Study on the Influence of Elevation of Tailing Dam on Stability

Shuai Wan¹, Kun Wang¹,*, Songtao Kong¹, Runan Zhao², Ying Lan¹ and Run Zhang¹

¹Chongqing University of Science & Technology, Chongqing, China
²Wuhan Electric Power Technical College, Wuhan, China
Email: 2644686842@qq.com

Abstract. This paper takes Yunnan as the object of a tailing, by theoretical analysis and numerical calculation method of the effect of seismic load effect of elevation on the stability of the tailing, to analyse the stability of two point driven safety factor and liquefaction area. The Bishop method is adopted to simplify the calculation of dynamic safety factor and liquefaction area analysis using comparison method of shear stress to analyse liquefaction, so we obtained the influence of elevation on the stability of the tailing. Under the earthquake, with the elevation increased, the safety coefficient of dam body decreases, shallow tailing are susceptible to liquefy. Liquefaction area mainly concentrated in the bank below the water surface, to improve the scientific basis for the design and safety management of the tailing.

1. Introduction

Tailing is a kind of special industrial buildings, and it is also one of the 3 major mines of control engineering. On country level, it is one of the 9 categories of major hazard sources. Tailing operation quality is not only related to the economic benefits of mining enterprises, but also closely related to the life and property and the surrounding environment of reservoir downstream residents [1-2]. China is a big country of mining. Every year, there is a small part beneficiation tailing annually produced in addition to as mine filling or comprehensive utilization, but most of tailing as a man-made high potential debris flow hazard [3]. Once the tailing dam break out, it will cause serious consequences. Therefore, whether it is environmental protection or sustainable development, there is a significant economic and social benefits significant of the research on the stability of the tailing. This paper combined with practical engineering, the tailing are analyzed, which has certain guiding significance for the safe management and operation of the tailing.

Tailing dam stability analysis method is the traditional method of safety coefficient. By determining the landslide of the tailing dam, it used rigid body limit equilibrium method, such as the Sweden Arc method, Bishop method to calculate the safety factor of slope tailing in addition to judge the stability of the tailing [4-6]. According to the safety technical regulations of tailing dam, the minimum safety factor of tailing reservoir is greater than 1.05, which meets the stability requirements.

In China, there are majority of tailing dam used the upstream to build up. But the tailing dam seepage line is high in this way, and the majority of tailing dam is saturated. According to China earthquake experience, the earthquake liquefaction of tailing dam lost stability easily. So the liquefaction analysis of tailing dam’s stability has an important significance [7-8]. Moreover, liquefaction is one of the
important subjects of geotechnical earthquake engineering research, and it has been paid much attention by scholars and engineers all over the world [9-10].

2. Tailing Reservoir Survey
At the beginning of the tailing dam type for permeable dam, dam height is 56.5m, and take the upstream to build up dam. The largest dam height is 80.0m. The final dam height is 136.5m. And the total capacity is $500.03 \times 10^4 m^3$. According to the code for design of tailing facilities, this tailing belongs to the third kind of dam. The main structures (facilities) is grade 3, the same to initial dam and flood discharge facilities. The secondary structures (facilities) or the same construction level is grade 5, such as the pump room. The tailing dam crest dispersed ore on the roof of the mine, the coarse sediments will be in front of dam, and the fine particles will discharge to the end of dam. It make use of the tailing to stack up when it stack to the initial dam.

3. Numerical model of tailing dam
According to the actual situation, the maximum cross section of tailing dam is selected as the analysis model. The whole two-dimensional plane model of tailing dam is set up as shown in Figure 1.

![Figure 1: Analysis model of tailing dam](image)

In static analysis, because of the stress-strain relationship of the rock-fill material is strongly nonlinear, it usually used the constitutive model of Duncan Chang. This can basically reflect the actual deformation characteristics of rock-fill dam. The dynamic characteristic of soil has nonlinear, hysteretic and elastic-plastic properties, so the dynamic analysis based on static analysis using the equivalent linear viscoelastic model [11]. In dynamic analysis, the stone material generally can be regarded as viscoelastic material. It used the equivalent shear modulus and equivalent damping ratio to reflect dynamic nonlinear stress - strain relationship and hysteresis. This paper in calculation uses the improved Hardin-Drnevich equivalent viscoelastic model as the constitutive model of the dam.

3.1. Meshing
As shown in Figure 2, the model is meshed, and the model is divided into 3262 nodes and 3140 units.

![Figure 2: Mesh model of tailing dam](image)

3.2. Phreatic line calculation
The analysis of the tailing dam seepage line is calculated. According to the tailing dam engineering geological exploration report data, it used the software of seepage calculation module. Calculation results obtained at different elevation line infiltration through iteration. As shown in Figure 3 below 1030 meters elevation of saturation line calculation results.
3.3. Seismic wave introduction
The tailing dam seismic fortification intensity is 8 degrees. According to the standard, it determined the maximum horizontal acceleration of 0.3g. According to the specification of tailing, it determined the seismic wave duration should not be less than 35s. With EI-Centro seismic wave, we synthetized artificial seismic wave as an input seismic wave. The overall response time of the earthquake should be in 35s. Figure 4 is the history curve of seismic wave acceleration.

Figure 4  Seismic wave acceleration time history curve

3.4. Calculate elevation and related parameters
The tailing dam analysis has four elevation calculation: 950m, 980m, 1010m, 1030m. Through checking the minimum safety coefficient under different elevation changes in calculation to ensure the different height of tailing dam can operate stably under earthquake. The relevant parameters are shown in Table 1.

| Site and soil layer | wet density (kN/m$^3$) | saturated unit weight (kN/m$^3$) | angle of friction ($^\circ$) | Cohesion (kPa) |
|---------------------|------------------------|----------------------------------|-----------------------------|----------------|
| Initial dam         | 23                     | 23.5                             | 35                          | 0              |
| Tailing sand        | 17.5                   | 20.2                             | 26                          | 6              |
| Tailing powder      | 18.3                   | 21.2                             | 22                          | 8              |
| Tailing clay        | 17.2                   | 19.3                             | 10                          | 12             |
4. The theoretical analysis of safety factor and liquefaction

4.1. Safety factor time history analysis

The basic ideas of all limit equilibrium methods are the sliding soil which is divided into finite width. The slice is assumed as a rigid body. According to the distribution of the static equilibrium condition and the limit equilibrium condition to obtain the force on the slide surface force, so as to calculate the safety factor. Because the actual soil is a kind of elastic and plastic materials, and there is no limit equilibrium method to meet the coordination of strain and displacement, which has certain limitations mainly in two aspects: On the one hand, we cannot consider the variation of local safety coefficient; On the other hand, it is inconsistent with the actual situation that to obtain the stress distribution for sliding surface generally. In order to overcome these limitations, it can be introduced to analyze the stability by using the limit equilibrium method. The key physical factor is the stress-strain relation, and that is the finite element limit equilibrium method, also named the finite element circular method [12].

Compared to the traditional limit equilibrium method, the finite element limit equilibrium method has many advantages:

1) There is no need to assume the forces between bars;
2) The stress distribution obtained by numerical simulation shows that there is no iterative convergence problem (but must be iteratively calculated in finite element simulation);
3) It meets deformation compatibility;
4) The calculated stress on the sliding surface is close to the actual situation;
5) In the analysis of stability, the stress induced by earthquake can be taken into account directly (It need dynamic finite element method to calculate stress distribution) and so on.

Finite element method of limit equilibrium regard soil as a deformation body. According to the deformation characteristics of soil, we calculate the appearance of stress distribution by finite element method, and then introduce the concept of circular slip surface. The stress application has been calculated and checked the overall calculation of the stability of soil slope. The calculated of anti-slide safety coefficient definition is $F$ which is between the sum of a shear slip surface $S_r$ and the sum of the glide shear along the surface $S_m$ [13]:

$$ F = \frac{\sum S_r}{\sum S_m} \quad (1) $$

The shear and glide shear forces at the bottom of the floor are calculated by the lower approach (without considering the strength of unsaturated soil):

$$ S_r = s\beta = (c' + (\sigma_n - u_0)\tan\phi' + (u_n - u_0)\tan\sigma'b) $$

$$ S_m = \tau\beta \quad (2) $$

In the formula, the effective shear strength at the center of the chip is $s, \beta$ is the length of base surface. $\sigma_n$ is the central normal force of the floor. $\tau$ is the central slip shear stress at the center of the chip.

The local safety factor is defined as the ratio of the shear resistance to the glide shear of each slice of the $F_{local}$, which is not available in the conventional limit equilibrium method.

$$ F_{local} = \frac{S_r}{S_m} = \frac{s\beta}{\tau\beta} = \frac{s}{\tau} = \frac{(c' + (\sigma_n - u_0)\tan\phi' + (u_n - u_0)\tan\sigma'b)}{\tau} \quad (4) $$
The normal stress $\sigma_n$ and the glide shear stress at the center of the underside $\tau$ are obtained based on Mohr's circle equation:

$$\sigma_n = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x - \sigma_y}{2} \cos 2\theta + \tau_y \sin 2\theta$$  \hspace{1cm} (5)

$$\tau = \tau_y \cos 2\theta - \frac{\sigma_x - \sigma_y}{2} \sin 2\theta$$ \hspace{1cm} (6)

In the formula, the $\sigma_x$, $\sigma_y$ are the total stresses at the bottom center and the X direction and the Y direction. The $\tau_y$ is the shear stress at the bottom center and the X direction and the Y direction; The $\theta$ is the angle from the X direction to the normal stress line.

The strength and stability analysis of seismic dynamic force is calculated by the finite element limit equilibrium method:

$$F = \sum \left( c' + (\sigma_x - u_x) \tan \phi' + (u_x - u_u) \tan \sigma' \right) \beta$$ \hspace{1cm} (7)

This is calculated using the effective stress dynamic finite element method to calculate dynamic stability safety coefficient of rock-fill dam for downstream dam slope. It will make the most use of dangerous sliding surface when each time step the dynamic analysis produced. We can use the sliding force and anti-sliding force of (7) formula of slip surface to calculate the minimum safety coefficient each time step made.

4.2. Liquefaction analysis theory

In the analysis of the earthquake response of tailing dam, the soil mass is considered as a viscoelastic body, and its dynamic equilibrium equation is:

$$M\ddot{\delta} + C\dot{\delta} + K\delta = -M\ddot{\delta}_g$$  \hspace{1cm} (8)

In the formula, $M$, $C$ and $K$ are the total mass matrix, the total damping matrix and the total stiffness matrix of the dam; $\delta$, $\dot{\delta}$ and $\ddot{\delta}$ are the velocity array, acceleration array and displacement array of the dam body; And $\ddot{\delta}_g$ is the acceleration array of the input seismic wave [14].

Considering the nonlinear dam material, $\gamma$ is the equivalent linear model, and the dynamic shear modulus and damping ratio are shear strain a function. The dam liquefaction analysis proposed by Seed [9] and the shear stress analysis of liquefaction stability comparison method, through comparing the calculated dam seismic shear stress and liquefaction test the anti-liquefaction of sand liquefaction. First by the power calculation of $\theta - t$ period to determine the maximum shear stress $|\tau_{max}|$, the peak shear stress of $\tau$ appeared time is $n$. Second, calculate the group $|\tau / \tau_{max}|$, and according to the ratio of the correspond, the conversion coefficient is $\beta$; Finally, the liquefaction safety degree is $F = \tau_x / (0.65|\tau_{max}|)$; If $F > 1$ is considered, and the unit is not liquefied; If $F \leq 1$, the unit is considered liquefied.

5. Calculation results and analysis.

5.1. Dynamic safety coefficient

This paper takes the dynamic 1030m height time history analysis as an example. 1030m elevation dynamic safety coefficient curve is shown in Figure 5. From the curves of tailing dam, we can know that the safety factor changes constantly under the influence of earthquake. When the earthquake makes the tailing dam slope decreased, the safety coefficient of tailing dam is relatively large. When the earthquake makes the tailing dam slope large, the safety coefficient of tailing dam is relatively small.
5.2. Liquefaction analysis
Liquefaction analysis of tailing dam on the 1030 elevation, the earthquake liquefaction area at the end of tailing dam is shown in Figure 6. Figure 6 shows under the earthquake, liquefaction area is the saturated region for infiltration line.

5.3. Elevation comparison
The four elevation were 950m, 980m, 1010m, 1030m. After calculation, the minimum safety factor of the earthquake were 1.369, 1.333, 1.161, 1.156. It is Visible that tailing dam minimum dynamic safety factor decreases gradually along with the increasing height of tailing. But it is greater than the provisions of technical specification for tailing safety value 1.05 [15]. Therefore, the tailing dam is stable under the earthquake intensity earthquake. The liquefaction zones of the four elevations are located below the phreatic line and on the right side of the dry beach.

6. Conclusion
We obtained the initial stress through the static solution, and then we carried out seismic dynamic analysis on the basis of the solution. Through the analysis of tailing dam will appear local liquefaction under earthquake, it will reduce the safety coefficient of tailing dam. The under 8 degree earthquake, the shallow tailing prone to liquefaction, liquefaction areas are mainly concentrated the water in the pool below the line. In the earthquake, with the increase of altitude, the minimum safety coefficient is smaller.
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