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Tailings dam breach disaster on-line monitoring method and system realization

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Abstract

In recent years, the issue of safe production of tailing ponds has become a common social problem facing China. Safe operation of the tailings dam is one of the main issues to ensure safety of the lives and properties as well as social stability in the areas where the tailing ponds are located. On the basis of the structure of the tailing ponds on-line monitoring system, this paper systematically studied the dam displacement GPS on-line monitoring method and the vibrating wire type saturation line on-line monitoring method with regard to the technical indicators for the dam displacement and saturation line that should be observed for tailing ponds rated at Class IV or higher, and come up with the structure and fulfilling means for the on-line monitoring system of these two indicators. This paper also studied the basic functions and data flow that the on-line monitoring system of an enterprise should have. The aforesaid achievements may be used as a basis for China's metal and non-metal mining enterprises to install the tailings dam online monitoring systems.

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Keywords: Tailings dam; Dam displacement; Saturation line; On-line monitoring

1. Introduction

A tailing pond is a space formed by building a dam across the mouth of a valley or through building an embankment around a place, which is intended for stockpiling tailings discharged from a metal or non-metal mine as a result of ore separation and is the necessary facility for maintaining normal production of a mine, though it is also a major source of hazard in metal and non-metal mines all over the world [1, 2]. Once dam breach occurs to the tailing ponds, major damage will be caused to the people's lives and properties, which will directly impact the social stability. For example, the extraordinary severe dam breach accident occurred to the tailing pond of Xiangfen Xinta Mining Co., Ltd., Linfen City, Shanxi

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Province, China on September 8, 2008 has caused some 277 casualties. According to relevant statistics, in 2004, there were 3 accidents occurred to the tailing ponds in China, resulting in 5 casualties; the year 2005 witnessed 9 such accidents, resulting in 17 casualties; the 12 accidents occurred in 2006 caused 57 casualties; the 14 accidents occurred in 2007 caused 56 casualties; and the year 2008 witnessed 18 accidents, resulting in 320 casualties [3]. Therefore, the application of online monitoring and other technological means is quite necessary in order to improve the tailing ponds operation safety and management skills.

In developed countries, the safety monitoring has been applied in geotechnical engineering for many years [4]. Many researchers studied the corresponding early warning technologies and back analysis of measured data [5. 6]

China started late in the tailing ponds disaster monitoring and early warning areas, and in the present time, the main practice is to conduct the measurements on the sites artificially by using traditional instruments. This not only causes a heavy burden, but also is susceptible to the impact of weather and field conditions, and cannot be used to obtain real-time operating data of tailing ponds. And the measured data has a certain system errors and human errors. The reorganization and analysis of data lags behind, as a result, any hidden hazard existing with the dams cannot be found in a timely manner. At present, a small percentage of mines have also adopted remote real-time monitoring systems to monitor some of the safety indicators [7, 8], however, due to a lack of systematic theoretical research and critical technological achievements, a comprehensive and sound monitoring and early warning system has not been formulated, thus, there is a lack of scientific means and methodology in the efficient early warning and forecast of dam breach disasters. In the 1990's, research on GPS automated deformation monitoring system began to be conducted on dams and high side slopes, and now, the GPS technology has been applied in the dam or high side slop deformation monitoring of the Three Gorges Project, the Yellow River Xiaolangdi Hydro Project, Zhejiang Tianhuangping Pumped Storage Station, Hubei Qingjiang Geheyan Hydro Project, the Longyang Gorge Reservoir Shore, etc., and the research achievements in the relevant fields have provided a reference and idea for the research and development of tailing ponds online monitoring system.

On the basis of the structure of the tailings dam on-line monitoring system, this article systematically studies the dam displacement GPS on-line monitoring method and the vibrating wire type saturation line on-line monitoring method with regard to the technical indicators for the dam displacement and saturation line that should be observed for tailing ponds rated at Class IV or higher, and comes up with the structure and fulfilling means for the on-line monitoring system of these two indicators. This article also studies the basic functions and data flow that the on-line monitoring system of an enterprise should have. The aforesaid achievements may be used as a basis for China's metal and non-metal mining enterprises to install the tailings dam online monitoring systems

2. On-line Monitoring System

2.1. Structure of online monitoring system

The tailings dam online monitoring system should provide true data indicating the production and operation status of a tailing pond, and should send out early warning for any hidden safety hazard of the tailings dam, so that the mine operator is able to strengthen its hidden safety hazard remedial efforts accordingly, improving the safe operation conditions of the tailing ponds, fulfilling a long-term safe operation thereof.

A tailings dam online monitoring system should consist of the sensor network of a dam displacement GPS monitoring subsystem, a saturation line monitoring subsystem and other indicators monitoring subsystems. Its basic structure is as schematically shown in Fig. 1

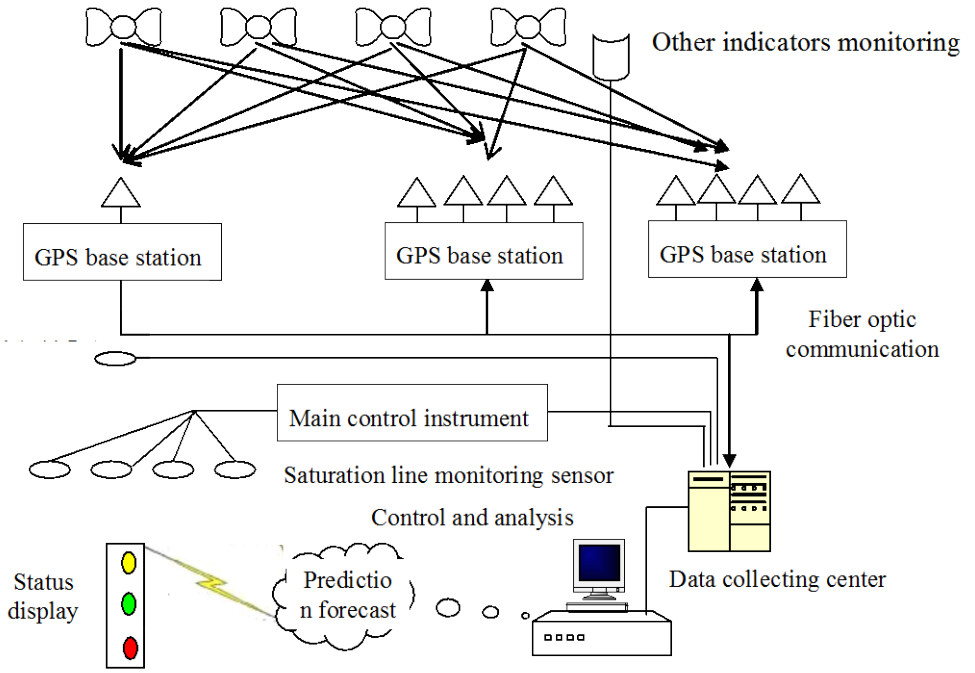

Fig 1 A diagram showing structure of online monitoring system

GPS monitoring station and saturation line monitoring sensors are deployed on the dam surface of the tailing pond; the GPS receiver and the saturation line control instrument located in the data monitoring center are used to receive the dam displacement and saturation line depth among other parameters; the sensor signals are transferred to the data collection center via a fiber optic communication network; the collected data is controlled and analyzed by using the tailings dam breach disaster early warning model, thus, realizing an accurate assessment as well as prewarnning and forecast

2.2. Dam displacement online monitoring method

In the case of any dam breach disaster occurred to a tailing pond, dam displacement is a direct demonstrative indicator of the disaster evolution process. Therefore, through mastering the deformation of the downstream slope of the tailings dam, it is possible to find the deformation rate of the tailings dam as well as the development speed in a timely manner, which is helpful for the safety supervision authorities and the enterprises to make a rational responsive decision and take emergency countermeasures, thus, avoiding the disaster from occurring or reducing the damage to be resulted from the disaster. Fig. 2 is a deformation vector diagram of a tailings dam, and it can be known from this diagram that a downward and downstream deformation has occurred to the downstream slope of the dam.

This paper also studies the methods for implementing the tailings dam GPS monitoring technologies with reference to the hydro project GPS displacement online monitoring technology and experience. The tailings dam GPS displacement online monitoring system is composed of three parts: the monitoring unit, the data transmission and control unit as well as the data processing, analysis and management unit. These three parts form an integral part. The monitoring unit is intended to track the GPS satellites and

collect the data in real time; data is transmitted to the control center via the communication network, and the relevant GPS software at the control center processes and analyzes the data. In this manner, the slope displacement of the tailings dam is monitoring in real time. For the structure and process flow of the tailings dam GPS real-time differential deformation monitoring system, please refer to Fig. 3.

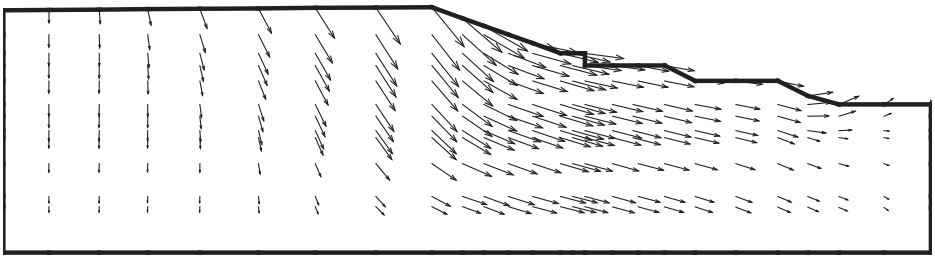

Fig 2 Tailings dam deformation vector diagram

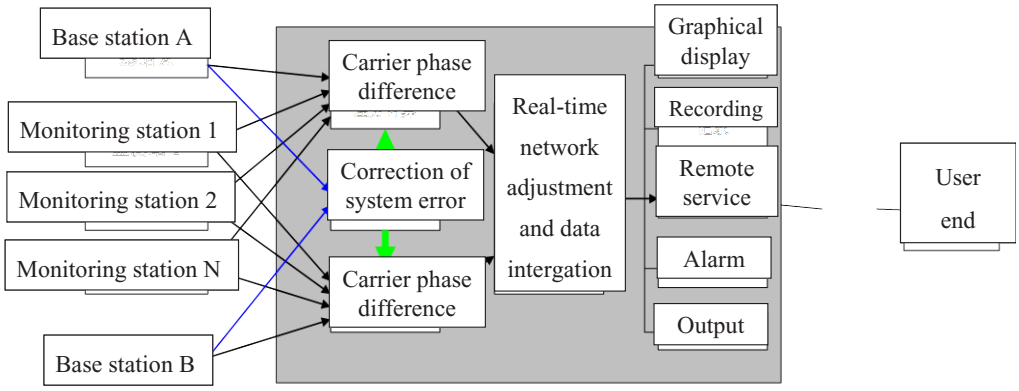

Fig 3 Structure of GPS displacement monitoring system

When GPS is used for real-time monitoring of the tailings dam displacement, at least 2~3 monitoring profiles should be selected according to the dam length. In general, monitoring profiles should be provided at the highest position of the dam as well as where the topographic and geological variations are relatively big. For each profile, 4~6 monitoring points shall be evenly provided on the surface of the dam slopes from top to bottom according to the dam height. The bottommost point should be located on the ground surface within 5~10m range at the dam toe in order to monitor the displacement when the entire dam moves.

2.3. Saturation line online monitoring method

The saturation line is also the free water surface line of the seepage flow net, which is the lifeline of the safety of tailings dam, because the height of the saturation line directly relates to the stability and safety performance of the dam body [9]. Therefore, the monitoring of the saturation line positions is one

of the important tasks of the tailings dam safety monitoring. Fig. 4 shows the line when the pore water pressure is 0kPa, which is the saturation line of the tailings dam.

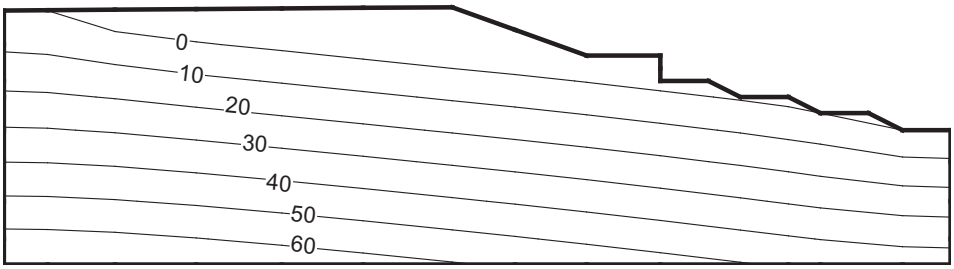

Fig. 4 Pore water pressure distribution diagram of tailings dam (Unit:10kPa)

Vibrating wire type sensors can be used for online monitoring of the tailings dam saturation line. Since its invention in the 1930's, vibrating wire type instruments have been gradually applied in actual projects due to its advantages such as simplified structure, high precision and high interference resistance, etc. The steel wire of a vibrating wire type sensor is fixed on a sensitive diaphragm, and the pressure change causes the diaphragm to deflect, thus, causing the change of the steel wire's tension force, making it possible for monitoring of the seepage water pressure change. For the structure of the saturation line monitoring system, please refer to Fig. 5.

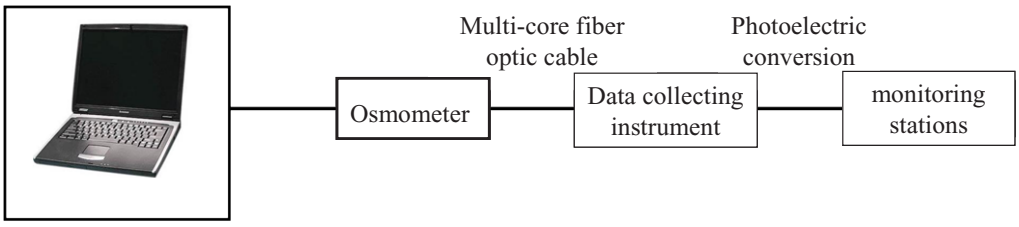

Fig. 5 Structure of saturation line monitoring system

For saturation line monitoring, the largest cross-section on the tailings dam or the cross-section on the tailings dam which is likely to cause major damage to the lower reach in case of accident is generally selected as the monitoring profile. In the case of large-scale tailing ponds, monitoring profiles should also be provided at the thin sections of the dams. Each monitoring profile should be provided with at least 5 monitoring points, and the monitoring points should also be selected flexibly according to the pressure variation gradient of the pore water at the downstream slope of the dam as indicated in the design input information.

With respect to the burying positions of the saturation line monitoring instruments, these should be buried at the positions of dam saturation line calculated according to the working conditions specified in the "Safety Technical Regulation for The Tailings Pond". When conducting the dam slide-resistance and

stability analysis, the saturation line specified in the design code must be indicated per two working conditions, namely, normal operation and operation with flood. During design, the indicated position of the saturation line should be an important basis for determining the buried depth of the monitoring instruments. Currently in China, the buried depth of the saturation line is generally not allowed to be less than 6~8m in the design of a tailing pond.

3. On-line Monitoring System

The tailings dam displacement and saturation line online monitoring systems should have the following functions:

(1) Data collection. The system should allow automatic collection and automatic storage of all data. Monitoring data of the various subsystems should be collected by the various types of sensors, which should, through remote control, collect the data automatically per the set time and mode. All data collected by the various sensors shall be summarized and stored on temporary basis at the field collecting station, meanwhile, the data should be transferred to the servers at the monitoring center for storage.

(2) Data display. The system can display the data monitored by multiple sensors at the tailings dam monitoring and early warning system control center; and can generate and print out monitoring data report of the various kinds and analyze the calculated results; can display the technical information and safety regulation among other information.

(3) Data storage. The system allows for two-level storage of the measured data. Server of the field collecting station can store the measured data on a temporary basis, and the server of the monitoring center receives the monitoring data from the monitoring instruments and automatically checks it and stores it into the database of the monitoring mainframe, and the database of the monitoring mainframe may further store, process and analyze the data.

(4) Management and alarm. The monitoring mainframe has a certain monitoring data management capability. As a comprehensive terminal management center of the system, the information management mainframe of the control center has such management functions as real-time data monitoring, database management, management of the monitoring instruments, graphical formation of reports and charts, browser and auxiliary tool management, etc. The information management mainframe at the control center may also send out alarms for the data overrun at the measuring points.

To streamline the data flow of the tailings dam online monitoring system is one of major tasks in scientific research and development of the system. Fig. 6 gives the data flow in the dam breach disaster monitoring and early warning system. In a tailings dam, the system will collect the data concerning the displacement and saturation line depth and other data of different types and modes. These data are collected into the data collection center located on the dam in the first place. At the tailings dam data collecting center, different types of data are respectively converted into optical signals, and fiber optic communication system is employed to collectively transfer the data to the data monitoring and early warning center. On the basis of data screening and processing, the system carried out a comprehensive analysis and assessment of the indicators closely related to the tailings dam breach disaster by employing typical tailing ponds disaster numerical model and calculating method, and ultimately obtains a conclusion about the safety status. In order to assist the background data analysis and assessment and visually keep abreast of the operating status of the tailings dam, a visualized window is usually embedded at an important location in the system, so that a visual judgment can be made about the personnel on the dam and the equipment operating status, etc.

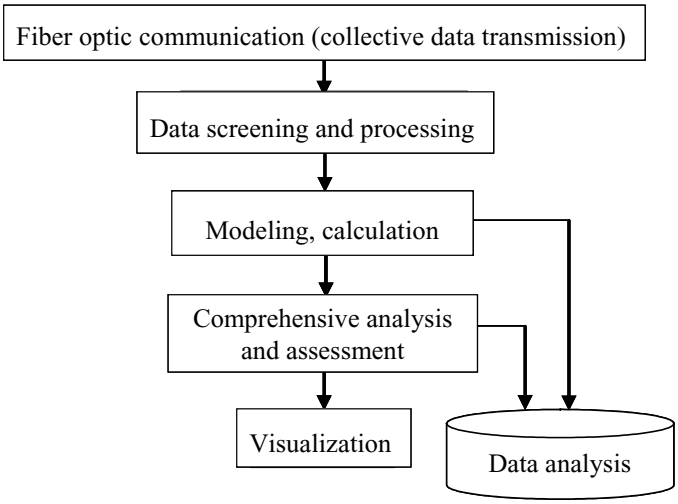

Fig. 6 Data flow diagram

Therefore, when designing the tailings dam online monitoring system proposals for the metal and non-metal mining enterprises, the monitoring indicators and monitoring point deployment plans should be selected scientifically and rationally according to the actual conditions of the tailings dam which should, on the basis of ensured effectiveness of monitoring and early warning, reduce the cost of online monitoring system as far as possible.

4. Concluding remarks

At present, safety of the tailing ponds is of great concern in China. The gradual implementation and popularization of the tailings dam safety monitoring system is helpful in enhancing the tailing ponds safety supervision and routine management skills and in strengthening the early warning response capabilities of the enterprise, society and government with respect to dam breach. This paper comes up with the tailings dam displacement GPS online monitoring fulfilling method and the general principle for deploying the monitoring points for tailing ponds rated Class IV and above, as well as the vibrating wire monitoring technology and deployment plan for the buried depth of saturation line, and on the basis of actual conditions of the enterprises, it proposes the system functions and data flow design method that should be considered by the enterprises when it comes to installation of online monitoring systems. The above research results may be used as a basis for China's metal and non-metal mining enterprises to install the tailings dam online monitoring systems.

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References

[1] Strachan, C. Tailings dam performance from USCOLD incident-survey data[J]. *Mining Engineering,* 2001, 53(3): 49-53

[2] Sharma, R.S, Al-Busaidi, T.S. Groundwater pollution due to a tailings dam[J]. *Engineering Geology*, 2001, 60(1): 235-244

[3] Li Q, Chen X & Wang Y. Research on material physical and mechanical characteristics tests of Houjing tailing reservoir of Xishimen[J]. *China Journal of Safety Science and Technology,* 2009, 5(3): 73-77. (In Chinese)

[4] Gioda G. & Sakurai S. Back analysis procedures for the interpretation of field measurements in geomechanics. 1987, Vol. 11: 555-583

[5] Cividini. A & Gioda. C. el. Some aspects of characterization problems in geomechanics. *Int. J. Rock Mech. Min. Soil & Geomech. Abstr*. 1981, Vol. 18: 487-503

[6] Sakurai. S & Takenchi. K. Back analysis of measured displacements of tunnels[J]. *Rock Mech. and Rock Eng*, 1983, 16(3): 173-180

[7] Jiang W, Li X & Wu D. An automatic safety monitoring system for the No.2 tailings dam in Dexing Copper Mine[J]. *China Journal of Mining R & D*, 2003, 23(1): 33-44. (In Chinese)

[8] Sakurai S. Interpretation of the results of displacement measurements in cut slopes. Proceedings of the 2nd International Symposium on Field Measurements in Geomechanics. In: S. Sakurai Field Measurements in Geomechanics. Balkema. Rotterdam: 1988, 1155-1166

[9] Stauffer, Peter A. Pore water pressure conditions in tailing dams[J]. *Geotechnical Special Publication*, 1988, 21: 924-939