Application of information technology in safety monitoring and early warning of tailings pond

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Abstract. The safety monitoring and early warning of tailings pond are effective means to reduce accidents and ensure the safety of tailings ponds. With the development of information technology, network and automation technology are effectively applied in the safety monitoring and warning of tailings pond. The development of safety monitoring and early warning technology is analyzed comprehensively. Current monitoring and early warning means are summarized in this paper. A tailing pond of Jiangxi province is taken as an example, the application of safety monitoring and early warning system are introduced. The flood early warning is also elaborated. The shortages and the development trend of the safety monitoring and early warning are concluded. This study provided a reference for safety monitoring and early warning of tailings pond.

1. Introduction
Tailings pond is an important part of the mine and also a major hazard source. It is used to store tailings or other industrial waste of metal or non-metal mines [1]. In China, the upstream embankment method is often adopted for tailings pond, which leads to poor stability. Furthermore, the location of the tailings pond is often close to residential areas. Once break, it will seriously endanger the safety of people's lives and properties in the downstream, and produce serious social effects.

The safety monitoring and early warning is a common measure to prevent the accident of tailings pond. Since the 1990s, the safety supervision and other departments in China have promulgated a number of laws and regulations to emphasize the necessity and importance of tailings pond safety monitoring. For example, the People's Mine Law of China issued in 1993 clearly stipulated that various protective measures should be taken against possible hazards caused by tailings pond. Safety Regulations for Tailings Pond and Regulations for Tailings Pond Safety Supervision and Management implemented in 2006 both point out the important role of tailings pond safety monitoring. The Technical Specifications for Tailings Pond Safety Monitoring issued in 2011 clearly defined the framework and specific contents of tailings pond safety monitoring. In subsequent revisions of Safety Regulation for Tailings Pond and Safety Supervision and Management Regulations for Tailings Pond clearly pointed out that production and business operation entity shall establish a perfect safety monitoring and early warning system for tailings pond, which was combined of artificial monitoring and on-line monitoring, and the system should include the function of water early warning and dam seepage damage or collapse warning. The promulgation and implementation of these laws and
regulations provided an institutional basis for the establishment of safety monitoring and early warning system for tailings pond by means of informatization.

The safety monitoring technology of tailings pond mainly experiences three stages: manual monitoring, semi-automatic monitoring and all-automatic monitoring [2]. The safety monitoring of tailings pond in China is mainly carried out manually. In recent years, with the continuous occurrence of tailings pond safety accidents and the development of automation and information technology, the automatic monitoring technology of tailings pond has gradually become the mainstream of tailings pond safety monitoring in China. And researches and applications were implemented, the results showed that the online monitoring system of tailings pond based on information technology had advantages compared with others and achieved better results.

The development of tailings pond safety early warning technology based on the online monitoring data is relatively backward. Non-standard monitoring system, the lack of effective maintenance of monitoring facilities and systematic analysis of monitoring data are the mainly backwards. Therefore, the system cannot provide continuous and reliable information for early warning. Zhang Jian [3] analyzed the key technology of online monitoring of tailings pond, and proposed the hardware and software system scheme for safety monitoring and early warning. Yang Bo [2] built the safety warning model for tailings pond based on BP neural network and genetic algorithm, established the safety warning index system, and drew up the warning criteria based on the safety coefficient, which provided important scientific and technological support for the safety warning of tailings pond.

This study summarizes and analyzes the safety monitoring and early warning of tailings pond based on information technology. Taking a tailings pond in Jiangxi Province as an example, the safety monitoring and early warning technology used in the tailings pond based on information technology are introduced, and the shortcomings and development direction of the current safety monitoring and early warning of tailings pond are also provided.

2. Methods

2.1. Safety monitoring technology of tailings pond
The safety monitoring factors of tailings pond include phreatic line, displacement of dam (surface and internal displacement), water level, rainfall, and so on. Various monitoring means are adopt for monitoring those factors. The safety monitoring means are mainly manual monitoring in the past. However, manual monitoring is susceptible to weather and field conditions, the observed results may have larger systematic or manual error. Moreover, smaller errors may induce greater safety risks, so the safety warning of tailings pond requires higher accuracy of monitoring data.

With the development of sensor technology, wireless transmission technology, electronic communication technology, computer network technology and other modern information technology, the online safety monitoring system of tailings pond has been widely used. The online monitoring system of tailings pond mainly includes the automatic collection, transmission, storage, monitoring and data display [4, 5].

Figure 1 shows the structure of online monitoring system of tailings pond. The system is made of sensors, server and service center [6]. The sensors include hydraulic gauge, level, rainfall gauge, water level gauge, etc. The hydraulic gauges are installed in the pressure-measuring pipes, which are embedded in the cross section of the dam. The data collected by the hydraulic gauges are transmitted to the monitoring center through the terminal, Router and coordinator in real time.

GPS technology is commonly used in on-line monitoring of dam displacement [7]. The 3D coordinate position information of the target can be automatically searched and determined by the GPS intelligent monitor, and then the information is transmitted to the monitoring center through the terminal node for data analysis. Ultrasonic water level gauge is often used in the system. The water level is determined by the elevation difference between ultrasonic water and surface water, so as to determine the flood storage capacity of tailings pond. Automatic rainfall gauge is installed to monitor
the rainfall around the tailings pond. Heating modules should be also installed to ensure the accuracy of rainfall observation for the northern areas of China with lower temperature in winter.

2.2. Safety early warning technology of tailings pond

Early warning generally refers to the unsafe state alarm of a specific object. The early warning of tailings pond system is to find out the unsafe factors as soon as possible, and offers a warning to the management personnel of tailings pond, so as to provide effective guidance for preventing accidents. The key to the safety warning of tailings pond is the warning thresholds. The warning thresholds of tailings pond is usually set according to Safety Technical Regulations of Tailings Pond, design documents and the current situation of tailings pond. Table 1-3 show the minimum warning thresholds of different levels of tailings ponds.

Table 1. Minimum free height and beach width of the upstream tailings pond

| Dem level | 1   | 2   | 3   | 4   | 5   |
|-----------|-----|-----|-----|-----|-----|
| Minimum free height /m | 1.5 | 1.0 | 0.7 | 0.5 | 0.4 |
| Minimum beach width /m | 150 | 100 | 70  | 50  | 40  |

Table 2. Minimum beach width of the downstream and centerline tailings ponds

| Dem level | 1   | 2   | 3   | 4   | 5   |
|-----------|-----|-----|-----|-----|-----|
| Minimum beach width /m | 100 | 70  | 50  | 35  | 25  |

Table 3. Minimum depth of the phreatic line of embankment

| Embankment height H /m | H≥150 | 150>H≥100 | 100>H≥60 | 60>H≥30 | H<30 |
|------------------------|-------|-----------|-----------|----------|------|
| Minimum depth of the phreatic line /m | 10~8  | 8~6       | 6~4       | 4~2     | 2    |

Red, orange, yellow and other warning thresholds are often required for early warning system of tailings ponds. The early warning indicators of monitoring projects of different levels are set according to the Engineering Technical Specification for Online Safety Monitoring System of Tailings Pond (GB51108-2015). The red warning thresholds of minimum free height and minimum beach width are able to be calculated according to Table 1 or Table 2. The orange warning thresholds of them are set as 1.2~1.5 times of the red warning thresholds, and the orange warning thresholds of them are 1.2~1.5 times of the red warning threshold. The infiltration line for red warning threshold is obtained
according to Table 3, and the orange warning threshold is set to be 1.1 times of the red one. The warning thresholds of water level are calculated according to the free height and beach crest. The early warning threshold of rainfall is determined according to the flood control standard of tailings pond.

3. Case

3.1. Study area
The design dam height of a tailings pond in Jiangxi Province is 208m, with a designed total storage capacity of \(8.35 \times 10^8\) m\(^3\), which is a first-class tailings pond (Figure 2). At the initial stage of the design, the dam is a clay inclined rockfill dam with a crest elevation of 110m, a bottom elevation of 72m, a crest height of 38m and a crest width of 10m. The accumulation dam is built by centerline embankment method, and the average inner slope ratio is 1:2.5 and the outer slope ratio is 1:3.0. At the downstream of starter dam, finger-shaped drainage pipes with lengths of 200m and 180m are set on both sides respectively, and the water is collected and educed from the drainage mattress. The catchment area up the tailings pond is 14.3km\(^2\). The designed flood is 0.02% frequency, and the flood control height is 4.0m. Two sets of flood discharge system are arranged in the left of the tailings pond. The first flood drainage system adopts the chute-tunnel-discharge chute type, the second flood drainage system adopts the chute-tunnel-culvert-tunnel-open chute type, and the outlet of the open chute is connected with the discharge chute of flood drainage system.

![Figure 2. A tailings pond in Jiangxi Province, China](image)

3.2. safety monitoring and early warning system
In this study, the tailings pond is first-class with a safety monitoring grade of I, and the monitoring factors are dam displacement (surface displacement and internal displacement), phreatic line, beach width, water level, rainfall, etc.

Surface displacement monitoring points are uniformly arranged on the dam. The axis of the dam is longer than 1000m, and 4 longitudinal profiles are laid out. Seventeen surface displacement monitoring points with an interval of 40m are set up in these longitudinal profiles. GNSS (Global Navigation Satellite System) is installed in those points to monitor.

A monitoring profile is set for the monitoring of internal displacement in the tailings pond, on which 5 monitoring vertical lines are set, and 24 monitoring sensors are installed. The inclinometer is used to monitor the unidirectional horizontal displacement.

The monitoring profiles of the phreatic line are the same as that of the surface displacement. Forty-six monitoring points are set, and the interval of the profile was 10m. The vibration string hydraulic meter is used to monitor phreatic line.

Three monitoring profiles are set for beach width monitoring, and monitoring point is set for each profile to monitor the elevation at the foot of the tailings dam. Combined with the water level
elevation and beach slope, the beach width and free height are calculated, and the water level elevation is monitored by radar level meter. One monitoring point is set for the water level monitoring which is located near the drainage chute, and percolation gauges is adopted for water level. The basin up tailings pond has a monitoring point to monitor rainfall and uses tipping-bucket rainfall gauge.

The rainfall monitor data are shown in Figure 3. And the system could preliminarily analysis the data, such as statistical maximum, minimum, statistical total, etc. Time period could also be set to query historical data in the system. Dam displacement (surface displacement and internal displacement), phreatic line, beach width, water level data in the system has similar statistics and query functions.

![Figure 3. Rainfall data in online monitoring and early warning system of tailings pond](image)

3.3. Flood early warning in the system

Flood caused by precipitation or dam-failure is one of the most serious disasters in tailings pond. Flood early warning is embedded in the safety monitoring and early warning system, which include early warning thresholds setting, water level calculating caused by rainfall event, and flood early warning.

Reasonable early warning thresholds are meaningful for timely and accurate warning the safety situation of the tailing pond. According to the current situation and design information of this tailings pond, relevant standards and specifications, the warning thresholds are shown in Table 4.

| Item               | Red warning threshold | Orange warning threshold | Yellow warning threshold | Blue warning threshold |
|--------------------|-----------------------|-------------------------|--------------------------|------------------------|
| Water level/m      | 264.5                 | 263.8                   | 262.8                    | 261.22                 |
| Free height/m      | 4                     | 4.8                     | 6.4                      | 7                      |
| Beach width/m      | 300                   | 360                     | 480                      | 520                    |
| Flood control height/m | 2                 | 3                       | 4                        | 4.5                    |

Figure 5 shows the process of water level is obtained by flood regulation calculation for the real-time rainfall process. During the rainfall process (Figure 3), the maximum water level is 261.79m, and the blue warning is issued by comparing the warning threshold (Table 4).

4. Conclusions

The safety of tailings pond is a major event related to the security of lives and property of the people. Strengthening the safety monitoring of tailings pond is an effective means to prevent the occurrence of accidents of tailings pond. At present, the online monitoring of tailings pond still has some backwards, such as poor reliability, high cost, inaccurate early warning and insufficient data analysis ability. Therefore, it is necessary to strengthen the system construction and enhance the analysis and processing ability of monitoring data, so as to provide scientific and technical support for the safety of tailings pond.
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