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Research Article

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Study on the slope stability of typical super-high tailings dam with using the centerline method to dam

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ABSTRACT

The safety operation of tailings dam is the necessary conditions to ensure that the tailings dam is steady. Field investigation and sampling of a tailings dam were carried out in Jiangxi Province. The dam composite and tailings deposition law are discussed in this paper. Dam stability was studied under different working conditions and the disaster prevention measures were discussed. The research results indicate that: the change trend of the tailings in the tailings dam for outer to inner is very obvious from coarse to fine while that from top to down is not. The change is slow in the deposited beach and the slope relatively flat. There is no tailings mud in the tailings dam. The calculated safety factor under normal or operation condition and flood operation condition could meet the standard requirements on the stability of the dam. However, the safety factor is far lower than the standard requirements on that under the full saturation condition and seismic condition. The stability of dam is reduced significantly, which may lead to the instability of the tailings dam.

Key words: Tailings dam; Geotechnical investigation; Tailings deposition law; Dam stability

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INTRODUCTION

Tailings dam, an important establishment in the mine production, is a prerequisite to guaranteeing the normal operation and continuous production of a mine. At the same time, it is one of great danger sources for mine safety management due to the problems of safety, environmental protection and resource reserve. If the tailings dam-break accident occurred, great losses would be made to the life safety of people and the property of the nation. A tailings dam in Jiangxi Province is a most typical central line embanked dam, which is of clay wall rock fill starter dam with the crest elevation of 110m at the initial phase and of two-step cyclone classified tailings dam by central line embankment method. Both sides of the tailings reservoir area are steeper, characterized by exposed local bedrock is exposed and developed vegetation. Ravines are scattered and trees closed covered within the area. The major average longitudinal slope is about 0.01. The ditch bottom width is about 200m while the upstream is open. The main ditch above the dam site is about 5 km long and the area of water catchment about 15 km2. The ground level of the tailings dam site is 72m. The finally designed level is 280m and the maximum height 208 m. The downstream side slope is built to be 1:3.0. The total storage capacity is 800 million m3.

By the time of March, 2008, the dam has become the largest tailing one in China and Asia with the crest level of the dam reached 218m and the embankment 146m. Because of the frequent tailings dam accidents in recent years, as an important safety establishment installation of tailings pond and mine, a tailings dam is directly related to the stability of a tailings pond and plays a vital role in the downstream villages and the production of the whole mine. [1] For instance, on September 8, 2008, the tailings dam break accident took place at Ta-ershan Iron Mine, Xinta Mining Industry Limited Company in Xiangfen, Shanxi Province, directly resulting in the death of 276 people. Therefore, accurate stability evaluation of a mine tailings dam is the premise to prevent tailings dam from instability, break or threat to people's life and property safety, and the basis provided for the final control of the mine tailings dam.

At present, due to the particularities of the tailings dam, foreign countries such as the countries of European Union, Canada and Australia, etc. pay great attention to the safety of the tailings dam, in particular, the stability of the tailings dam in earthquake. Seid[2] analyzed the Mochikoshi tailings dam by using commercial software FLAC, and discussed the seismic resistant measures briefly. Ishihara [3] analyzed the seismic stability of Mochikoshi tailings dam with the theory of the residual strength. Troncoso[4] studied the dynamic characteristics of tailings sands of a silt mine under the earthquake load, also concluded that the silt tailings sands with fine particles tend to be liquefacient. Finn [5] studied the dynamic strength and characteristics of the tailings sludge/slurry? and also considered that the tailings sludge/slurry with more fine particles tend to be liquefacient. While in China, some studies have been done in the dynamic and static stability of tailings dams and some achievements have been reached. Wang Wenxing[6] believed that the excess pore water pressure is an important factor that influences the seismic stability of a tailings dam. Wang Feiyue[7] applied the fuzzy theory to the research of the stability of the tailing dams for the first time for the reliability analysis method of the fuzzy and random in tailings dam engineering, which provides a new way for the calculation of the tailings dam stability. Yuan Bing[8] studied the liquefaction identification of tailing dams specifically and put forward a simplified identification method by which the earthquake magnitude, the tailings median particle diameter, relative density, static stress, and physical mechanical indexes of tailings are taken into comprehensive consideration. RuanYuancen[9] studied the static and dynamic characteristics of the tailings, and pointed out the complexity of the research on tailings. Li Xingxing[10] analyzed the dynamic finite element of tailings dams and his results showed that the dam body's damage becomes more serious and dam stability also worse when the seismic frequency is closer to the natural frequency of the tailings dam, the earthquake lasts longer and acceleration becomes greater. Although domestic and foreign scholars have made many achievements in the stability of rock fill dams up to now, there are little research results in the stability analysis of central line embanked high tailings dam. Therefore, in this paper, some research of the stability of the high tailings dam has been made based on the site investigation and indoor experiments for the high tailings dam of a copper mind in Jiangxi Province and its on-site photo is shown in Figure 1.

Figure 1 On-site photo of high tailings dam

ENGINEERING GEOLOGICAL INVESTIGATING

2.1 Geological structure and stratum

1) Geological structure

There are two faults in the site area: ①Fault F5, is located in the base of the dam in the valley, with the strike of 355° ～5° , the tendency 265° ～275° and the dip angle 50° ～65° . Fault fracture zone is composed of fracture rock and breccia with the color ranging from mouse grey to celadon. The fracture rock displays its dramatic extrusion and fracture while the breccia looks subangular with apparently seen scratches. The cement is of fault gouge and iron oxide, often showing puce and less tight cementation. The vertical thickness of the fault fracture zone in the borehole is 1.40~2.30m. ②Fault F6, is exposed in the west shoulder of dam site, with its strike of 20° ～25° , the tendency 110° ～115° and the dip angle 70° ～80° , which belongs to wrench fault or strike-slip fault. The influenced width of the Fault rupture is 1.50 ~ 2.00 m and the rock in the belt is crushed, Folder with thin gouge. See a group of pictures of nearly parallel scratch surface.

2) Stratum

It is phyllite which is exposed in the dam area which belongs to the fourth segment of Shuangqiao Mountain Group, Sinian System (Zsh4). The stratum strike is 260° ～270° , dips southwardly, and the dip angle is 70° ～ 75° . Quartz, feldspars, sericite, calcites and chlorite are the main mineral components. The structure is of palimpsest and phyllitic type. According to the regional data, it can be divided by the degree of weathering.

I. Intense weathered layer: bronzing, yellow and taupe, well-developed joint fissure. Black oxide can be usually seen on the joint surface with the cohesive soil filling. The drill cores are earthy or crushed. The rock blocks can be broken by hand. The layer thickness ranges is from 1.00 to 8.50 m.
II. Medium weathered layer: mouse gray～brown grey, developed joints with black oxide filling. Some minerals are of metamorphic type. The rock blocks sound hoarse after hammering and tend to be breakable. The drill cores are massive or crushed. The layer thickness ranges from 1.30 to 14.80 m.

III. Weak weathered layer: taupe～celadon, rather developed joint that looks dark brown on the surface, with black oxide and quartz veins filling. The layer thickness ranged from1.00 to 16.40 meters. The rock blocks sound brittle after hammering and tend to be unbreakable. The drill cores are massive or columnar. The layer thickness ranges from 1.00 to 16.40 m.

IV.Unweathered layer: gray～celadon. Joints are almost closed and rarely develop, filled by quartz veins. Cleavage is rather developed. The rock is compact and hard. The drill cores are columnar or short columnar. The layer thickness is more than 60 m.

The slopes and valley bottom are mostly covered by eluvial-slope wash layer, which had been cleared prior to construction of initial dam. Some boreholes had been drilled into the intense weathered or medium layer during this construction.

2.2 Hydrogeology

According to the simple observation and the catalog of hydrogeology of the drill holes, the groundwater is born in the tailings fine sand and silty clay stratum. The tailings fine sand is regarded as a strong-medium permeable layer, the silty clay an aquitard while the intense weathered phyllite can be seen as an impermeable layer or aquiclude. The type of groundwater is void phreatic water. Seventeen drillholes reveal that the overall buried water depth of groundwater is from 24.00 to 99.8 m and the elevation of groundwater is between 76.71 and 186.61 m above sea level. However, in reservoir area, the buried water depth is from 41.70-52.00 m and the elevation of the water level between 160.67 and 172.89 m; while in the dam area, the buried water depth and the water level are from 24.00 to 99.80 m and from 76.71 to 186.61 m above sea level respectively. Obviously, the water level in the reservoir area is higher than that in the dam area. There is no large surface water body around the site and the tailings pond is still in use. The main replenishment sources of groundwater are water from discharging the tailings and atmospheric precipitation.

ENGINEERING GEOLOGICAL SURVEY

3.1 Arrangement of Prospecting and drilling line

Three prospecting lines were arranged, vertical to the dam axis, in the tailings pond at the interval of 200 m. Their numbers are 1-1, 2-2 and 3-3 respectively. A total of 17 drillholes was arranged, 7 along the Prospecting Line 1-1, 5 along Line 2-2 and 5 along Line 3-3. The closest distance between drillholes is 60 m (ZK4 and ZK5 in Section 1) and the farthest 113.2 m (ZK14 and ZK15 in Section 3). See Figure 2 for the location of drillholes.

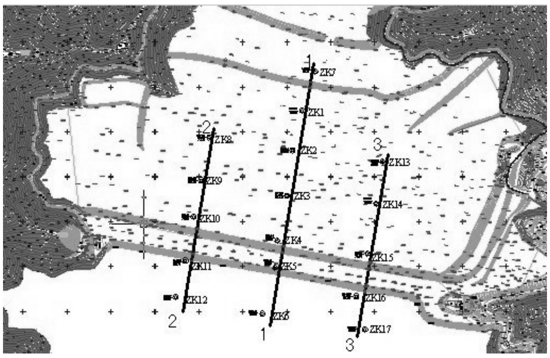


Fig 2Prospecting and drilling line of tailings dam in the floor plan

3.2 Sampling drilling

Undisturbed soil samples were taken from all the drillholes. Sampling interval was generally controlled to be 2.00 ~ 2.50 m. More sampling intervals were arranged in the section of soil layer with frequent changes of physical mechanical properties while less in that with little changes. Open thin-wall soil sampler was used for the original tailings soil and the weak dam foundation soil while common soil sampler for the clay of the initial dam and the soil of the non-weak dam foundation. A total of 392 original samples were taken during this drilling, for which regular tests such as permeation test, granule test, triaxial test and direct shear test were conducted in Wuhan Institute of Rock and Soil Mechanics, Chinese Academy of Sciences while the dynamic triaxial test was performed in Yangtze

River Scientific Research Institute.

3.3 Deposition rules of tailings

Based on the drilling results during the site geological prospecting and the indoor geotechnical test results of tailings samples obtained by the State Key Laboratory of Geomechanics and Geotechnical Engineering, Wuhan Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, it is known that the tailings accumulations are composed of 5 kinds of tailings materials: tail-fine sand, tail-silty sand, tail-mild sand, tail-light loam and tail-heavy loam. the geological map of tailings deposition rules with the 1-1 section is shown in the Figure 3.

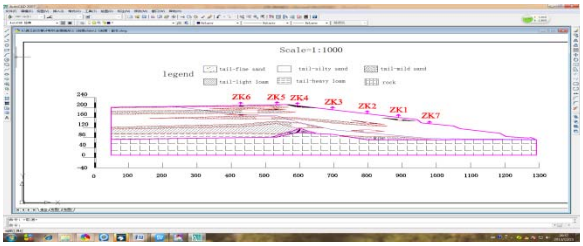


Fig 3 geological map of tailings deposition rules with 1-1 section(unit:m)

COMPUTATION AND ANALYSIS ON THE STABILITY OF TAILINGS DAM

4.1 Calculation approach

According to the Seismic Magnitude Zoning Map of China, the seismic magnitude of the Copper Mine in Jiangxi Province,is less than VI. According to the stipulations in the Specifications for Seismic Design of Hydraulic Structures DL5073-2000, when the design grade of structures is VI, there is no need to do the antiseismic calculation. However, in recent years, the frequent natural disasters have happened in China. Especially, the seismic catastrophes have brought great losses. The earthquake intensity has far exceeded the basic antiseismic intensity in many places of the earthquake zone. Moreover, the height of the tailings dam has reached 140m and the consequence would be unimaginable in case of its accident. Therefore, in this paper, the earthquake magnitude is considered to be VII based on which the value of the horizontal seismic coefficient is taken to be 0.1, and the vertical 0.067. In the stability analysis of the tailings dam, four schemes are taken into account.

SchemeI: when the tailing reservoir is in normal working condition, the actual measurement of the saturation line will be used as the water level.

SchemeII: The tailing pond is in the state of running flood, the minimum safe height of the Class-I tailings dam (1.5m) will be considered.

SchemeIII: The tailing pond is in full saturated working condition.

SchemeIV: The tailing pond is in seismic working condition.

Meanwhile, the classic Bishop method of the limit equilibrium methods is used to make the stability analysis with its calculation formula as follows.

$$Fs = \frac{\sum \frac{1}{m_{mi}} \left\{ c_i \cdot b_i + \left[W_i - \mu_i b_i + \left(X_i - X_{i+1} \right) \right] \tan \phi_i \right\}}{\sum W_i \sin \alpha_i + \sum Q_i \frac{E_i}{R}} \tag{1}$$

$$m_{mi} = \cos \alpha_i + \frac{\tan \phi_i \cdot \sin \alpha_i}{Fs} \tag{2}$$

Where: Ei and Xi separately represent normal and tangential force; Wi the weight of a bar, Qi the horizontal acting force; c,φ efficient cohesion and inner friction angle of the material respectively.

4.2 Calculation parameters

All the parameters adopted in this paper, shown in Table 1, are determined by the experimental data obtained by Wuhan Institute of Rock and Soil Mechanics, Chinese Academy of Sciences and Yangtze River Scientific Research Institute (the dynamic triaxial test).

Table 1 Soil indicators of dam stability calculation

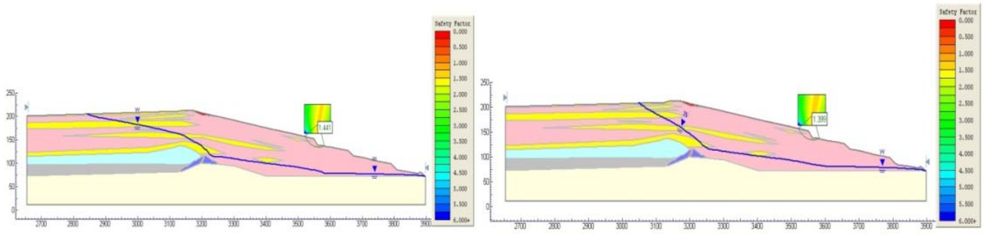
Soil group	Unit weight	Saturation unit weight	Effective stress strength parameters		Tailings dynamic triaxial experiment parameters	
	γ KN/m3	γ_{sat} KN/m3	c' kPa	ϕ' o	Cd(kPa)	Φd(°)
rock	23.0	23.5	10000	45	5000	32.0
tail-fine sand	20.0	20.5	0	28	0	16.8
tail-silty sand	18.8	20.1	2	25.2	0	16.5
tail-mild sand	19.4	20.4	4.5	24	0	16.4
tail-light loam	18.8	19.3	8	24	0	16.3
tail-heavy loam	18.5	19.0	10	22	0	16.1

4.3 Calculation results and analysis

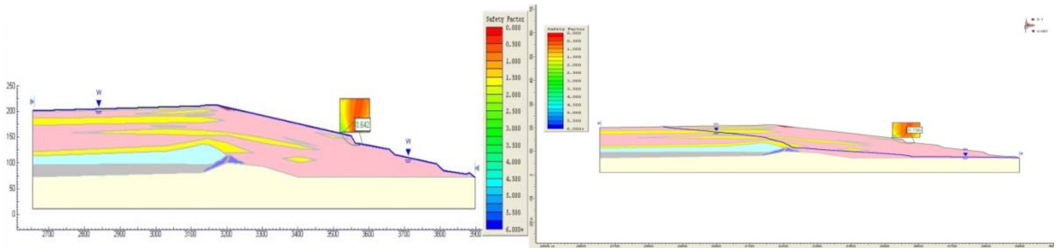
When the tailings dam is in normal working condition or in the state of running flood, the calculated safety coefficient can meet the requirements of the above specifications. Therefore, in the present building conditions, as long as the saturation line is below the height of flood and no special accident happens, the tailings dam should be stable. However, when the tailings dam is in fully saturated or seismic working conditions, the calculated safety coefficients are far below the requirements of the specifications and the stability of tailings dam declines obviously to make the dam in an extremely unstable state. The calculation results can be seen in Table 2.

Table2 Stability calculation results

Calculation approach	Working conditions	Computational safety coefficient	Minimum safety coefficient required in the specifications
Scheme I	Normal working condition	1.441	1.30
Scheme II	Flood working condition	1.399	1.20
Scheme III	Fully saturated working condition	0.642	1.20
Scheme IV	Seismic working condition	0.714	1.10



Normal working condition Flood working condition



Fully saturated working condition Seismic working condition

Fig 4 Calculation of dam stability

From the calculation results, it can be seen that in the case that the tailings dam in normal and flood working conditions, without the earthquake taken into consideration, are basically safe under its current crest height. However, in fully saturated working conditions, the calculated safety coefficient cannot meet the requirements of the specifications, and the slippage may come into being. Thus, the tailings dam should be avoided from running in the fully saturated conditions. The calculation results can be seen in Fig 4.

In addition, given that instability and cutting-slippage of the tailings dam may occur in fully saturated and seismic working conditions, it is suggested that the management of the tailings dam reservoir should be enhanced in the rainy season to prevent the dam from full saturation conditions. At the same time, collecting information on earthquake prewarning should be also strengthened. After the earthquake is prewarned, the downstream residents should be immediately evacuated to avoid personnel injuries and accidents. It is also suggested that multifunctional remote real-time monitoring system (like tailings reservoir remote monitoring system) should be set up to monitor the water level of tailings reservoir, the length of dry beach, the deformation inside and outside the dam, the inner gap pressure and the saturation line, etc.

CONCLUSION

(1) The exploration results suggest that the sediment rules of center line embankment is as follows: the tendency of tailings from coarse to fine is obvious from dam area to reservoir while that is not so obvious from top to bottom. The sedimentary beach of the tailings dam is slow and flat in shape. No tailings sludge (slime) layer is found during the drilling.

(2)When the tailings dam is in normal or flood working conditions, the calculated safety coefficient can meet the requirements of the specifications and the tailings dam is relatively stable. While the tailings dam is in full saturation working conditions, the calculated safety coefficient is far below the requirements of the specifications and the stability of dam decreases obviously, which leads to the extreme instability of the dam.

(3) When the earthquake magnitude of 7 is taken into account, the strength parameter of tailings will decrease largely and the calculated safety coefficient is far below the requirements of the specifications due to the earthquake load. In this case the geologic hazards are more likely to occur, such as landslip of tailings dam, dam break and so on.

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