DETECTION METHOD FOR DAM DEFORMATION OF TAILING POND BASED ON FAULT DIAGNOSIS ALGORITHM

by

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The existing methods of dam deformation detection of tailings reservoir have the problems of poor accuracy and slow speed. Therefore, a fault diagnosis algorithm based on tailing dam deformation detection method is proposed. The grey theory is used to accumulate the original feature sequence, and the first cumulative sequence is obtained. Based on this, the grey detection model is constructed, and then the concrete deformation of tailings dam body is accurately detected by precision test. Experimental results show that the method has high accuracy, high speed and practicability.

Key words: *tailing pond, dam deformation, fault diagnosis*

Introduction

China is a major mining country [1]. According to preliminary statistics, there are about 2700 tailings facilities with the certain scale. Metal and non-metal mining companies crush the ore through the concentrator, and then, after the useful mineral components are separated, the slag produced is tailings [2]. The equipment site constructed by stockpiling tailings is called the tailing pond. The tailing dam used to block water and tailings is called the tailings dam. There are about 10 tailings ponds with the storage capacity of more than 100 million cubic meters in China, and the largest is 800 million cubic meters. In terms of quantity, small tailings account for more than 80% of China's total tailings, but in terms of storage, large and medium-sized tailings store about 80% of the country's tailings. According to the survey data, the domestic tailings warehouse is less than 70%, and nearly 50% of the tailings ponds in some industries are in the extended service state. This is the huge hidden danger, even the disaster. Due to engineering investment problems, the general tailings ponds are built not far from the plant, close to roads or railways, and near rivers. Therefore, once the tailings pond is wrecked, its destructiveness is enormous [3]. In order to prevent accidents, in production practice, people constantly sum up experience and lessons, study the law of accidents, find out the source of danger, and understand why accidents occur, how accidents occur, and how to take measures to prevent them [4].

It is very important to quickly and efficiently detect the deformation of the tailings dam body. For example, the detection method for dam deformation of tailing pond based on approximate target posterior information proposed by Zhao, *et al*. [5]. Firstly, the low-rank and sparse matrix decomposition algorithm is used to detect the anomaly of the tailings dam

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image, and the abnormal pixels in the detection result are averaged and used as the approximate target spectrum. Finally, the original image is constrained by using the approximate target to realize the deformation detection of the tailings dam body. Yang *et al.* [6] proposed the detection method for dam deformation of tailing pond based on big data. The objective function is changed to correct the frame's error rate calculation method, and the new outlier data detection model ILD-BOOST is formed. The model is used to detect the deformation of the tailings dam body. Yu and Xia [7] proposed the detection method for dam deformation of tailing pond based on the Gaussian process model. The Gaussian process can be based on the training sample from the prior distribution to the posterior distribution, the hyperparameter of the kernel function is inferred, the predicted output has a clear probability interpretation, and the deformation of the tailings dam body deformation is realized. The detection method for dam deformation of tailing pond based on big data analysis was proposed by Miao [8]. Combined with the current mainstream big data analysis technology, the deformation data of the tailings dam body is analyzed in real time to find the hidden rules behind the big data, and to warn the upcoming tailings ponds dam deformation. Finally, deformation detection of the tailings pond dam is realized.

However, the aforementioned methods all have the problem of low detection accuracy. Therefore, the detection method for dam deformation of tailing pond based on fault diagnosis algorithm is proposed in this paper. The idea is: the grey theory is used to accumulate the original characteristic sequence of the tailings dam to form the first cumulative sequence. On this basis, the accuracy test method is used to detect the deformation of the tailings dam body.

Materials and methods

Overview of tailings dam related information

(1) Tailings dam composition

The tailings dam consists of two parts: the initial dam and the tailings accumulation dam. The initial dam is the dam body where the early tailings are piled up. The initial construction of the dam is built on the dam site with materials such as stone and cement, whose main function is to support the entire dam and drainage. The tailings accumulation dam is built on the initial dam, and the tailings are used as damming materials to form a stepped dam formed by layering and stacking.

The tailings dam can effectively block the tailings and wastewater in the reservoir, which can protect the ecological environment of the reservoir area and avoid damage caused by arbitrary discharge. At the same time, it plays a protective role in the production safety of the tailings reservoir area and the life and property safety of the surrounding residents; making full use of water resources, the tailings water can be used for recycling in the mine after being treated in the warehouse; protecting mineral resources, some tailings It contains available resources such as rare minerals and precious metals, which can be recycled in the future [9-11].

(2) Tailings dam classification

According to the relative position of the crest axis and the initial dam, the way of tailings accumulation can be divided into the following five forms:

- Upstream stacking dam
  The upstream dam is started from the initial dam top. Generally, on the sedimentary dry beach surface, the coarse tailings in the reservoir area are taken up according to the designed inner and outer slope ratio.
- Downstream stacking dam
  The downstream type dam is made up of thick tailings with high tail shear strength and strong permeability, which are gradually piled up in the downstream direction of the initial

dam, and layered and rolled up. The foundation of the dam construction is good, and it is easy to control the tailings discharge. Compared with other dam construction methods, it has good stability and is easy to meet the seismic design requirements of the tailings dam.

– Midline stacking dam
  The mid-line dam construction method is shown in fig. 1.
– Reservoir type tailings accumulation dam
  Reservoir type tailings accumulation dam is shown in fig. 2.

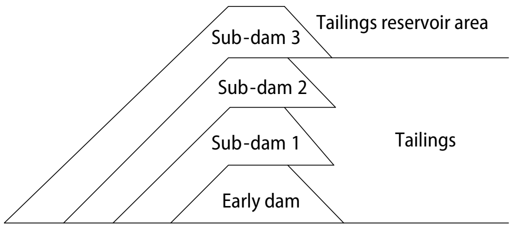

Figure 1. Dam construction method of midline tailings

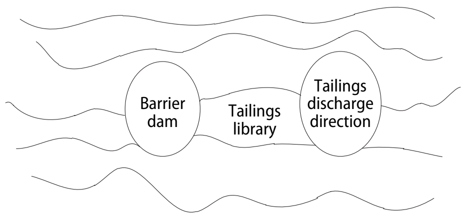

Figure 2. Reservoir type tailings dam construction method

– High concentration tailings accumulation dam
  The high concentration dam method is a new type of accumulation method produced abroad. The concentration of the concentrated tailings slurry is transported to a certain area by a sand pump and discharged into a cone-shaped pile.

Dam deformation displacement prediction model

(1) Overview of forecasting methods

The prediction is to conduct the scientific investigation and analysis of objective facts, history and current situation, to speculate the future from the past and the present, and to reveal the future development trends and laws of objective facts.

Forecasting methods are generally divided into qualitative and quantitative predictions. Qualitative prediction refers to that based on historical data and visual materials, personal experience and analytical judgment, the future development of things is judged at nature and extent by people and experts with proficient, experienced and comprehensive analytical skills. Then, the opinions of all parties are integrated and used as the main basis for predicting the future. Quantitative prediction is a mathematical model that uses historical data or factor variables to predict demand. This paper mainly studies quantitative prediction methods and grey system theory [12].

(2) Modeling of grey theory

The main problems solved by the gray model are as follows: The determination is made as to the logical and mathematical relationships that exist between the feature data extracted in the system. Then, using the differential equation model, the internal features of the gray system are accurately de-whitened. When building a model, the grey system theory is divided into five steps, as shown in fig. 3.

(3) Construction of grey theory prediction model

Since the establishment of the Grey Theory System, $GM(1,1)$ models have been most commonly used in predictive related problems in their related theories. The model is simple to operate, and there are not many

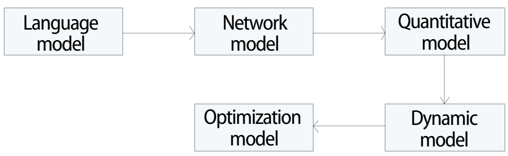

Figure 3. Gray theory diagram

requirements for the internal data of the system during the modeling process. In the gray system, the method is estimated by the least square method. In the case of system interference, the model prediction results are not easy to produce great deviation. The $GM(1,1)$ model is a single-sequence first-order linear dynamic model. It is modeled according to the three steps of accumulating, establishing a gray model and restoring. The modeling process is as follows:

Assume that the original feature data sequence $X^{(0)}$ is recorded:

$$X^{(0)} = \{x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n)\} \tag{1}$$

– Accumulate the original feature sequence once to get the accumulated sequence $1-AGO$:

$$X^{(1)} = \{x^{(1)}(1), x^{(1)}(2), \cdots, x^{(1)}(n)\} \tag{2}$$

Then the generated cumulative sequence can highlight the regularity of the enhanced data for research.

– Gray model:

$$x^{(0)}(k) + az^{(1)}(k) = b \tag{3}$$

where a and b are the parameters to be determined, a can indicate the development trend of the system, called the development coefficient, b can reflect the change relationship of the data, called the gray action. Equation (3) is the $GM(1,1)$ model whose whitening equation is:

$$\frac{\mathrm{d}x^{(1)}(k)}{\mathrm{d}t} + ax^{(1)}(k) = b \tag{4}$$

– Values of a and b

Let

$$P_1 = \begin{pmatrix} a \\ b \end{pmatrix}$$

be the parameter package of $GM(1,1)$. Under the least squares' criterion, the parameter package satisfies:

$$P_1 = \begin{pmatrix} a \\ b \end{pmatrix} = (B^T B)^{-1} B^T y_N \tag{5}$$

Then the time response equation of eq. (4) is:

$$x^{(1)}(t) = \left[x^{(1)}(1) - \frac{b}{a} \right] \mathrm{e}^{-at} + \frac{b}{a} \tag{6}$$

Substituting eq. (4) into eq. (6), the time response equation of the $GM(1,1)$ model is obtained, and the predicted value of $x^{(1)}(k+1)$ can be obtained:

$$x^{(1)}(k+1) = \left[x^{(0)}(1) - \frac{b}{a} \right] \mathrm{e}^{-ak} + \frac{b}{a}, \quad k = 1, 2, \cdots, n \tag{7}$$

After the predicted value of $x^{(1)}(k+1)$ is subjected to the subtractive reduction process, the predicted value of the original feature sequence can be obtained:

$$x^{(0)}(k+1) = (1 - e^{a})\left[x^{(0)}(1) - \frac{b}{a}\right]e^{-ak} \tag{8}$$

The previous formula is the predicted value sought by the model.

In the test of the model, the four methods of residual test, correlation test, step deviation test and post-test difference test are often used for accuracy test. Using the prediction model previously constructed, the deformation of the current tailings pond dam can be obtained. Through the deformation information of the dam body, the potential danger of the tailings pond is discovered in time, which reduces the loss of life and property caused by the tailings pond.

Results

In order to verify the validity of tailing dam deformation detection method based on fault diagnosis algorithm, the test is carried out from two aspects: benchmark stability and detection accuracy.

Benchmark stability analysis

Taking the tailings pond of a certain area as an example, the four reference points of the tailings pond are solid and stable, which is convenient for long-term preservation and far from the building. In the more than 30 observations that have been carried out, the four benchmarks have been checked. The results are adjusted by the adjustment software, and the results are reliable. More than 30 results are compared, which are less than the tolerance. It is proved that the reference point is stable and reliable, and is not affected by the settlement of the tailings pond.

The displacement changes of each observation point are shown in figs. 4 and 5.

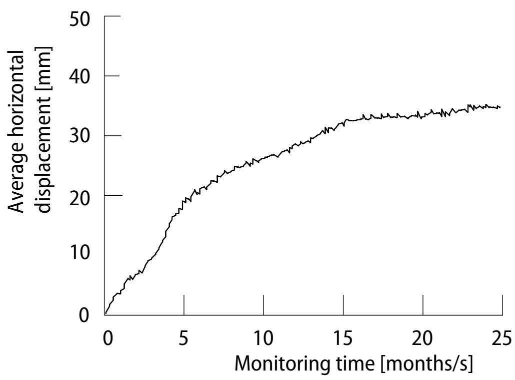

Figure 4. Average horizontal displacement curves

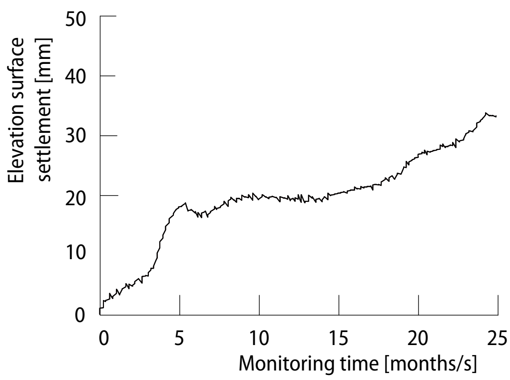

Figure 5. Elevation surface settlement curves

It can be seen from figs. 4 and 5 that the change of the tailings pool in the early stage is relatively large regardless of the displace ment or the settlement angle. But as time goes by, the amount of change gradually becomes smaller and tends to be stable. According to the analysis of the existing data, from the radial point of view, the tailings reservoir is displaced to the downstream as a whole. More than 30 observations show that the cumulative average displacement of the initial dam is about 35 mm, and the displacement rate is about 8/1000000, which is in line with the building deformation measurement procedure.

According to the experimental data, the accuracy of the monitoring data is very high and can be used as subsequent experimental data.

Accuracy of deformation detection

In order to further verify the effectiveness of this method, the deformation characteristics of tailings dam are measured by simulation experiment. It is assumed that the actual deformation coefficient of the collected tailings pool is 0.25. The deformation characteristics of the tailings dam body are measured using the methods described in reference literature [5] method, the literature [6] method, the literature [7] method, and the literature [8] method and the experimental sample data under different methods are obtained [5-8], and the experimental sample data are obtained under those different methods. The details are shown in tab. 1.

Table 1. Deformation detection data table of tailings dam body

Method name	Sample data	Deformation uniformity coefficient	Deformation coefficient
[5] method	36	0.44	0.22
[6] method	40	0.46	0.25
[7] method	37	0.44	0.23
[8] method	35	0.45	0.22
Method	40	0.45	0.20

The deformation characteristics of the tailings dam body are measured using a comparative method, and the obtained results are shown in fig. 6. Wherein, the ordinate is the deformation coefficient, and the value is the constant expressed by C. The abscissa is the deformation uniformity coefficient, and its value is the constant expressed by C.

The deformation measurement results of the tailings pond dam obtained by the proposed method are shown in fig. 7. Wherein, the ordinate is the deformation coefficient, and the value is the constant expressed by C. The abscissa is the deformation uniformity coefficient, and its value is the constant expressed by C.

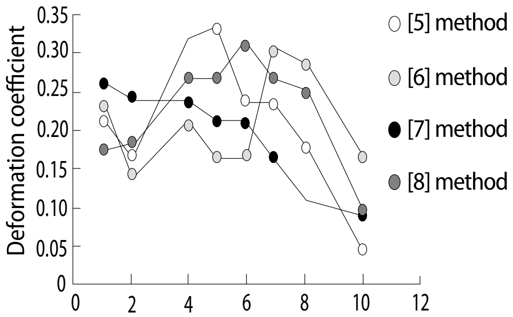

Figure 6. Measurement results of several literature methods

A comprehensive analysis of figs. 6 and 7 can be used to obtain the large fluctuation in the deformation parameters of the tailings dam body obtained by the comparison method. The test results are shown in tab. 1.

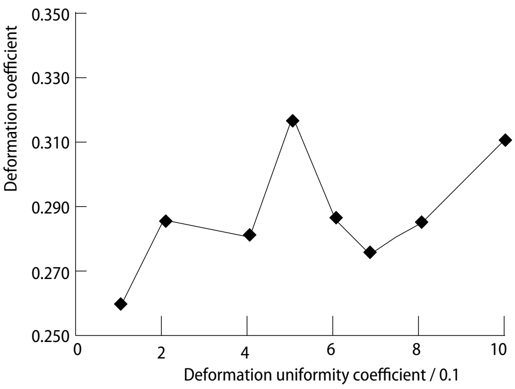

Figure 7. Measurement results of the proposed method

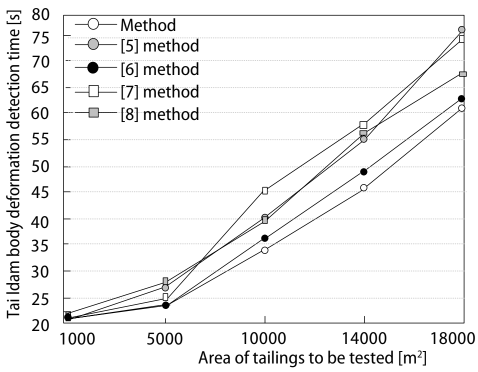

Figure 8. Comparison of deformation speed detection of tailings dam

According to the data in tab. 1, the deformation characteristics of the dam body obtained by this method are consistent with the actual situation. It is proved that this method is effective and accurate in measuring deformation characteristics of dam body of tailings reservoir and has high application value.

Discussion

The detection speed of deformation is another important indicator to measure the effectiveness of the detection method for dam deformation of tailing pond. The dam body deformation detection speeds of the proposed method, the literature [5] method, the literature [6] method, the literature [7] method and the literature [8] method are compared, and the results are shown in fig. 8. Among them, the abscissa is the area of the tailings pond to be detected, and its unit is square meter; the ordinate is the deformation time of the tailings dam body deformation, and its unit is seconds.

It can be seen from fig. 8 that in the six detection methods for dam deformation of tailing pond, the detection speed of the proposed method is the fastest, followed by the literature [6] method, and the detection method of the literature [7] is the slowest. It can be seen from the previous experimental data that the deformation detection of the tailings dam body can be realized in the relatively short time by the proposed method.

In summary, the proposed method can realize the deformation detection of the tailings dam body in a short time, and the detection accuracy is high. The accurate and rapid detection effect greatly improves the personal safety of the staff and surrounding living personnel in the tailings dam body.

Conclusion

To improve the deficiencies of existing testing methods, the detection method for dam deformation of tailing pond based on fault diagnosis algorithm is proposed in this paper. The experimental data show that the detection accuracy of the proposed method is very high, which can maximize the safety of life and property of personnel in the tailings pond. In the future research phase, the method will continue to be optimized to further expand its application range.

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