DESIGN CASE ANALYSIS AND SAFETY MANAGEMENT COUNTERMEASURE OF HIGH TAILINGS DAM IN CHINA

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ABSTRACT

Because of the limit of land resources, a number of tailings dams constructed by upstream method were built in valley area of China, Which height reaches 200m. The design, operation and management of high tailings dam is very important for the success of mine production. Taking a 210m high tailings dam as an example, a generalized zoning model of tailings dam is established based on the characteristics of sedimentary tailings in the pond. The stability of high tailings dam is obtained by rigid limit equilibrium method, and the control indexes of tailings dam in different stack heights are analyzed. On this basis, construction method and seepage drainage facilities of the tailings pond are designed and safety management countermeasures are put forward.

1. INTRODUCTION

The mining industry generates large quantities of tailings. This by-products, which may potentially be harmful to the environment, need to be safely managed. China is a big mining country, producing about 1.6 billion tons of tailings every year. Except for a few fillings, most of them are stored in tailings ponds. Due to the increasing demand for mineral resources and the limitation of land resources, China has designed and constructed a number of upstream tailings dams over 200 m and 300 m in valley area. The design and operation management of high tailings dam is very important to the success of mine production. *Finn,W.D.L(Finn.W.D.L, 1976,1990)believes that the upstream construction of tailings dams is potentially dangerous.*Vick,S.*G.(Vick.S.G., 1990)pointed out that all tailings dams reported to have flowing damage in earthquakes have been constructed by upstream method. The tailings in these tailings dams and tailings ponds are usually in a saturated and loose state, with finer particles and larger proportion, and are prone to liquefaction and destructive deformation in earthquakes. However, the upstream method has been the most widely used dam construction method in China for decades because of its simple technology and easy management(*CHEN,S.Y, 1995*). At present, the maximum design height of tailings dam of upstream method in China has reached 325m.*Jiayu YIN et al (YIN, J.Y, 1980), pointed out that the internal friction angle of tailings under high pressure would be lower than that under low pressure. Jianlong ZHANG et al(ZHANG, J. L, 1995), pointed out that the strength envelope of saturated tailings exhibited downward bending under higher stress conditions. Michael et al(Michael, R. 2008), conducted triaxial tests on tailings in earth quake-prone areas. The results show that the shrinkage and ductile failure of tailings under high effective stress are probably caused by particle breakage. Haiming LIU et al(LIU, H. M, 2012), deduced the power function formula of the molar strength of tailings under high pressure, and obtained the confining pressure threshold value of tailings material particle breakage during shearing process through particle analysis before and after the test. At present, the mechanical properties of tailings under high stress conditions have not yet been clearly designed, so it is urgent to carry out relevant engineering exploration and experience summary. Taking a 210m high tailings dam in China as an example, this paper puts forward a generalized zoning model of the tailings dam after on-site geological survey, verifies the stability of tailings dam through stability calculation, and finally introduces the safety management countermeasures of tailings dam. The results can provide guidance for the construction decision of high tailings dam of upstream method in the future.

2. ENGINEERING BACKGROUND

Tailings dam is an important structure in mining engineering and a potential dangerous source of high potential energy. Due to the restriction of land use and other factors, the number of high tailings dam is increasing. According to statistics, up to now, there are 5 tailings ponds with total dam height over 200m, 183 tailings ponds with total dam height in 100m to 200m, and 751 with height in 60m to 100m in China's all 8869 tailings ponds. This paper takes a tungsten-molybdenum tailings pond located in Henan Province as the background to carry out relevant research. The catchment area of the tailings pond is 6.87km^2. The valley distributes from northwest to southeast. The terrain is high in northwest and low in southeast. The ratio of river bed is 0.08. The width of the valley is 4m to 25m. The longitudinal river bed is in V formation. The slope of the left bank is 25 to 50 degrees, the slope of the right bank is 20 to 40 degrees, and the relative elevation difference of the tailings pond area is 400m. The main lithology in the tailings pond area is dolomitic limestone with dolomite, besides a small amount of quaternary bleaching stone and quaternary slope gravel silty clay, as shown in Figure 1.

Figure 1 : Topography and landform of tailings pond area.

The tailings pond is designed in the form of starter dam and upstream embankment. The total dam height is 210m, the total storage capacity is 59.90 million m^3, and the effective storage capacity is 53.91 million m^3, which is classified as grade two in China. The starter dam is a roller compacted rockfill dam with a height of 60 m and a slope ratio of 1:1.8 in the upstream and downstream slopes. The height of upstream embankment is 150m, the average accumulation slope ratio is 1:5, and the current tailings embankment height is 75m. The capacity of the tailings is designed to be 15000t/d. After the tailings are collected in the concentrator, they are transported to the tailings pond under pressure for discharge, and the weight concentration of the tailings slurry is 35%-37%. Tailings size data are shown in Table 1.

Table 1 : Table of tailings particle size composition.

Particle composition (%)	2mm~0.5mm	0.1
	0.5mm~0.25mm	9.9
	0.25mm~0.074mm	28.8
	0.074mm~0.037mm	27.4
	0.037mm~0.02mm	15.6
	0.02mm~0.01mm	11.5
	0.01mm~0.005mm	3.7
	0.005mm~0.002mm	2.1
	＜0.002mm	0.9
d10		0.013
d30		0.032
d60		0.072
+0.074mm taking (%)		38.8
-0.02mm taking (%)		18.2

3. SEDIMENTARY LAW AND GENERALIZED ZONING OF TAILINGS

Sedimentary regularity of tailings in upstream embankment is controlled by the slope of deposited beach, the nature of tailings, particle size, slurry concentration, dispersed ore drawing discharge and ore drawing form. The structure of tailings dam is complex, the number of lens bodies is large and interpenetrating each other, and the profile shape is very complex. According to the section diagram of engineering geological exploration results (shown in fig. 2), the tailings deposit of the tailings dam presents three characteristics. (1) Tailings in front of dam are coarse and finer along the deposited beach. When the tailings slurry flows from the dam top to the direction of the tailings pond end, the ability of slurry to carry tailings gradually decreases, and tailings gradually deposit from coarse to fine. The median diameter d_{50} of sedimentary tailings in the range of 300m along deposited beach changed from 0.25mm to 0.074mm, and from 0.074mm to 0.035mm in the range of 300m to 420m. (2) The accumulative tailings are thick in the top and fine in the bottom in vertical direction. With the increase of the dam height, the top of the dam moves upward continuously, and fine tailings are deposited at the bottom of the dam body. From top to bottom, the thickness of tailings fine sand layer is 10-22m, thickness of tailings silt sand layer is 30-58m, and the thickness of tailings silty soil layer is 24-60m. (3) There have interbedded and different layers alternate with each other phenomena of the tailings in the embankment.

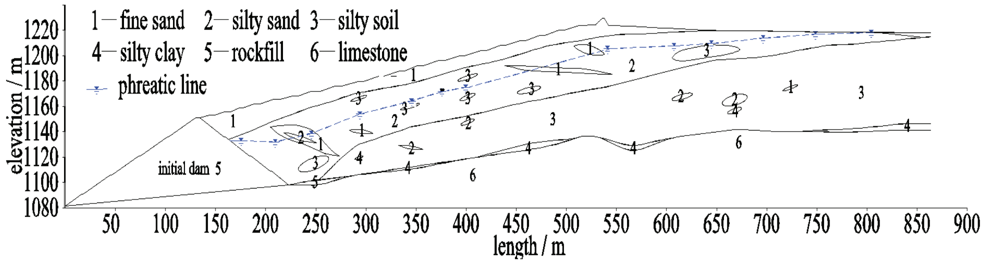

Figure 2 : Engineering geological exploration profile of tailings dam.

From Figure 2, it can be seen that the calculation of anti-sliding stability of tailings dam with complex profile and interpenetrating lenses requires a high computational program and a large amount of work. Therefore, the section can be simplified and the generalized zoning model can be formed before calculation. Specifically, it mainly includes, (1) Retain the larger lens and remove the smaller lens. (2) When the intensity of the lens is higher than that of the surrounding tailings, replace it with the surrounding soil. (3) When the intensity of the lens is smaller than that of the surrounding soil, it is retained. The computed section diagram obtained by such simplification (Fig. 3) can better reflect the measured results of engineering geological investigation.

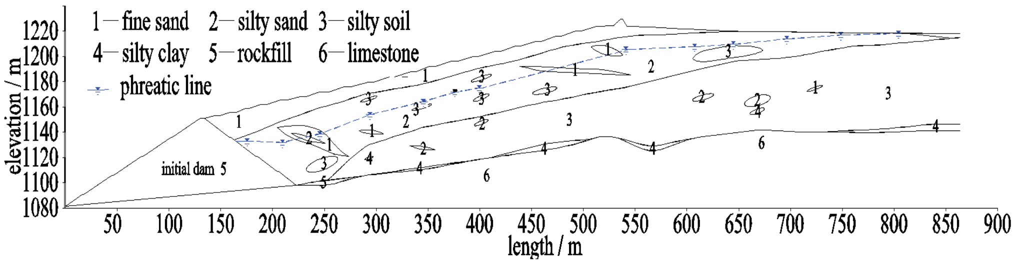

Figure 3 : The profile of tailings dam after simplified treatment.

4. STUDY ON SAFETY ANALYSIS AND CONTROL INDEX OF TAILINGS DAM

The anti-sliding stability of tailings dam decreases slowly with the gradual increase of dam (HU, M.J, 2004). High tailings dam break risk is high. Once dangerous situation occurs, it often brings extremely bad impact on the safety of life and property of surrounding people and environment. Therefore, there must be a higher safety reserve of high tailings dam. According to the relevant requirements of Code for design of tailings facilities(China Planning Publishing House, 2013), based on the above generalized zoning model and laboratory test results, the stability analysis of tailings pond is carried out by rigid body limit equilibrium method. In order to consider the influence of high stress conditions on the strength of tailings.

Use decrease value of the internal friction angle of tailings under high stress conditions recommended in the last reference(ZHOU, Q.Y. 2009), that of the tailings silty sand decreased by 3.2-6.0 degrees, the tailings silt soil by 2.4-2.7 degrees and tailings silty clay by 4.0-4.1 degrees. The calculation parameters of this stability analysis are shown in Table 2. Specific calculation scheme is as follows.

(1) Current dam height is 135m and final dam height is 210m.

(2) Normal conditions, flood conditions and earthquake conditions are considered.

(3) Swedish arc method and simplified Bishop method are used as computing methods.

Table 2 : Physical and mechanical properties of foundation and materials in tailings dam.

Material	Unit weight (KN/m³)	Permeability coefficient *k* (cm/s)	Cohesive force C (KPa)	Internal friction angle f (°)
Tailings fine sand	21.4	1.65×10^{-3}	8	28
Tailings silty sand	20.9	4.93×10^{-4}	9	24
tailings silty soil	21.5	1.34×10^{-4}	9	20
Tailings silty clay	21.8	6.01×10^{-6}	18	12
Rockfill	21.0	4.56×10^{-1}	10	32

In the analysis of anti-sliding stability of tailings dam, firstly, the seepage field of tailings dam under normal water level and flood level is simulated by GeoStudio software. On this basis, the gravity of dam, pore water pressure, seepage pressure and seismic load are considered. Finally, the stability of tailings dam is analyzed by different calculation methods. The results are shown in Table 3.

Table 2 : The results of dam stability.

Dam height	Computing method	Condition	Result	Value required in Code	Analysis of stability results
135m	Swedish slice method	Normal	1.884	1.25	Meet the requirements
		flood	1.789	1.15	Meet the requirements
		earthquake	1.514	1.05	Meet the requirements
	simplified Bishop method	Normal	2.009	1.35	Meet the requirements
		flood	1.912	1.25	Meet the requirements
		earthquake	1.616	1.15	Meet the requirements
210m	Swedish slice method	Normal	1.604	1.25	Meet the requirements
		flood	1.470	1.15	Meet the requirements
		earthquake	1.283	1.05	Meet the requirements
	simplified Bishop method	Normal	1.672	1.35	Meet the requirements
		flood	1.555	1.25	Meet the requirements
		earthquake	1.338	1.15	Meet the requirements

The phreatic line is the lifeline of the safety of tailings dam. In order to strengthen the safety management of tailings dam during its operation, the controlled position of the phreatic line is proposed in Code for design of tailings facilities[10], that is, the phreatic line of tailings dam when the safety factor of anti-sliding stability can meet the minimum requirement in the code, and the phreatic line of tailings dam is always lower than the controlled phreatic line in the course of operation. For this reason, four groups of artificial fitting phreatic lines are adopted, and the buried depth of the phreatic line corresponds to 10m, 15m, 20m and 25m respectively. The anti-sliding stability analysis of the dam with different buried depth of the phreatic line is carried out. The results are shown in Fig. 4.

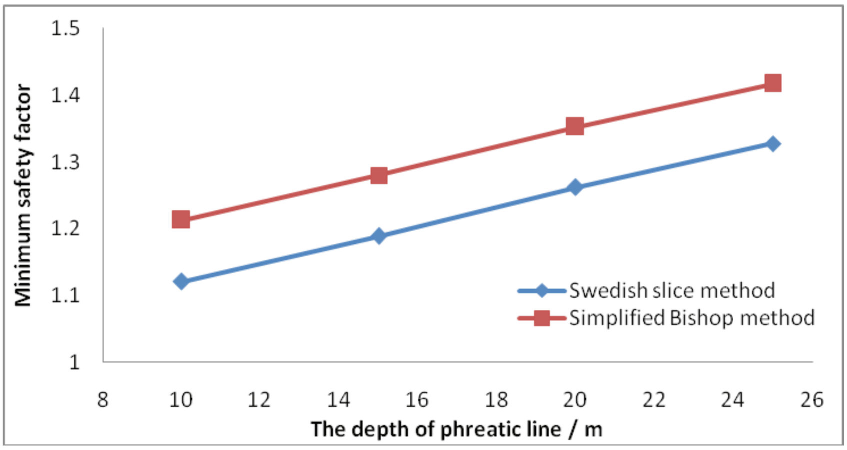

Figure 4 : Calculation results of dam stability under different controlled positions of the phreatic line.

From Figure 4, it can be seen that the result 1.262 calculated by Swedish slice method is larger than the minimum safety factor 1.25 which is required in the code under the normal condition of 20m phreatic line depth. The stability safety factor calculated by the simplified Bishop method is 1.352, that is close to 1.35 which is the minimum safety factor required in the code. So the controlled phreatic line depth of the tailings dam is 20m.

5. SAFETY MANAGEMENT COUNTERMEASURE OF TAILINGS DAM

The safety of tailings dam is not only related to the normal production of mining companies, but also to the safety of life and property of residents downstream of the tailings pond area and the stability of the surrounding ecological environment. In order to strengthen the ability of safe operation and management of tailings ponds, the Chinese government and mining companies have formulated relatively perfect rules and regulations which mainly include the following points.

(1) The operation of tailings pond needs to declare safety production license. Mining companies need to entrust professional organizations to carry out safety evaluation of tailings pond every three years. Only after assessing as normal tailings ponds can they handle the extension of safety production license.

(2) Tailings pond chief system must be practicable. All the tailings pond chiefs must be selected from government departments to urge mining companies to investigate and deal with hidden dangers and to implement relevant safety input.

(3) The state requires strict monitoring of tailings pond operation parameters, including displacement monitoring, phreatic line monitoring, deposited beach length and slope monitoring, etc.

(4) Emergency rescue reserve plans for tailings ponds should be worked out and drills should be organized and the level of early warning, emergency rescue plans, disaster evacuation routes should be determined to curb the occurrence of major accidents.

6. CONCLUSIONS AND SUGGESTIONS

High tailings dam has become the necessity of tailings dam construction in China. On the basis of summarizing the mechanical characteristics of upstream tailings dam under high stress conditions, taking a 210m high tailings dam as an example, this paper establishes a generalized zoning model of tailings dam, and uses rigid body limit equilibrium method to analyze the stability of the tailings dam, and introduces the safety management countermeasures of the tailings dam in China. Through the above calculation and analysis, here are some points of understanding.

(1) According to the depositional law of the dam, the upstream embankment has the characteristics such as large number of weak layer and weak intercalated layer in bottom, and high phreatic line. So the upstream method should be avoided in high tailings dam as far as possible.

(2) Although the calculation results according to the existing mechanical parameters can meet the requirements of the code, the safety reserve of tailings dam is not enough, so the safety reserve of tailings dam can be improved by methods such as further reducing the dam phreatic line and strengthening the dam with geogrid.

(3) At present, the engineering mechanical properties of tailings under high stress conditions are not clear. It is necessary to study the structural failure characterization of tailings under high stress conditions and the related research on engineering mechanical properties and evolution law.

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