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Study on the Risk Assessment of the Tailings Dam Break

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Abstract

Public pay more and more attention to how to ensure the safety of tailings dam downstream residents and property. This article establishes a risk evaluation system which bases on the tailings dam failure probability analysis and dam failing consequence assessment. The tailings dam failure mode is established through the research of tailings dam failure mechanism. Meanwhile established the tailings dam stability assessment index system, applied the set pair analysis to assessment the stability of the tailings dam; established the controlling equation, simulated the routing and movement of tailing flow in the downstream after tailings dam break, investigated the distributions of personnel and structures in the influence range, use comprehensive factor weighted method to construction the tailings dam break serious consequences evaluation model, the model considered the tailings dam scale, loss of life, economic losses and social environment impact, points out key point and the difficulty of the tailings dam break impact research, the tailings dam for precise quantitative risk assessment is very difficult, the risk assessment index is a kind of qualitative risk analysis methods,established the tailings dam risk assessment software based on risk assessment index methods.

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Keywords: Tailings dam; Dam break; Set pair analysis; Risk assessment software

1. Introduction.

Our country has a large capacity of mining. Tailings facility covers metallurgy, nonferrous metal, chemical industry, nuclear industry, building materials and light industry. According to preliminary statistics, there are around 1500 tailings facilities formed a certain scale. Tailings dam is a necessary facilities used to storage tailings of metal and nonmetal mines; investment of tailings facilities is large, generally accounted for about 5% ~10% of the total investment of mine construction. Tailing reservoir is a man-made mud-rock flow with high potential energy, existence the dam break risk, so it is significant hazards, threat to downstream residents and facility safety. According to statistics, the major disasters of the world, tailing disaster after the earthquake, cholera, floods and bomb blast is eighteenth [1] .

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In recent years, people pay more and more attention to tailings safety, want to ensure the safety of downstream environment and public, now not only the user cares for the tailings dam safety, safety management about tailings dam, not only need to evaluation the stability of tailings dam, but also downstream impact evaluation of dam break is also needed, in order to take the corresponding emergency measures to reduce the loss of accidents. Therefore, tailings dam risk assessment research should be carried out, at present, the tailings dam risk evaluation research basically still in the exploratory stage, risk evaluation is still lacking legal conditions and technical basis, we should establish a tailings dam risk evaluation system based on tailings dam failure probability evaluation and consequence assessment, provided technical support for the tailings dam risk evaluation and risk management and guaided to make and implemente dam failing emergency plan.

2. Tailings dam risk assessment

China scholar has just begun tailings dam risk assessment research in recent years, focused primarily on the evaluation of stability of the tailings dam, the research of the severity of consequences of tailings dam break was very rare, ShuYongbao assessed the economic loss risk on the accident of tailings dam break from aspects of the loss of life,property and environmental resource, then, the severity of tailings dam breaks was classified according to both the deaths and its economic loss risk,at last, the losses influence of the accidents of tailings dam break on local socialand economic in different areawere comparable based on an overall consideration of space factors[4]. Xu Hongda studied on tailings dam risk management and risk evaluation, pointed out that the problems of tailings risk assessment and management and the future direction of the main research contents [5].

Tailings dam risk assessment studies, including the main elements of Figure 1.

3. Tailings dam stability assessment

Mainly factors affect the deformation and stability of the tailings dam including the tailings dam material composition, physical, mechanical properties and the geometric parameters of dam (dam high, inside and outside the slope ratio, dry beach length, warehouse inner water level, groundwater level elevation and earthquake). Tailings dam failure mode was summarized from the cause of the tailing dam failure factors. Analysis of the factors leading to tailings dam break, get tailings dam failure mode. Tailings dam failure mode can be divided into flood overtopping failure mode and the structure failure mode, the dam structure failure mode can be divided into seepage failure mode, slope instability failure mode and seismic disaster failure mode, and seismic disaster failure mode can be divided into seismic liquefaction failure mode and seismic instability failure mode. Through the establishment of the risk rate calculation model of each failure mode to get tailings dam failure probability, can also be based on failure mode of building application event tree, using event tree analysis to get tailings dam failure probability.

Quantitative calculation of the tailings dam break probability is very difficult, qualitative evaluation is a good way to solve this problem, set pair analysis is in 1989 our country scholar Mr Zhao Keqin created a door handle uncertainty system theory and method, it can description and processing the uncertain systems determine by the factors of randomness, fuzziness, incomplete and deterministic [2]. Tailings dam system is a complex dynamic system.There are many uncertainty factors, therefore, the use of set pair analysis method to assess the stability of tailing dam.

$$\mu=a+bi+cj+dk \qquad (1)$$

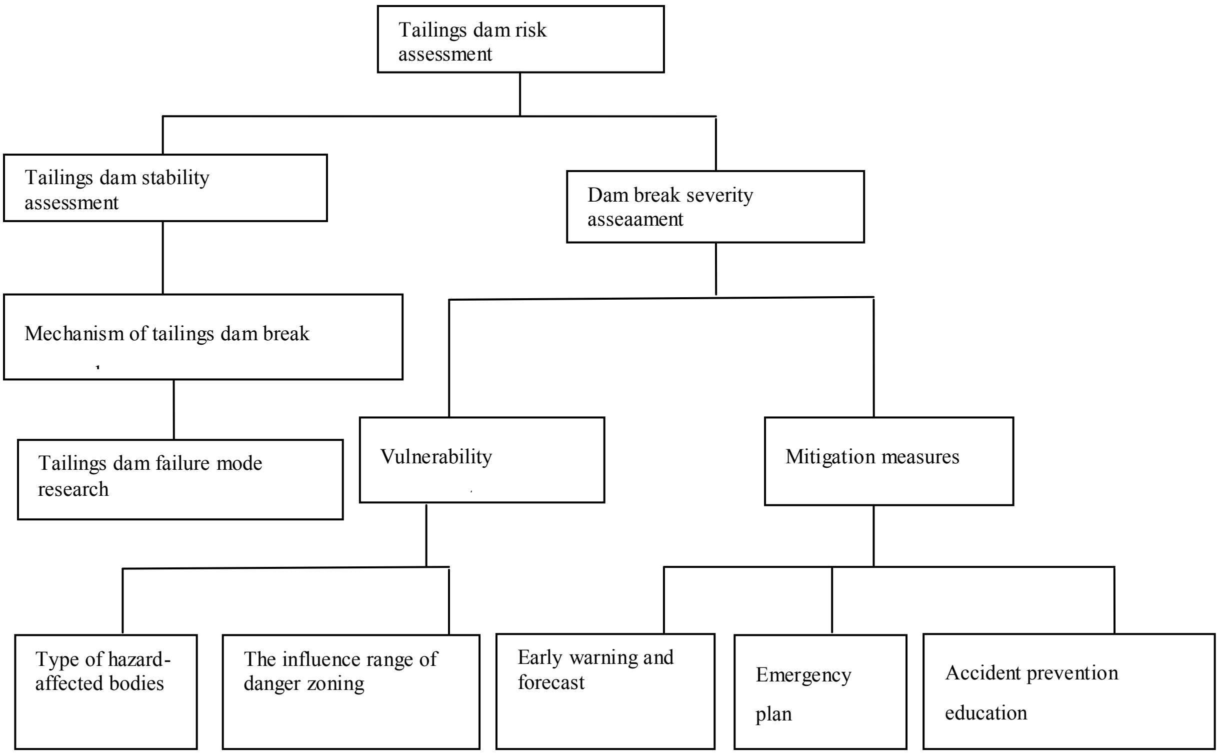

Fig.1.Tailings dam risk assessment

Safety of tailings dam mainly according to the tailings pond flood control capacity and tailing dam's stability, divided into four levels. Tailings pond safety grade also reflects the tailings dam stability, so the tailings dam break probability grading and tailings safety level can be linked, the tailings dam break probability classification in table 2.

According to the established index system, see table 1, using the method of set pair analysis of four ement connection number（Eq.(1):

Can be obtained by calculating the safety of tailings pond grade, In the formula A representative is conducive to the stability of dam, B represents the basic conducive to stability of dam, C represents is not conducive to the stability of dam, D represents a very detrimental to the stability of dam.

Experts score for the target item of tailings dam stability assessment index system, according to" the principle of sharing", I = 0.33, j = - 0.33, using formula (1) to get the tailings dam assessment results, by connection number “μ” representation; after normalization, connection number “μ” range is [-1, 1], according to the principle of sharing, connection number corresponding to the dam break possibility grade and quantitative assignment are shown in table 2.

Table 1 Tailings dam stability assessment index system

1 level index	2 level index	3 level index
Tailings dam stability assessment	Geological factors B_1	Tailings properties C_1 Geological features C_2
	Engineering factor B_2	Deposited beach length C_3 The starter dam downstream slopeC_4 Leakage facilities C_5 Types of Tailings damC_6 Tailings dam heightC_7 Drainage facilities C_8 Groundwater conditionC_9 Earthquake intensityC_{10}
	Daily maintenance and environmental factors B_3	Safety management C_{11} Dam protection C_{12} Dam safety monitoringC_{13}

Table 2 Classification standard

Grade	tailings dam.break at any time	Safety facilities exist serious hidden trouble, if not timely treatment will lead to tailings dam break	Tailings dam meet the basic conditions for safe production	Tailings dam fully equipped with the conditions for safe production
Connection number	$-1 \leq \mu < -0.5$	$-0.5 \leq \mu < 0$	$0 \leq \mu < 0.5$	$0.5 \leq \mu \leq 1$
Quantitative evaluation	4	3	2	1

4. Tailings dam break severity assessment

4.1 Simulate the routing and movement of tailing flow in the downstream after tailing dam break

The tailing flow discharged after tailing dam break essentially belongs to landslide or debris flow, the movement of the tailing flow is similar to that of fluid flow, in order to determine the possible consequences of tailings dam break, we must first get the Sphere of influence of the tailings dam break, then estimate the consequences of dam-break according to the loss of the residents, structures, roads, lifeline engineering, environmental and other land resources within the affected areas.

As a result of tailings pond effective storage capacity in a large proportion of total storage capacity, so do not calculate flow process like ordinary dam break, this burst of discharge flow should include water and tailings. Based on the DAMBRK model [5 ~ 7] and the water volume balance equation to find out the dam-break water flow process line, and then seek out the dam-break sand flow process line.The tailing flow discharged after tailing dam break essentially belongs to landslide or debris flow, the movement of the tailing flow is similar to that of fluid flow, and continuity equation and motion equation of tailing flow can be established according to the law of mass conservation and momentum conservation in the case of considering tailing flow movement affected by its gravity, hydrodynamic pressure and bed shear resistance. Equations consisting of continuity equation and motion equation are controlling equation that can be used to describe the routing process of tailing flow, the continuity equation（Eq.(2)）and motion equation （Eq.(3a), Eq.(3b)）as follows:

$$\frac{\partial h}{\partial t}+\frac{\partial(uh)}{\partial x}+\frac{\partial(vh)}{\partial y}=0 \tag{2}$$

$$\frac{\partial(uh)}{\partial t}+\frac{\partial(u^2h)}{\partial x}+\frac{\partial(uvh)}{\partial y}=gh\sin\theta_x-gh\frac{\partial h}{\partial x}-\frac{\tau_{bx}}{\rho_m} \tag{3a}$$

$$\frac{\partial q_y}{\partial t}+\frac{\partial uq_y}{\partial x}+\frac{\partial vq_y}{\partial y}=gh\sin\theta_y-gh\frac{\partial h}{\partial y}-\frac{\tau_{by}}{\rho_m} \tag{3b}$$

4.2 Tailings dam downstream people and building investigation

The loss of life measures was assessed from aspects of the number of residents within the affected areas, residential location and the distance from the dam, population density, housing ruggedness, etc., economic losses of tailings dam break including three parts as follow:the direct economic losses, indirect economic losses and disaster relief costs, need to get the information about the construction, agricultural, livestock breeding, water conservancy, lifeline engineering, road, rail, resources, bridges and machinery and equipment and so on in the influence range.

4.3 Tailings dam break consequence severity assessment model

Tailings dam failure consequence, is composed of tailings dam and the dam itself and the factors caused the loss of two factors together determine the specific size available, tailings dam, loss of life, economic losses and social environment influence the four subsystems to measure. Tailings dam failure consequence severity evaluation function by the comprehensive weighted factor method.

$$C=W_1D+W_2H+W_3P+W_4S \tag{4}$$

Type D, H, P, S, respectively is the tailings dam scale, loss of life, economic losses and social environment influence, W1, W2, W3, W4 are the four factors weight.

Tailings dam break consequence study, the important and difficult in the following aspects:
① how to determine the sphere of influence of tailing flow discharged
②What degree of damage to personnel and building of tailings dam downstream by difference depth and velocity of tailings flow, how to carry out danger degree partition of tailing flow discharged after tailing dam break

Tailings dam break consequence severity is divided into the following four levels, see table 3.

Table 3 Dam break severity classification

Dam break severity	Light effect	Moderate effect	Height effect	Extreme effect
e range	1≤c<1.75	1.75≤c<2.5	2.5≤c<3.25	3.25≤c≤4
Quantitative evaluation	1	2	3	4

4.4 Tailings dam break risk assessment

The risk assessment index is a kind of qualitative risk analysis methods [8 ~ 9]. This method although not as precise quantitative analysis, but it combines risk assessment matrix, gives the risk with qualitative index to evaluate the risk grade, then on this basis to establish different levels of risk area.

Tailings dam integrated risk classification in table 4.

Table4 Tailings dam integrated risk classification

Tailings dam integrated risk classification		Dam break severity classification			
		Extreme effect (4)	Height effect (3)	Moderate effect (2)	Light effect (1)
Tailings dam break probability	tailings dam.break at any time (4)	16	12	8	4
	Safety facilities exist serious hidden trouble, if not timely treatment will lead to tailings dam break (3)	12	9	6	3
	Tailings dam meet the basic conditions for safe production (2)	8	6	4	2
	Tailings dam fully equipped with the conditions for safe production (1)	4	3	2	1

The red indicates the project would have to be give up

The orange indicates that need to amend the proposed measure, by changing the design or take compensatory measures.

The green indicates that index critical value shoule be set, index once it reaches a critical value, will change the design or compensatory measures should be taken on thea negative impacts

The yellow indicates that appropriate action does not affect the project

The white indicates risk weak, without review, acceptable

5. Project example

Carring on the risk assess to Shouyun iron mine Heshangyu tailings dam, Shouyun iron mine Heshangyu tailings dam located in the valley, distance of about 1km northwest mining area is the tailings dam.The total capacity of 1350 x $104m^3$, the catchment area of $0.47km^2$, the starter dams are two, located in east and west. The main facilities of Shouyun iron mine tailings dam: Shouyun iron mine distance of approximately 1.2km to tailings dam; Beijing railway from the tailings dam is approximately 1.5km; Miyun Road distance of tailings dam is approximately 2km; the main village of tailings dam downstream areTongzi village (about 1200 people), Douge village (about 1500 people), Zhaojia Village (about 500 people), Jinshanzi village (about 500 people). The village buildings are mostly residential, brick structure. The villages from tailings dam approximately 2km.

Ask experts scoring on each index of tailings dam stability index system, using set pair analysis method to calculate, getting μ is 0.538, the quantitative value of 1.

If Shouyun Heshangyu tailings dam break, sand flow process line is shown in figure 2, after tailings dam break, tailings sand flow at several different moments is shown in figure 3.

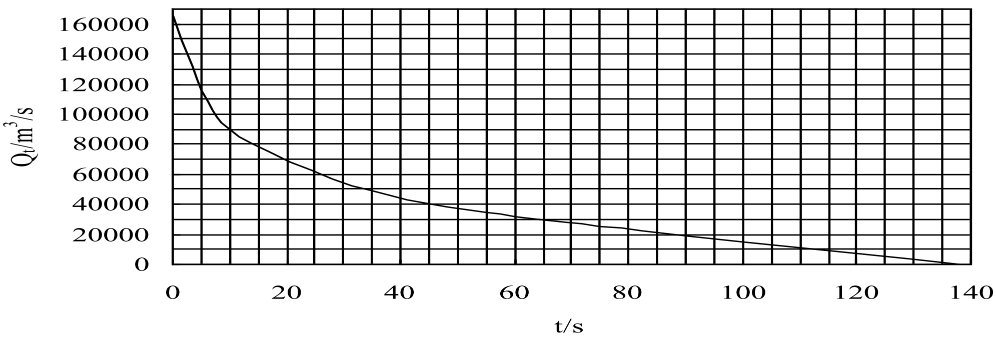

Fig.2 The process line of discharged tailing flow

According to the tailings dam break consequence assessment model, combining the personnel and buildings condition of buildings of tailings dam downstream and the sand flow influence range prediction, the tailings dam break consequence severity value is 3.1, the quantitative value of 3.

Shouyun iron mine Heshangyu tailings dam risk value of 3, the risk grade was two, less risk, appropriate action does not affect the project. Although the ultimate risk grade was two, but the dam severity of consequence for high impact, because there are many people in the Shouyun iron mine Heshangyu tailings dam downstream, ore dressing plant itself is also in tailings dam downstream, idam break, the consequences are very serious, therefore, we can not relax vigilance, conversely, should strengthen the tailings dam safety management, improve the stability of tailings dam, reducing the likelihood of tailings dam break, while improving the early warning and emergency rescue measures of tailings dam downstream.

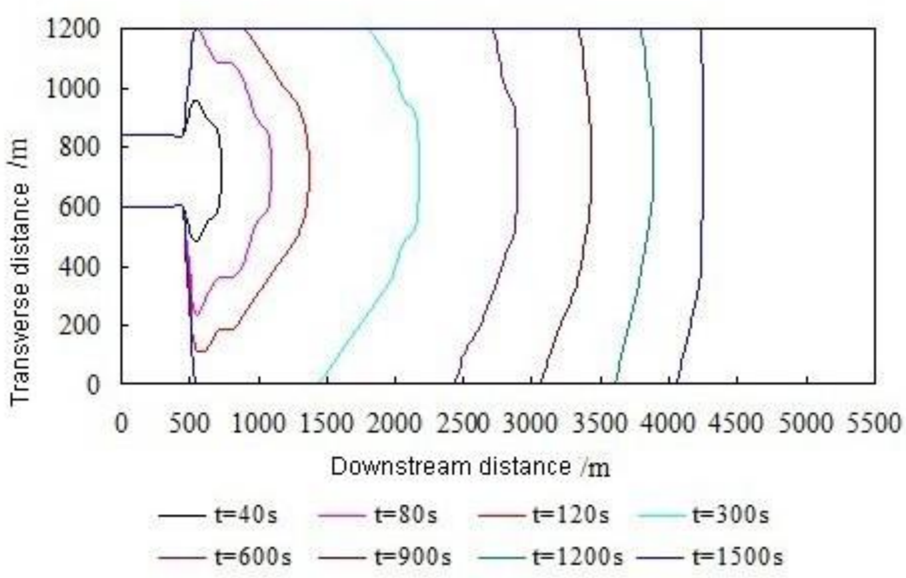

Fig.3 The deposition process of tailing flow

For convenience of tailing dam risk assessment, benefit management intuitive, systematic understanding of tailings dam risk status, using web development technology based on the JSP, development of the tailings dam risk assessment software. The software system includes function modules include: the tailings dam break probability calculations, the tailings dam break consequence calculation, tailings dam risk assessment, tailings dam risk classification management, the relevant laws and regulations and the tailings dam expert system. See figure 4

6. Conclusion

(1) At present, people pay more and more attention to the tailings dam safety, people want to ensure downstream environmental and public safety, to carry out risk assessment of tailings dam, can more effective to improve the safety of tailings dam and solve our current situation and problems, Tailings dam risk assessment mainly includes the contents of tailings dam break possibility and consequences study.

(2) Analysis the cases of tailings dam accident at home and abroad, and reference to the relevant data to establish a tailings dam stability evaluation index system, the theory of set pair analysis was used on assess the tailings dam break possibility, provided a new way to solve the problem.

(3)Put forward the comprehensive weighted factor model of tailings dam break consequence assessment, the previous dam break evaluation only considering human casualties and property losses, this model also takes into account the tailings dam scale and the influence of the social environment, these two factors effects the dam break severity, this model is a more perfect method, pointed out at present the emphasis and difficulty of tailings dam break impact research.

(4) Using the risk assessment index to assess the tailings riskt, development of the tailings dam risk assessment software, using the software of the tailings dam risk assessment to rank the risk,which is

beneficial to the management department to know the risk distribution of tailings dam, can make the limited resources to usd on the high risk tailings dam, the software includes tailings expert module, can input the expert basic situation, to provide personnel support for tailings dam safety management.

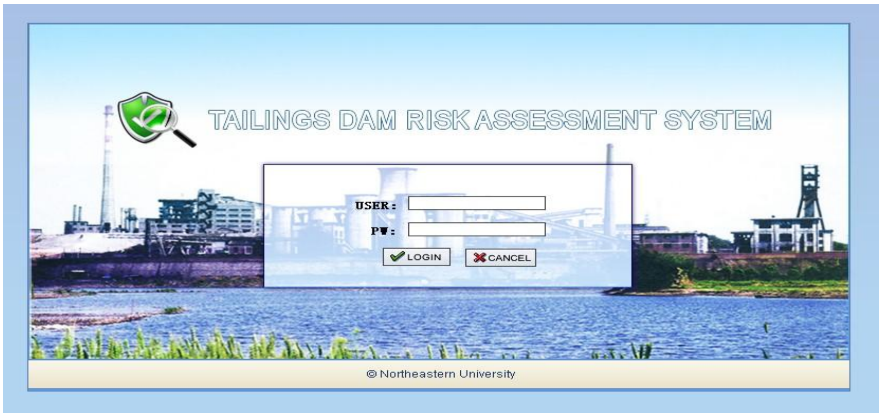

Fig.4 Tailings dam risk assessment sofeware

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