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Applications of online monitoring technology for tailings dam on digital mine

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Abstract: Considering its structural features, geometric shapes, service mode, environmental media, mechanical behavior, etc, the special nature and complexity of tailings dam were summarized. The technical approach to safety management for tailings dam was proposed, which is the on-line automated monitoring and early warning information. The results show that a strong theoretical basis can be provided for security monitoring and security management of tailings dam. Online automated monitoring system for tailings dam has full implementation of the information. It is applied widely in Lingnan gold mine, Xiadian gold mine and Hedong gold mine in Zhaoyuan, Shandong Province, and achieves good effect.

Key words: digital mine; tailings dam; online monitoring; security monitoring; digitization

1 Introduction

Tailings pond is formed by damming at valley interception or damming all sides, which is used to store tailings and other industrial waste produced by metal and nonmetal mines. Tailings dam is an important part of tailings pond, which refers to initial dam and later fill dam. According to incomplete statistics, there are 104 400 metal and nonmetal mines in China, which produce about 300 million tons of tailings annually. More than 6 000 tailings dams are built at present. Among them, more than 1 500 dams are large and medium-sized tailings dams. These dams spread in six industries including the non-ferrous industry, metallurgy industry, chemical industry, nuclear industry, gold industry, and building materials industry. There are 26 dams which are more than 100 m high. The maximum design height is 260 m, which is rare in the world, and the high frequency of accidents and severity of damage are also rare. Once an accident happens, an enormously destructive debris flow will flock to the downstream area, causing great harm to downstream lives and property and polluting the environment seriously. For example, the breaking audient of Stave tailings dam in Italy in 1985 leads to 300 people killed and huge damage to property [1]. So the scientific stability evaluation, management and treatment of the tailings dam become priority. For that, the State Department issued a special document No. 23 named Notification of Further Strengthening the Work Safely on 2010−07−19. And the notification demands that advanced technology and equipment are forcedly applied and online monitoring system must be installed in the whole process of a large tailings ponds to ensure the safety of large tailings pond. Therefore, the urgent need for tailings management was referred, the digital safety monitoring of large-scale tailings dam was researched and discussed, and the scientific basis was provided for online monitoring to the entire process of large-scale tailings pond.

2 Particularity of tailings dam

The special features such as structural features, geometric shapes, service modes, compositive media and mechanical behaviors of tailings dam etc, are important to its stability.

2.1 Particularity of structural features

At first, a starter dam should be constructed with

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local stone. When tailings pond is full, the height of the post-dam should be enhanced with coarse-grained tailings. Tailings dam is different from the dam. The dam requires anti-seepage, while the tailings pond has drainage requirement, otherwise, it is easy to form the debris flow. From the use of terms, the application of dams is drainage when water storage exceeds a certain level. However, tailings dam is simply to hold water rather than the transfer station, which mainly splits flow in the upstream and has enough volume to store rainfall that deposited in the reservoir area, in that way avoiding heavy rain on its destruction.

Tailings dam is usually constructed by the rolling natural terrain, and it has a material inlet port, discharge port and return port. The clarifying return water will be reused through pumping station in the dam. According to the method of dam construction, there are upstream embankment method, centerline embankment method, downstream embankment method and once dam method.

2.2 Particularity on geometric shapes of tailings dam

There are great differences on geometric shapes between tailings dam and common dam. The common dam is a representation of water retaining building. From the view of geometric shape, the dam is rectilinear, extending in one direction only. And it once forms, its geometric shape will not change usually. However, according to the difference on the site, there are four kinds of tailings dam, which are the valley-based type, the hillside type, the ground-based type, and sectional river type. As far as the ground-based type, the tailings dam is not a linear, and is around, which extends in three dimensions with several inflection points (shown in Fig. 1). The safety coefficients near the inflection point need to be learnt clearly, and then the monitoring sections are designed on the basis of them. Moreover, the safety coefficient near the inflection point changes with the positive angle and the height of the slope.

2.3 Particularity on service modes of tailings dam

The term of the service is also the period of building the tailings dam that is a long time, in which construction and production are at the same time. That is the most prominent feature that is different from the general dams.

2.4 Particularity on compositive media of tailings dam

The tailings dam usually consists of the starter dam that is built by soil, stones and other materials and embankment that is built by tailings. And the tailings are a kind of slag, being the fine particle, which is minus, the ore being milled and separated, as the material of

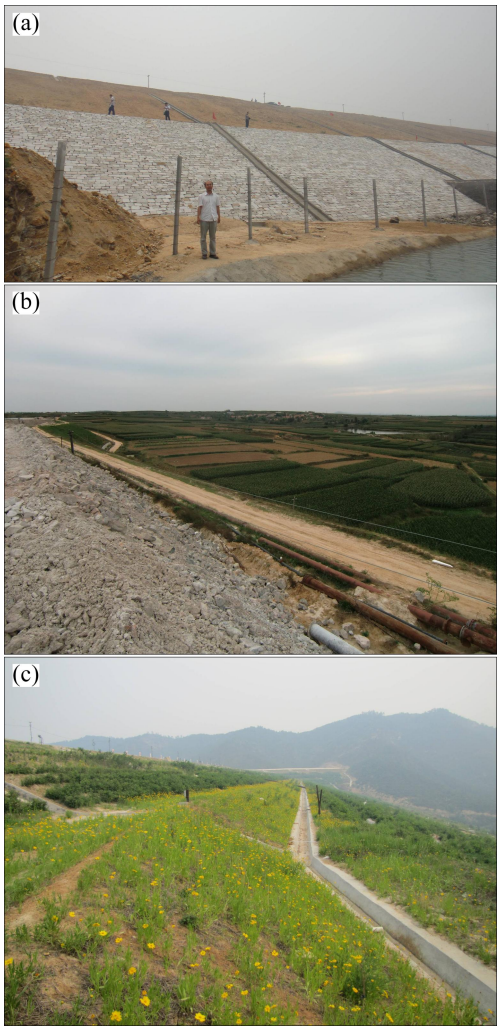

Fig. 1 Three tailings dams in Zhaoyuan: (a) Minus ore damming; (b) Ground circuit damming; (c) Damming on valley

damming. Tailings dam is built step by step with the tailings particle itself, increasing the height of the dam. Tailings particle is a kind of minus ore, being milled and separated, with other industrial residue. So there are diversity and uncertainty on array structure, particle moisture content and degree of particle breakage, physical and mechanical properties of the packing material. The consolidation and thixotropy of mine tailings have great influence on the overall stability of the tailings dam [2].

Meanwhile, the internal structure of embankment material directly affects the penetrability and phreatic line, and further affects the strength properties of the overall tailings dam. The weak link or a weak position is especially the main causal factor, and may control the deformation of dam, even the stability to some extent.

2.5 Particularity on mechanical behavior of tailings dam

Tailings dam is a particular engineering. It has the

special stress condition, not only affected by the tectonic stress, earthquake, but also impacted by flood erosion and drainage, tailings drainage and live load from damming on, complex physical and mechanical parameters, repeated coupling of seepage field and stress field. Deformation field has obvious timeliness [3−5].

2.6 Complexity of tailings dam

Tailings dam is a very complex geotechnical engineering, and the specific aspects include multidimension, multiphase, multi-level and multi-structural:

From the macro point of view, tailings dam is a three-dimensional body, and from the microscopic point of view, it is piled up by different levels of aggregate gradation, having obvious features of the fractal dimension. At the same time, its strength, flow conditions and other parameters change over time, that is, a four-dimensional body, considered the time evolution, causing the stability evaluation increasing greatly.

As a mixture of solid, liquid and gas, the seepage pressure under internal tailings dam, reduces its shear strength, and changes at any time, even liquefaction failure.

Tailings dam, as a composition of various components, is a cross-structure level complex, which can be regarded as a complex systems consisted of a number of parts, elements and subsystems. Therefore, it should be described through the macro, mesoscopic and micro levels, and combine the systems science point of view and approach, deeply study the relationship between various levels, thus get the complex process of formation and evolution of it.

Tailings dam is a combination of a variety of structures, the starter dam, sub-dam and embankment. There are also the culverts, drainage pipes and other drainage structures within it, multiple structure interaction existing; meanwhile, with production carried on, the dam height is increasing, for stability the tailings dam need to develop inwards, forming multi-step formation of the dam [6−12].

3 Digital technology of tailings dam safety monitoring

Considering the complexity and the risk of tailings dam, it is necessary to research the adverse factors affecting its security and stability, give a scientific analysis, and conduct its safety monitoring, evaluation, and other digital management.

3.1 Online monitoring

To analyze the 3 500 tailings ponds used in America, the break probability of the tailings dam is 10 times than that of the conventional impounding dam, so it has important meanings for the safety monitoring during the tailings pond in using time [14].

To reinforce the safety management of tailings dam and take a long monitoring to the displacement of the dam, seepage, dry beach, the changes of reservoir level even the precipitation, wind speed, wind direction and temperature, the possible danger should be timely predicted.

In tailings dam's safety monitoring, the necessary monitoring project and relevant facilities should be set up according to the tailings dam's design level, dam style, topography and geological conditions. The system should be monitored regularly and the relevant information (shown in Table 1) such as reservoir level, dry beach length, height restriction, internal displacement of the dam, pore water pressure in the dam, seepage line and the turbidity, drainage structures and the stability of the dam reservoir, water discharge, etc should be collected. Then the site monitoring should be designed, the points and lines should be setup, and the remote automatic monitoring can be conducted.

Table 1 Items of tailings pond security monitoring

Pond level	Fifth level	Fourth level	Third, second and first level
Displacement	√	√	√
Saturation line	√	√	√
Dry beach	√	√	√
Reservoir level	√	√	√
Precipitation		√	√
Online monitoring system		Better to be installed	Should be installed

Pore water pressure, water infiltration and turbidity should be monitored

During the whole process of monitoring system, data from variety of sensor are transmitted into the automatic collection box, and through the transmission module into the core. In the whole process, we should make sure the continuity of displacement meter and udometer and the accuracy of precision (generally the displacement meter's precision should achieve 1 mm and the udometer's should achieve 0.1 mm). Meanwhile, it also should control the inaccuracy on the process of installation and working. Only guaranty the transmission equipment's timely and stability can we ensure the accuracy of the monitoring dates. So the choice of instrument, laying and commissioning should be done according to the specification strictly (as shows in Fig. 2).

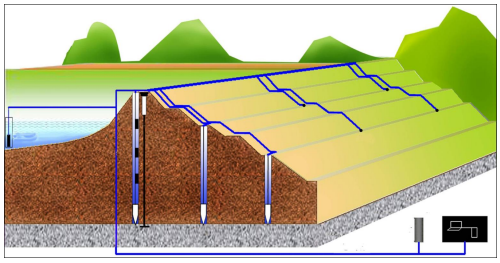

Fig. 2 Workflow diagram of tailings dam monitoring system

3.2 Safety precaution

In order to make the monitoring system more directly and easily guide the tailings dam's safety working, the safety precaution device must be installed for the safety monitoring system. When the monitoring value reached alarm value, the safety precaution device can achieve system's automatic alarm, which can help the manager to take the remedy method in time and to prevent the occurrence of dam-break. According to the safety norms and the requirements of site conditions, Fig. 3 shows the pre-warning curves of saturation line [15].

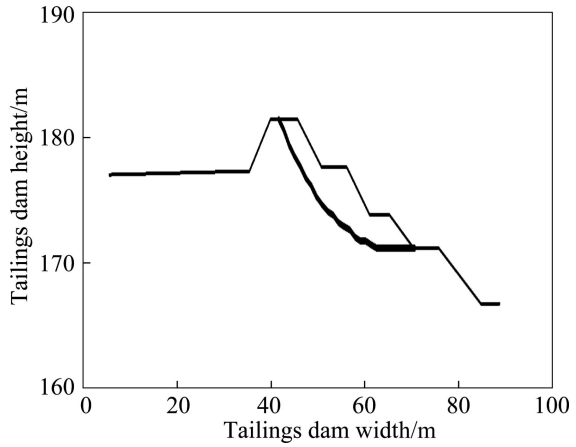

Fig. 3 Graph of saturation line precaution

3.3 Key technical points

1) To achieve "basic theoretical support, and lots of practices"

The study of the tailings dam's stability is a leading topic. Due to the heterogeneity and strength discontinuity of the dam's composition, during the tailings dam deformation, damage inoculation process and the dynamic instability process, the theoretical analysis, as called "prior analysis" in this essay, focus on the bad factors that influence the key scientific problems of its stability evaluation. Meanwhile, the practicality of tailings dam management is huge, which is not only related to the mining and beneficiation knowledge, but also involves hydraulics, soil mechanics, sediment flow mechanics, and the technology of building dams, while the engineering factors are complex, the safety monitoring and assessment information management turn into a complicated and comprehensive practical subject.

2) To achieve "Monitoring comprehensively, and setting points scientifically"

The monitoring work should be comprehensive, scientific, and keep current, informationized, and networked, as the water, dam stress, dry beach feature point elevation, annual rainfall, and the real-time flood storage ability which involve the tailings dam safety data acquisition. These should all be automated and guide the production directly based on the data changes. Meanwhile, the selection of monitoring sections that can reflect the overall security situation of the tailings dam should be ensured. For example, there is inflection point in the process of tailings dams accumulation, and in choosing monitoring sections, whether to set the monitoring instruments near the inflection point or not deserves full and comprehensive consideration.

3) To achieve "Multistage linkage, and online safe monitoring"

Display engineering, mines and the full view of the monitoring system, the ichnography and profile map of the setting points, various monitoring data of process line, distribution lines, relevant lines and other graphics; Display alarming state, and show all monitoring data, monitoring results, various reports, analysis and calculation results; Show the technical materials of engineering safety and the information of inspection.

4) To achieve "Visible engineering terminal, comprehensive decision-making platform"

The monitoring subsystem, communications subsystem, video surveillance subsystem, software analysis and evaluation of the subsystem, the GSM SMS alarm subsystem, lightning protection design subsystem and so on should be established. These sub-systems work collaboratively realize visible engineering terminal and the comprehensive decision-making of the safety management.

5) To achieve "Mass data acquisition, classified storage sharing "

System stores all measured data in 3 levels, measurement device can store test data temporarily, and data will be automatically covered when the storage is filled. The host monitor accept all test data from the measurement device, check automatically, alarm automatically for the data which is out of tolerance, and deposited data in a database after testing; Qualified monitoring data including artificially monitoring data and inspection information all be deposited in database to be filing or further treatment. The adopted signal is of high frequency and many channels, the collected data's capacity and bandwidth is big, and be demanded to take

real-time record, to complete the collected signals restore, display, and post-processing; while do the intelligent analysis based on the historical data acquisition, to give the development trend of the deformation condition in a certain period, so that the administrative staff can make the accident nipped in the bud, and greatly improve engineering and mine safety and control.

6) To achieve "Establish safe and stable model, and integrate analysis and calculation"

Combined the historical and real-time data and according to the state standards, the related process line analysis, potentials analysis, calculation and analysis of subsidence time lag, horizontal section analysis, alignment analysis, online analysis, safety status analysis and so on are carried out. Model is superior to data, because the future, the past and the present can all be showed in the model, but the dates can only show the latter two.

7) To achieve "Reliable quick warning, priority practiced measures"

The safety monitoring of tailings dam should be informationized. The host monitor should both have the general management ability and the alarm function when the signal is overrun, and the system self-check function, which can test the state information of data storage, CPU, clock, power supply, battery voltage, measure circuit, monitor the host and manage self-inspection state information, so that the host can maintain the system timely. The prevention measures should be taken first when abnormal data shows in system.

Firstly, take 24 hours' continuous online monitoring of the important safety index of the tailings dam, to solve the hidden dangers which caused by the nonstandard inspection of engineering and mining.

Secondly, set safety warning standard according to the characteristics of the tailing dam, the system will give early warning when it checks emergency and abnormal situation to help the managers do rescue and relief work.

Thirdly, according to the built-in tailings dam safety standards and the information collected and inspected, system evaluate the tailings dam, and automatically give advice based on the abnormal relevant data, and the national standard of a clearly defined, rectify shut-down, effects of restricting output measures.

4 Application of online monitoring technology to tailings dam

The technology has applied in the tailings pond's Digital Management at Lingnan gold mine, Shandong Zhongkuang Group, Lingnan gold mine tailings dam line in the Beicaojian tributary ditch, the north side of the upstream Luoshan reservoir, Linglong town, Zhaoyuan city. The online monitoring system is shown in Fig. 4. It was built from 1997−05 to 2000−07 go into service. By now, the dam's height is 58.32 m, and its length is 630 m. The tailings dam's reservoir capacity is 5.9×10^6 m^3 and the total reservoir capacity is 20.87×10^6 m^3. The tailings pond belongs to upstream type and valley mode. In the tailings pond's upstream, there are few important facilities. There are 1 200 people and 360 buildings in the downstream and significant facilities— Luoshan reservoir.

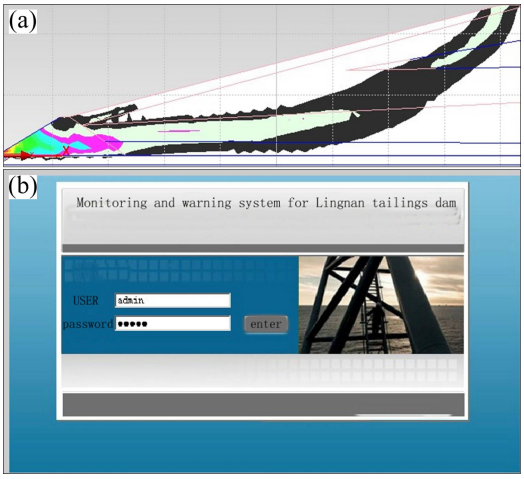

Fig. 4 Online monitoring system used in Zhaoyuan: (a) Outcome of deformation analysis of Lingnan tailings dam; (b) Monitoring precaution system of Lingnan gold mine tailings pond

5 Conclusions

1) The system can automatically monitor many factors such as the reservoir level, dry beach length, high restriction, internal displacement of dam body, pore water pressure within the dam, seepage line, seepage flow and the turbidity of seepage water. These factors greatly affect the stability of dam.

2) The allover process online monitoring can be fully realized using this system.

3) The system can evaluate the stability of dam at any time. At the same time, the early security warning can be done.

4) The scientific, information, real-time, intellectualization, networking and digitization become true during the safety management and production management.

5) All of these will promote the process of metal and nonmetal mine safety production, scientific management, value-added efficiency, scientific innovation and technological progress.

In order to fulfill the information of security monitoring of tailings dam, the following things should be done in the work to make sure of the safety of dam:

real data source, scientific advance-analysis, comprehensive monitoring points, quality instruments, rich information, reliable early warning values, transmission's fidelity, clear visualization, possible preventive measures and the theory's verified.

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