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Distributed Optical Fiber Intelligent Technology Risk Prediction Technology for Dam Structure Cracking

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Abstract. As an important facility for the safe operation of the reservoir, the dam is the key structure to ensure the normal operation of the reservoir. However, due to the influence of construction and environment, the dam is easy to appear hot and cold deformation, resulting in the cracking of the dam structure and other problems. Therefore, how to adopt effective methods to effectively monitor the dam structure deformation risk has become the main way to identify the dam structure safety. Optical fiber intelligent technology is an effective way to monitor the deformation of dam structure. The intelligent learning and fitting prediction of dam structure deformation and displacement can realize the risk prediction of dam structure deformation and cracking through intelligent methods. At the same time, combined with the conclusion of risk prediction, corresponding measures are formulated to ensure the safe operation of the dam. The results show that the distributed optical fiber technology can effectively obtain the deformation and displacement of the dam structure, and can be timely fed back to the monitoring and control center in real time. Meanwhile, artificial intelligence method (Gaussian process regression analysis) can be used to fit the deformation and displacement data collected. This method can effectively predict the structural deformation of levees and has strong feasibility.

Keywords. Hydraulic engineering, dam, distributed optical fiber, gaussian process learning, deformation

1. Introduction

As an important auxiliary large facility for safe operation of reservoir, dam is an important part of reservoir, and its daily operation, maintenance and management are of great significance [1]. Dam structure is usually dominated by concrete gravity dam, which is greatly affected by the external environment in the construction process [2]. Meanwhile, the maintenance and pouring form of the dam are also the main factors affecting the safety of the dam. During the construction of the dam structure, it is easy to appear the hydration thermal reaction, which leads to the cracking and damage of the internal and external structure of the dam, so the dam body is generally poured in sections. At the same time, the form of split joint is also the control method to reduce the adverse effect of thermal expansion and cold contraction deformation on the dam [3].

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As a method to monitor the safety deformation of dam structure, monitoring can effectively monitor the dam structure in real time [4][5]. In case of adverse deformation of the dam structure, the dam safety can be evaluated and predicted in time. At the same time, according to the safety of the dam, the construction workers can organize timely expert and safety meetings. The management can quickly customize the safety protection plan, effectively ensure the safe operation of the dam [6].

At present, a large number of scholars have studied dam deformation safety and monitoring. For example, Zhang Bin [7] et al. introduced the development history of dam safety monitoring automation system in China and the three key technologies of acquisition control, communication transmission and management system, and investigated the implementation of dam monitoring automation system in typical projects in China. The main parameters of acquisition control unit with high market share and the new technology and new method of automatic deformation monitoring system. Sun Futing [8] et al. studied the regularity intelligent recognition technology of dam safety monitoring data and proposed the data regularity recognition technology scheme by combining the characteristics of engineers' thinking and deep learning. On this basis, the regularity recognition model of dam safety monitoring data was established based on neural network. Huang Yuewen [9] et al. systematically summarized the research and application of intelligent perception and intelligent management technology in dam safety monitoring of Yangtze River Scientific Research Institute in recent years. By developing serialized intelligent sensors, intelligent acquisition units and iot sensing platform, they built a unified dam safety monitoring data resource pool and developed a universal safety monitoring cloud service system. The professional data mining platform and comprehensive visualization application have been built to realize the full link application of dam safety monitoring data perception, transmission, management, analysis and display, and form an intelligent solution for the whole life cycle of dam safety monitoring.

2. Project Overview

In order to meet the demand of water storage, a large reservoir needs to be built, and the dam is located on the southwest side of the reservoir. The rain bearing area of the reservoir above the dam site is 2200km^2. The dam is a large-scale water conservancy project that combines the functions of power generation, water supply, tourism and shipping. The water conservancy project consists of the main dam, the auxiliary dam, the first spillway, the second spillway, the East trunk canal water intake building, the West Trunk Canal No. 1 water intake building, the West Trunk Canal No. 2 water intake building, the power generation diversion tunnel and the power station building. Engineering class is I and major building class is 1.

Main and auxiliary dam concrete cutoff wall into a wall area of 13,100 square meters, the maximum wall depth of about 66.7m, wall thickness of 0.8m. The technical parameters of concrete cutoff wall are as follows: 28-day cube compressive strength $\geq$ 15MPa; Elastic modulus $\leq$15000MPa; Allowable penetration ratio (J) $\geq$80; Permeability coefficient is not greater than 1×10^{-7}cm/s. , the slot area of the slot segment with hole depth over 60m is 9450m^2, accounting for 72.1%. The cross-section of the dam is shown in Figure 1. According to the preliminary survey report:

- The main material composition of the clay core wall of the main and auxiliary DAMS is silty clay with gravel, and there are gravel and gravel clay in some parts. The core wall is thin and cracked;
- The impermeability, filling quality and filter size of the dam do not meet the requirements of Design Code for rolled earth-rock Dam (SL274-2020);
- The axis of the cutoff walls of the main and secondary DAMS has many steep bedrock faces, and the original cover plates at the bottom of some cutoff walls cannot be destroyed, so the geological conditions are extremely complicated.

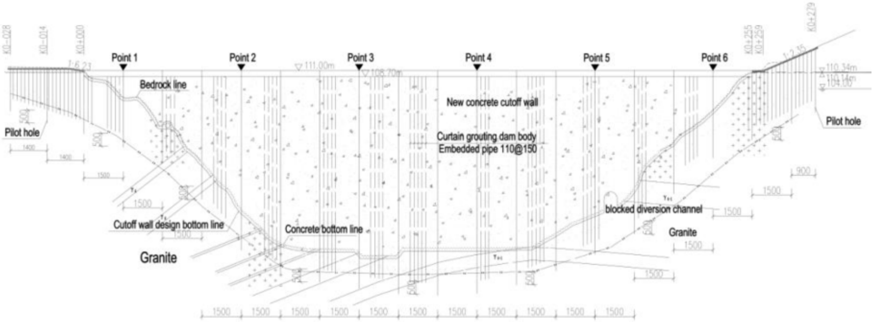


Figure 1. Dam Cross Section and Measuring Point Layout

3. Distributed Optical Fiber Technology and Monitoring

3.1. Distributed Optical Fiber Monitoring Technology

At present, the equipment commonly used for monitoring stress and deformation are steel string strain gauge, magnetic telescopic meter, strain cable, laser rangefinder and so on. Each device has different working principles, measuring accuracy and application range [10].

The steel string strain gauge is mainly used to measure the deformation of steel structure [11]. It is a point type measurement, which needs to be welded to the measured object. Magnetic telescopic instrument can continuously measure the deformation of the measured object, but the cost is very high, and the continuous measurement range is too large, the weight is very large, it is not easy to install and fix. Working according to the principle of light propagation, the strain cable has the characteristics of continuous long distance measurement, high precision, light weight and good stability.

It is intended to use environmentally friendly epoxy AB adhesive to fix the strain cable on the dam structure, and use the fiber optic strain monitoring system to monitor the dam deformation.

According to the characteristics of dam structure, it is necessary to measure the strain of dam deformation joint. The monitoring method is proposed to lay a optical cable circuit at the top of the dam and at the dam corner of the dam downstream, and one optical fiber is also used as temperature compensation. The proposed cable laying method is shown in Figure 2. The strain cable laying mode can be adjusted according to the actual situation.

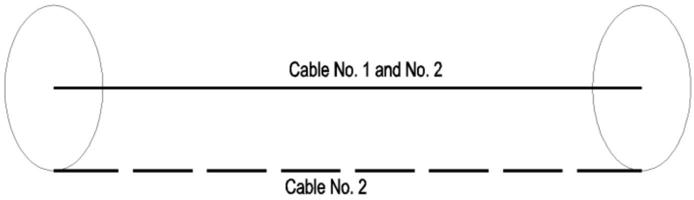


Figure 2. Strain Cable

- Put point: After the operators enter, the cable laying endpoint is released by measuring rope, and then the cable laying position is marked from the endpoint to the outlet according to the scheme;
- Lay: In order to prevent optical fiber aging off, along the cable laying position line will cable stick to the surface of the dam, and then the cable according to 1m straightening tension, with epoxy resin adhesive paste the surface.

The optical fiber strain monitoring system is used to collect optical fiber strain data. The system consists of optical fiber strain measuring host, strain optical cable, information processing and analysis system. The fiber optic cable is connected to the distributed fiber strain measuring host and the strain generated by the fiber laid along the structure can be monitored online. The optical fiber strain measuring host will demodulate the transmitted optical signal directly, and upload the demodulated data to the information processing and analysis system of the branch control center. The information processing and analysis system is composed of information processing and display software and server, which can realize the receiving, processing and display of optical fiber strain data and the management of optical fiber strain measuring host.

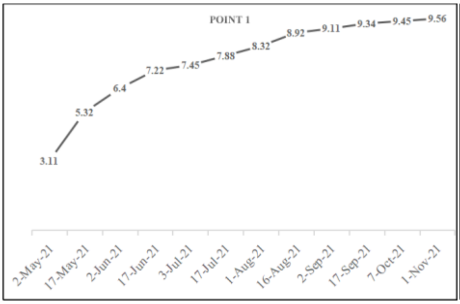
Brillouin frequency shift has a linear relationship with temperature and strain, satisfying the formula (1):

$$V_{Bs} = V_{B0} + C_T\left(T - T_0\right) + C_\varepsilon\left(\varepsilon - \varepsilon_0\right) \tag{1}$$

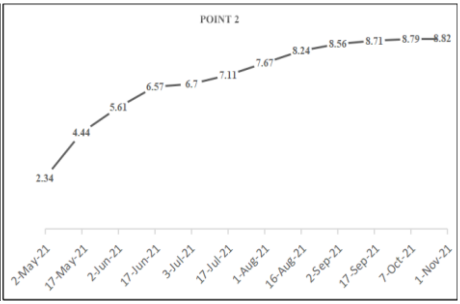
C_T And $C\varepsilon$ are respectively represent Brillouin temperature coefficient and Brillouin strain coefficient; ε is the measured strain; T is the measured temperature; T_0 and ε_0 are the reference initial temperature and strain of Brillouin frequency shift in the corresponding initial state. V_{B0} is the frequency shift in the initial state, V_{BS} is the frequency shift measured. By recording V_{BS} and temperature T, the deformation value ε of each measuring point at different time periods can be calculated.

3.2. Deformation and Displacement Monitoring of DAMS

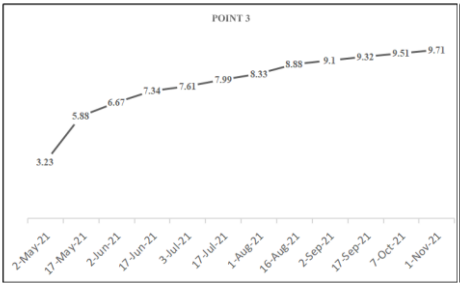
Dam crack deformation mainly occurs at the joint of the dam body. This monitoring is conducted for several typical deformation points at the joint, and the results of several groups of deformation values are shown in Table 1. The deformation occurred at the top of the dam, with a total length of 25.5 meters and monitoring points spaced 6 meters apart. The construction of the dam was completed on April 1, 2021. And when it's done. The water injection of the reservoir was carried out on April 28, 2021. The displacement of each measuring point was shown in Figure 3.



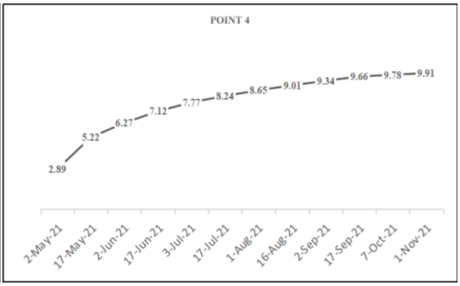
a) Point 1



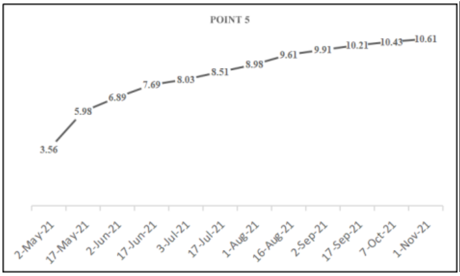
b) Point 2



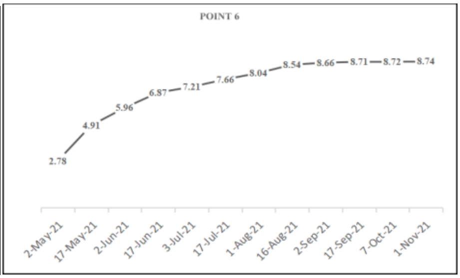
c) Point 1



d) Point 2



c) Point 5



d) Point 6

Figure 3. Each Measuring Point Monitoring Data

The deformation of a newly built dam after the waterflooding condition is a long-term developing process due to the influence of the bearing capacity of foundation, the lateral stress of water and the thermal reaction of concrete. The deformation process of the dam shows that the deformation rate is large in the early stage and converges continuously in the later stage. After January 2022, the deformation tends to be basically stable. Therefore, how to effectively monitor the safety of the dam in the deformation development period is the main factor to determine the safety of the dam operation.

4. Intelligent Deformation Prediction Technique of Gaussian Process

As a random process [12], Gaussian process is a machine learning method derived from Bayesian learning theory and belongs to a statistical science. The specific process is reflected in the learning of an arbitrary set of sets (the set is represented as a distribution form, called Gaussian distribution), and then the prediction of the extended part of the set. That is, for a group of random variables X and its corresponding function value Y at time t, they obey certain rules in the joint probability of n-dimensional space, which is called Gaussian process regression. Gaussian process regression has certain characteristics in statistics, specifically manifested as mean value $\overline{X}$ and covariance function $\varepsilon(t,\ t')$, which is defined as formula (2):

$$f(t) \sim GP[\overline{X}, \varepsilon(t,\ t')] \tag{2}$$

After fitting and obtaining a certain Gaussian regression model, the learning tool substituted new X^* samples and calculated through GP regression model to obtain the corresponding output value y*.

The standard linear adoption deviation of Gaussian process regression model is as follows:

ε-Gaussian random variable has a mean of 0 and a variance of σ_n^2.

The Gaussian process regression model is used to predict the displacement of concrete deformation, which mainly monitors the deformation size of the joint. Several groups of deformation values are predicted, and the results are shown in Table 1. Construction of the dam will be completed on April 1, 2021, after which the reservoir will be filled with water.

Table 1. Monitor deformation and forecast data

TIME	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6
May 2, 2021	3.11	2.34	3.23	2.89	3.56	2.78
May 17, 2021	5.32	4.44	5.88	5.22	5.98	4.91
June 2, 2021	6.4	5.61	6.67	6.27	6.89	5.96
June 17, 2021	7.22	6.57	7.34	7.12	7.69	6.87
July 3, 2021	7.45	6.70	7.61	7.77	8.03	7.21
July 17, 2021	7.88	7.11	7.99	8.24	8.51	7.66
August 1, 2021	8.32	7.67	8.33	8.65	8.98	8.04
August 16, 2021	8.92	8.24	8.88	9.01	9.61	8.54
September 2, 2021	9.11	8.56	9.10	9.34	9.91	8.66
September 17, 2021	9.34	8.71	9.32	9.66	10.21	8.71
October 7, 2021	9.45	8.79	9.51	9.78	10.43	8.72
November 1, 2021	9.56	8.82	9.71	9.91	10.61	8.74
December 16, 2021 (Forecast)	9.65	8.91	9.8	10	10.72	8.77
January 2, 2022 (Forecast)	9.69	8.96	9.84	10.04	10.78	8.81
January 2, 2022 （measured）	9.76	9.03	9.91	10.13	10.76	8.73
Relative Error	99.28 %	99.22 %	99.29 %	99.11 %	99.81 %	99.09 %

The displacement of monitoring points was studied by Gaussian process regression fitting. The independent variable was taken as its time function, and the function value was taken as the deformation displacement to predict the deformation displacement on January 2, 2022. By comparing the predicted displacement with the monitored displacement, it is found that the deformation values are close to each other, which can be used as the main method to evaluate and predict the dam deformation.

5. Conclusion

The safe operation of DAMS is the main key node of reservoir operation. How to effectively monitor the deformation and cracking of DAMS has become the main safety control method. At the same time, risk prediction based on deformation data is the key technology of dam risk assessment. Through engineering analysis, the following conclusions are drawn:

- As a multi-node, high precision, long time, safe and reliable method, distributed optical fiber can effectively monitor the deformation of dam structure and timely feedback the deformation and displacement information.
- The Gaussian process regression model can effectively predict the development trend of deformation and displacement over time with high accuracy, and can effectively predict the safety deformation risk of structure.
- This method is an intelligent automatic monitoring method for dam structure safety, which can be used for dam construction, affect the safe use of dam structure, and realize dam health monitoring in operation. Avoid major damage caused by improper dam management.

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