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GUIDELINE FOR DAM SAFETY MONITORING SYSTEM APPRAISAL

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ABSTRACTS

On the basis of reviewing relevant specifications and practical experience of dam safety monitoring at home and abroad, this paper has put forward the overall framework of dam safety monitoring system appraisal, appraisal elements and evaluation methods of monitoring facilities reliability and completeness, monitoring system operation and maintenance and monitoring automation system. Dam safety monitoring system appraisal shall cover monitoring facility completeness appraisal, monitoring facility operation and maintenance appraisal and monitoring automation system appraisal. The appraisal on completeness of monitoring facilities is based on whether monitoring facilities that are reliable or basically reliable as appraised with installation information, on-site inspection and testing and historical measured data analysis meet the requirements of dam safety monitoring. Monitoring facility operation and maintenance appraisal includes operation management guarantee, observation and maintenance, and data compilation analysis. Monitoring automation system appraisal includes data acquisition device, computer and communication facilities, information acquisition and management software, operation conditions and operation maintenance. The comprehensive appraisal results of monitoring systems are classified into three grades: normal, basically normal and abnormal. Those appraised as normal should be operated continually; those appraised as basically normal can be operated continually, but repair and completion should be done promptly; and those appraised as basically abnormal shall be replaced or renovated promptly.

Safety monitoring is an important non-engineering measure to monitor and know the operation behavior of the reservoir dams, an important means to guide the scientific dispatching of the reservoir and safe operation of the project, and an indispensable and important work in the reservoir dam safety management. It is specified in relevant regulations in China that, dam safety monitoring shall cover inspection, deformation monitoring, seepage monitoring, stress (pressure) strain and temperature monitoring, earthquake response monitoring, environmental monitoring, etc (Ministry of Water Resources of the People's Republic of China, 2012, 2013). According to statistics, 90% of large reservoirs and 2/3 of medium reservoirs in China are installed with safety monitoring facilities (J. Wang et al. 2018). Due to various reasons, in some safety monitoring facilities, there are phenomena such as missing basic data, equipment and instrument damage, system operation instability, monitoring data chaos after a period of operation following their completion. With the extension of reservoir dam service period, due to the inconsistency of engineering geological conditions and construction quality with the design assumptions, the uncertainty in project operation environment, and the creep of materials and structural aging, the operation performance of the dam may change, so the existing monitoring system may become unable to perform overall and effective monitoring of the dam safety (ICOLD, 2016). In order to scientifically evaluate the operation of the dam safety monitoring systems, ensure the continuous, reliable and effective operation of the dam safety monitoring systems for existing reservoir dams, and ensure the safety control of dams, the Technical specification for appraisal of dam safety monitoring system was compiled.

1. OVERALL FRAMEWORK

Dam safety monitoring system appraisal shall cover the monitoring facility reliability and completeness, operation and maintenance effectiveness and the automation system reliability. Monitoring facilities refer to monitoring instruments and their auxiliary facilities, such as protection devices, observation rooms, observation lanes, etc.; and automatic system collectively refers to monitoring data automatic collection, transmission, storage, processing device and software. The overall appraisal framework for monitoring systems is as shown in Fig. 1.

The reliability of monitoring systems is the basis for dam safety monitoring system appraisal, and the reliability appraisal is performed with measuring points as units. For multi-point measuring devices, such as collimation line device, wire extension line device, the appraisal can be made according to the actual engineering characteristics and measuring

point arrangement based on the separate appraisal of individual measuring point devices. For the monitoring facility completeness, it is evaluated by whether the monitoring items and measuring point arrangement based on reliable or basically reliable monitoring facilities can meet the need to monitor the present and future safety of dams. The operation and maintenance of monitoring facilities is an important measure to ensure the continuous and reliable operation of the dam safety monitoring system and plays a key role in the sustainable and reliable operation of monitoring facilities. The dam safety monitoring automation system is an important part of the dam safety monitoring system, and its appraisal content is obviously different from the reliability appraisal of monitoring facilities, so it is made an independent part in the appraisal system, and it is not included in the appraisal system if no automation system has been built for the project.

The comprehensive appraisal of monitoring systems is divided into three grades: normal, basically normal and abnormal. The monitoring system is appraised as normal when all three items of monitoring facility completeness, operation and maintenance and monitoring automation system (if provided) are appraised as qualified; it is basically normal when the monitoring facility completeness and monitoring automation system (if provided) are basically qualified; and the monitoring system is abnormal when the monitoring facility completeness is not qualified. The comprehensive appraisal of monitoring systems focuses on the completeness of monitoring facilities, and the incompleteness of monitoring facilities is set as a veto. As long as the monitoring facilities are reliable and complete, even if the automation system is not normal, data can be obtained through manual observation, and dam safety monitoring can be achieved. Therefore, there is no veto on the automation system. In the appraisal system, the monitoring system can be identified as normal only when the monitoring facility operation and maintenance is appraised as qualified, which reflects the importance of the monitoring facility maintenance. At the same time, it is considered that the monitoring facility operation and maintenance is a management measure, so no veto condition has been set on the monitoring facility operation and maintenance.

The Technical specification for appraisal of dam safety monitoring system specifies that the dam safety monitoring system shall be appraised regularly. The first appraisal shall be conducted within 3 years after the completion of the system or after the system is put into use. Thereafter, the appraisal shall be conducted every 3-5 years or when necessary according to the operation of the monitoring system. The appraisal should be carried out in conjunction with the dam safety appraisal. The agency undertaking the appraisal of the dam safety monitoring system shall have the corresponding qualifications or achievements, and the personnel engaged in the appraisal shall have the corresponding qualifications or practitioner experience. Monitoring systems appraised as normal shall continue to operate; those basically normal can continue to operate, but should be timely repaired and improved; and those abnormal shall be updated and transformed in time.

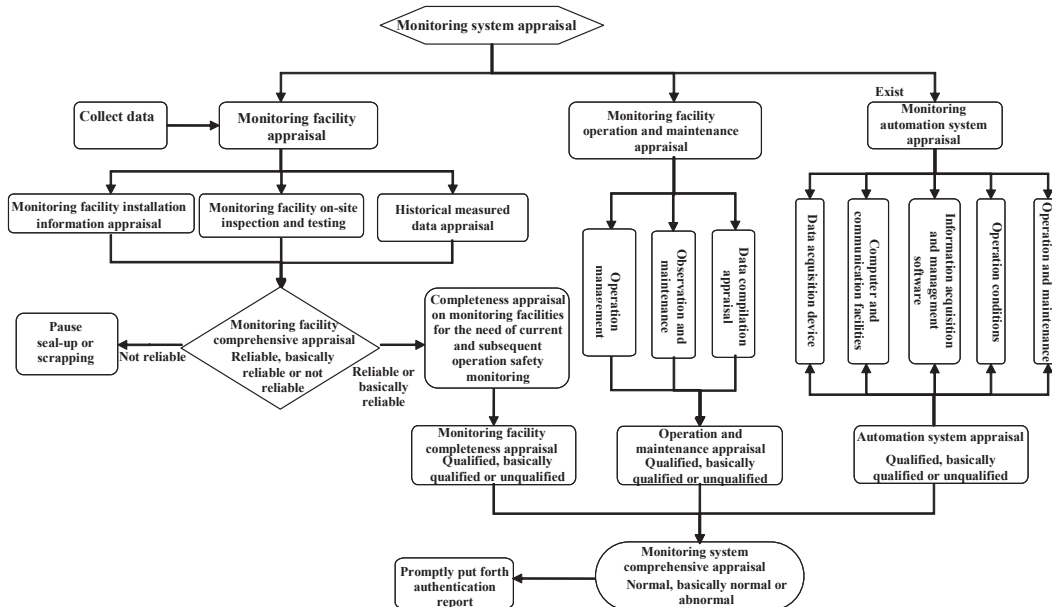


Figure 1 : The overall appraisal framework of dam safety monitoring system

2. MONITORING FACILITIES RELIABILITY APPRAISAL

The reliability appraisal of monitoring facilities includes three items: monitoring facility installation information appraisal, on-site inspection and testing, and historical measured data appraisal, the reliability of the monitoring facilities is appraised on the basis of the appraisal results of the three items. Only monitoring facilities appraised as reliable or basically reliable can be included in the measuring point system for monitoring facility completeness appraisal.

The monitoring facility installation information appraisal includes data integrity, monitoring instrument adaptability and monitoring facility installation accuracy. The monitoring facility installation information shall include the data of the ex-works inspection and test of instruments or the data of third-party inspection and test, and these data are the basis of observation data calculation and analysis. Different working conditions and environments require different performance indicators for monitoring instruments, so the selection of monitoring instruments shall be suitable for working environmental conditions, such as ambient temperature limit and load action. The technical performance indicators shall meet the monitoring requirements of physical quantity of the project under test; for example, if the range of seepage pressure changes at different positions of the dam is different, the range selected by the osmometer set at different positions should change accordingly, and the range should be consistent with the actual seepage pressure that can be withstood at the location. The installation of monitoring instruments shall avoid damage to the project structure, meet the relevant specifications and design requirements, and the monitoring results shall be able to reflect the characteristics of the monitored parts.

On-site inspection and testing is an important means to appraise the reliability of monitoring instruments installed in operation, and the on-site inspection and testing items and appraisal criteria are different for various monitoring instruments. On-site inspection mainly includes the appearance, identification, cables and conjunctions, working status, operating environment and observation conditions of monitoring facilities. In field test, the stability and accuracy of various instruments are tested according to their principles, embedding methods and possible conditions, for example, the stability of measured data is appraised by several consecutive measurements under the identical ambient conditions, and the accuracy is verified by comparing and analyzing measured data of manual readout with those collected by automation system or other manually measured data.

Historical measured data appraisal is an effective method to assess the reliability of monitoring instruments by using historical monitoring data, which is usually based on process line analysis. It can analyze the hydrograph of data change in conjunction with correlation diagram, spatial distribution diagram, characteristic value analysis and other methods to assess the reliability of monitoring facilities. Through the process line analysis, the hydrograph of deformation, seepage (uplift) pressure, seepage flow, stress, strain, temperature, water level and other physical quantities changing with time and the correlation between them and corresponding environmental quantities, such as periodicity, tendency, change type, development rate, variation amplitude, change range, and characteristic value, etc. can be judged. When the measured data of any engineering physical indicator does not conform to the regular change tendency, it indicates that the measured data may be abnormal. When the monitored physical quantity data are abnormal, the instrument frequency, resistance, voltage, current, resistance ratio, capacitance ratio and other measured data can be analyzed to find out the abnormal cause.

3. MONITORING FACILITY COMPLETENESS APPRAISAL

Monitoring facility completeness refers to whether the basically reliable monitoring facilities can meet the need to monitor the present and future safety of dams. It is necessary to consider both the comprehensiveness of monitoring items and the reasonable distribution of measuring points. Monitoring item rationality appraisal is based on monitoring facilities certified as reliable or basically reliable, to examine whether there are all-covering important monitoring items to monitor the key parameters for dam operation performance, whether the existing basically reliable measuring points in monitoring items can cover all monitoring scope of the project with their spatial distribution and can monitor key positions with due consideration of ordinary positions, whether the associated monitoring items match with each other, and whether appropriate redundancy is provided for measuring points of important monitoring items for key parameters of dam operation safety. The important monitoring items shall be complete without missing, the arrangement of important monitoring items and general monitoring items are reasonable, and then the monitoring facilities are complete. The monitoring facilities is not complete if any important monitoring item is missing, or the arrangement of important monitoring items is not reasonable, although there is no missing item.

The dam safety monitoring codes of China have stipulated the mandatory and optional safety monitoring items for different classes of dams, and the existing monitoring items of the monitoring system or their importance can be adjusted according to the actual situation of project operation and the concept of risk management (S.J. Wang et al. 2018) after the dam enters the operation stage. Due to changes in project operation environment and behavior, it may be necessary to add some important monitoring items, downgrade an important monitoring item to an ordinary one, or upgrade an ordinary item as an important one, for example, if phenomena such as harmful cracks, loss of stability or leakage occur in operation, they shall be taken as important items in operation safety monitoring. Considering the structural characteristics of various types of dams, it is stipulated that after adjustment, important monitoring items of earth-rock dams shall include at least the upstream water level, precipitation, surface deformation, seepage flow and seepage pressure; and important monitoring items for concrete dams shall include at least upstream water level, air temperature, surface deformation, seepage flow and uplift pressure.

4. APPRAISAL OF MONITORING FACILITY OPERATION AND MAINTENANCE

The operation and maintenance of monitoring facilities is an important measure to ensure the continuous and effective operation of monitoring system, and the appraisal on operation and maintenance shall cover aspects of operation management, observation and maintenance as well as monitoring data compilation and analysis.

Monitoring facility operation management appraisal shall include monitoring rules and regulations, professional monitoring personnel allocation and their post responsibility system. The appraisal of monitoring rules and regulations shall cover the completeness and rationality of tour inspection, observation contents, methods and requirements, data compilation, observation equipment management, maintenance and inspection regulations; the appraisal of the professional monitoring personnel staffing includes the number and capability of personnel and the allocation of various specialties; job responsibility system appraisal shall cover division of work and responsibilities for posts, professional quality of employees, work flow and examination objectives.

Monitoring facility observation and maintenance appraisal shall cover observation appraisal and maintenance appraisal. The content of observation appraisal includes observation frequency, observation accuracy, and observation traceability. The observation data should be traceable, that is, the observation data should be verifiable. The maintenance appraisal includes the effectiveness of maintenance measures, the timeliness of maintenance work and the completeness of spare parts for wearing parts.

The contents of monitoring data compilation appraisal include monitoring facility archives, monitoring data compilation and appraisal of preliminary analysis results. The appraisal of monitoring facility archives includes the completeness appraisal of monitoring data, tour inspection data, monitoring facility ex-works instructions and qualification certificate, data of installations, monitoring facility replacement, inspection and maintenance; the appraisal of monitoring data compilation includes reliability screening of monitoring data, conversion of electrically measured physical quantities, formula and method of engineering physical quantity, statistical table, process line and reliability and completeness appraisal of tour inspection data; the appraisal of preliminary analysis results of monitoring data includes the appraisal conclusions, the existing problems and the accuracy and rationality of the improvement suggestions.

5. APPRAISAL OF AUTOMATION SYSTEM

Automation system is an important component of dam safety monitoring. Automation system appraisal includes data acquisition device, computer and communication facilities, information acquisition and management software, operating conditions and operation maintenance.

The appraisal contents of data acquisition device include function, mean time between faults (MTBF), data acquisition loss rate and measurement accuracy. The emphasis is main functions, which are often used in the process of data acquisition device operation and ensure long term stable operation of data acquisition device, such as tour measurement, selected measurement, measurement at fixed time, communication, data storage, power-failure protection, lightning protection, and anti-interference, and system self-check, self-diagnosis, artificial measuring interface, anticorrosion are secondary functions; the appraisal contents of computer and communication facilities include running state, power failure protection, MTBF, etc.; the appraisal of information collection and management software includes functional completeness, functional correctness and operability; the appraisal of operating conditions shall include temperature and humidity, working power supply, lightning protection for power source and grounding network; and the contents of operation and maintenance appraisal shall include data backup, clock calibration, comparison test, spare parts, equipment inspection and maintenance, and so on.

6. CONCLUSIONS

- (1) Dam safety monitoring is an irreplaceable means to protect dam safety. Dam safety monitoring systems will become aged in operation, and the safety behavior of dams will change in the service period, so it is necessary to perform periodical appraisal of dam safety monitoring system, to ensure the sustained reliable and stable operation of the system and keep the dam safety under control.
- (2) Dam safety monitoring system appraisal covers the monitoring facility reliability and completeness, monitoring facility operation and maintenance and automation system. The monitoring facility reliability is the basis for dam safety monitoring system appraisal, and the monitoring facility completeness is to verify whether the safety monitoring items and measuring point arrangement can meet the need to monitor the present and future safety of dams. The operation and maintenance of monitoring facilities is an important measure to ensure the continuous and reliable operation of the dam safety monitoring system and plays a key role in the sustainable and reliable operation of monitoring facilities. Automation monitoring system is an important part of dam safety monitoring system, and is therefore included in the appraisal system.
- (3) Monitoring facility reliability appraisal is performed with three methods of monitoring facility installation data appraisal, on-site inspection and test and historical measured data appraisal; the appraisal on completeness of monitoring facilities is based on whether monitoring items and measuring points of monitoring facilities that are reliable or basically reliable as appraised can meet the requirements of dam safety monitoring requirements at

present and in the future; monitoring facility operation and maintenance appraisal includes operation management, observation and maintenance, and data compilation analysis; the appraisal of monitoring automation system includes data acquisition device, computer and communication facilities, information acquisition and management software, operation conditions and operation maintenance.

- (4) The comprehensive appraisal of monitoring systems is divided into three grades: normal, basically normal and abnormal. The system can be continually operated when all items of monitoring facility completeness, operation and maintenance and monitoring automation system (if provided) are appraised as qualified; when the monitoring facility completeness and monitoring automation system (if provided) is basically qualified and the monitoring system is appraised as basically normal, it can be operated continually but it should be repaired and improved promptly; those with unqualified monitoring facility completeness are appraised as abnormal and replacement and renovation shall be made promptly.

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