x_j} \right) + \frac{\partial}{\partial x_j} \left[ \frac{\mu}{3} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right] = (i = x, y, z) \]  

where \( u, v \) and \( w \) are velocities along \( x, y \) and \( z \) directions respectively. \( \mu \) is hydrodynamic viscosity.

2.2 Turbulence governing equations

The Renormalization group (RNG) \( k-\varepsilon \) turbulence model is selected in this paper. The RNG turbulence model was first proposed by Yakhot[7]. Based on applied statistics, the equations of turbulent flow (turbulent kinetic energy and dissipation rate) are derived (3-6). Compared with standard \( k-\varepsilon \) equation, RNG \( k-\varepsilon \) equation is more accurate for low intensity turbulence and strong shear flow. Since the tailings dam break is a complex fluid movement, which will cause turbulence and strong deformation, the model is the most suitable.

Turbulent kinetic energy \( k \) equation:

\[ \frac{\partial (\rho k u_i)}{\partial x_j} = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + P_k - \rho \varepsilon \]  

Dissipation rate \( \varepsilon \) equation:

\[ \frac{\partial (\rho \varepsilon u_i)}{\partial x_j} - \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] = \frac{\varepsilon}{k} \left( c_\varepsilon^2 P_k - c_\varepsilon \rho \varepsilon \right) \]  

Compared with the standard \( k-\varepsilon \) equation, the equation is modified by \( c_1 \):

\[ c_\varepsilon^2 = c_i \left( \frac{1 - \eta / \eta_i}{1 + \beta \eta} \right) \]  

In the equation, \( \mu_t \) can be expressed by \( k \) and \( \varepsilon \) as follows:

\[ \mu_t = \rho c_\mu \frac{k^2}{\varepsilon} \]  

where \( k \) is the turbulent kinetic energy and \( P_k \) is the kinetic energy generation rate; \( \mu_t \) is the turbulent viscosity; \( \mathcal{E} \) is the turbulent energy dissipation rate; \( \eta \) is the dynamic viscosity; \( \beta, c_1, c_\mu \) are empirical constants.

3. Example part

3.1 Calculation conditions and models

In this paper, the 3D model of a tailings pond is drawn by CAD and simplified. The model conversion format is imported into FLOW-3D software for numerical calculation (see Figure 1). The discharge body is selected as the tailings pond accumulation area, the slope height ratio of the accumulation area is 1:3, and the downstream area is set as a rectangular area of 1000 * 400 * 30m. The mesh number is 48592 when the model is divided into 3 m length. The model is endowed with boundary conditions. The flow outlet is set at the end of the breach and the end of the downstream area, and the other surfaces are set as "walls".
3.2 Verification example

Based on the convenient selection of boundary numerical solution in numerical analysis, and the empirical formula summarized by Kang [8] through relevant dam break and debris flow data is also of typical representative significance. The empirical formula is derived from the debris flow velocity Formula (7) proposed by Kang. In the 1960s, Kang first established the empirical formula of debris flow velocity based on relevant dam break information. Later, Fu [9] once again verified the importance of this method for debris flow research based on Kang’s method.

\[ U_c = 28.5h^{0.34} \left( \frac{2}{h^2 J^2} \right)^{0.5} \]  

where \( U_c \) is the maximum velocity of tailings at dam break. \( h \) is sand depth in front of dam. \( J \) is slope ratio outside dam.

| Example | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
|---------|----|----|----|----|----|----|----|----|
| Empirical solution (m/s) | 25.8 | 32.07 | 32.9 | 31.2 | 32.3 | 30.6 | 34.2 | 33.7 |
| Numerical solution (m/s) | 25.1 | 32.7 | 31.9 | 31.7 | 31.6 | 31.0 | 32.5 | 33.5 |

Therefore, the verification method selected in the verification example is to establish eight independent verification conditions by changing the relevant parameters of tailings mortar (such as density and viscosity coefficient), and calculate eight numerical solutions. The results are repeatable (see Table 1). The numerical solutions are compared with the empirical solutions of empirical formulas. The maximum error of the two results under this method is 3%, and the model is reasonable.

3.3 Calculation results and analysis

- Velocity distribution

Figure 1 Calculation model of a tailings pond

Figure 2 Top view of velocity distribution of tailings mortar at 10s

Figure 3 Top view of velocity distribution of tailings mortar at 20s

Figure 4 Top view of velocity distribution of tailings mortar at 30s

Figure 5 Top view of velocity distribution of tailings mortar at 40s
Relationship between velocity and time
When the tailings pond dam breaks, the tailings mortar moves to the downstream sections, which makes the speed reach the peak in a short time. Then the tailings mortar supply is gradually insufficient, and the speed gradually drops to a relatively stable value (see Figure 6). However, with the passage of time and the change of flow process, the flow velocity gradually decreases. The velocity distribution of tailings mortar in each time period is shown in Figure 2 to 5.

Figure 6 Relationship between velocity and time of tailings mortar movement at 200m and 400m away from the breach

3.3.1 Different density test
Due to the different composition of tailings in the accumulation area of tailings ponds, the density of fine sand is as low as 1800kg/m³, while the density of coarse sand is as high as 3200kg/m³. Therefore, the influence of different density on the tailing mortar is analyzed. Figure 7 shows that in the early stage of tailings mortar migration, due to the different density of tailings mortar in the same volume of tailings pond, the corresponding quality is different, which makes the gravity potential energy of tailings mortar with higher density larger. However, the test shows that the movement speed of tailings mortar with three different densities tends to be consistent after a period of time.

3.3.2 Different viscosity coefficient test
The viscosity of tailings mortar is affected by many elements, such as weight concentration, fine particles, etc. Based on the usual viscosity coefficient of 0.5kg/m/s, this paper establishes 5kg/m/s and 15kg/m/s to carry out comparative test. Figure 8 shows the relationship between the migration distance and time of tailings mortar with different viscosity coefficients. It can be clearly seen from the figure that the larger the viscosity coefficient is, the greater the resistance generated during its movement, resulting in the smaller migration speed.

3.3.3 Different roughness height test
The roughness height can reflect the surface roughness of the downstream, and generally, the surface roughness height of zero is regarded as the smooth surface. Due to the complexity of the downstream surface conditions, this paper selects 0.25m, 0.5m and 1.0m to test. Figure 9 shows that the higher the roughness height, the smaller the migration distance at the same time. Because when the roughness of the downstream ground surface increases, the corresponding resistance will also increase, which makes the transport speed of tailings mortar smaller.
4. Conclusions
Based on the three groups of tests and the obtained migration law of tailings mortar, the following conclusions are drawn.

(1) The downstream roughness height is an important factor affecting the velocity of tailings mortar. In the test of the effect of different roughness height on the movement speed of tailing mortar, the speed at 450 m away from the breach was reduced by 19.6%, 29.7% and 43.7%, respectively, compared with that at 300 m. The speed at 850 m points away from the breach was reduced by 58.5%, 64.8% and 66.6%, respectively, compared with that at 300 m points. In order to reduce the damage of tailings mortar to downstream area after dam break, vegetation and small water retaining facilities can be planted in the downstream area to increase the roughness height of downstream surface, which can effectively slow down the transport speed of tailings mortar in the downstream area. The other experiments show that different densities have little effect on the downstream movement of tailings mortar when it is discharged.

(2) The viscosity coefficient of tailings mortar is also an important factor affecting the velocity of tailings mortar. Reducing the moisture content of tailings mortar can effectively increase the viscosity coefficient of tailings mortar. In the test that different viscosity coefficients affect the movement velocity of tailing mortar, at the distance of 300 m from the breach the average velocity of tailing mortar is 27.22 m/s, 23.71 m/s and 22.96 m/s. At the distance of 850 m from the breach, the average velocity of tailing mortar was 9.66 m/s, 9.57 m/s and 9.03 m/s, respectively.

(3) After the dam break, the tailings mortar impacts from the breach to the downstream, forming a fan-shaped shape. When the tailing mortar moves to the downstream boundary on both sides, it will form accumulation at the boundary, and gradually move to the center. In terms of velocity change, it is fluctuant, which is very similar to the intermittent flow of debris flow, which indicates that the discharge movement of tailings mortar also has fluctuation.

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