A Measured-Data Processing Method Based on MATLAB wavelet for distributed optical fiber sensing system

A.H. Chen, H.Y. Zeng*, G.L. Jiang, P.Y. Zhu
Hunan provincial Key Laboratory of Health Maintenance for Mechanical Equipment, Hunan University of Science and Technology, Xiangtan China 411201

ABSTRACT

The development of the hidden hazard in earth and rockfill dams is a long-term process, but the symptom of its occurrence can be extracted from monitoring measured-data. However, severe disaster may happen since the cryptic proof in these measured-data was ignored. A method of data processing to identify the seepage degree is proposed. Distributed optical fiber sensing system is employed to monitor the change of the temperature caused by the seepage flow inside the dam. Due to tiny difference between two temperatures of the earth and stable seepage water, measured-data need to be processed further to identify unconspicuous seepage flow. MATLAB wavelet method is used to analyze these tiny changes hidden in measured-data, which is effective to tell the location and degree of the seepage.

Keywords: Measured-data, MATLAB wavelet, distributed optical fiber sensing, monitoring system

1. INTRODUCTION

Many dams have been built in China, and they are playing important roles in national economy. The condition of the dam whether it is safe or dangerous relates to the safety of the life and property of people who reside nearby these dam. The catastrophic consequence may happen when the dam burst. The running condition monitoring for the earth and rockfill dams is therefore quite important due to their special constructions. The possible project safety issues may appear caused by overtopping, seepage, piping, crack, landslide, scour and so on, which are generalized as abnormal change the temperature and deformation in the dam[1-2].

The development process of the hidden hazard in the earth and rochfill dams is a long-term behavior. And any failure of the dam usually has some symptom. Therefor, it is possible to monitor and make early warning for these hidden hazards. A monitoring system, which is based on distributed optical fiber sensing technology, is employed to monitor the change of the temperature and the strain in the earth and rockfill dams where the optical fiber sensors are installed in different tested sections [3-4]. Although the measured-data may have the information about hidden hazard happened in the dam, its details, such as the degree and the location of seepage or deformation are not clear owing to the noise and the amplitude of the signal. It is the key to identify the symptom, estimate the degree and decide the location of the hidden hazard from measured-data. The weak symptom, which may be ignored in normal data processing due to the tiny difference between two temperatures of the earth and the stable seepage flow, indicates the true condition with existed dangerous hazard in the dam. A method based on MATLAB wavelet to effectively identify and extract the symptom from measured-data is proposed. It is helpful to make early warnings timely and take effective measures to prevent severe disaster from happening.

2. PRINCIPLE OF ANALYZING

2.1 Pearson's correlation coefficient method

Person's correlation coefficient r_{xy} is a kind of coefficient to represent the relativity between two sampled continuous variables [5]. Assume that two variables X and Y as continuous variables, such as the age, the stature and the earning etc, measured by Pearson product-moment correlation, have values between -1 and +1. Variables X and Y are uncorrelated while the correlation coefficient is 0, and variables X and Y positive correlation with a value between 0.00 and 1.00 while X increasing with Y, and the variables X and Y positive correlation with a value between 0.00 and 1.00 while X decrease with Y, and the variables X and Y negative correlation with a value between 0.00 and -1.00 while X increase with Y decrease, and variables X and Y negative correlation with a value between 0.00 and -1.00 while X

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decrease with Y increase. The greater the absolute value of the correlation coefficient, the better the correlativity is. So correlation degree is better while correlation coefficient approach 1 or -1, and is worse while approach 0.

Correlation coefficient is 0, just means that there is no linear interrelation between X and Y but X independent of Y. When X or Y keep stable, the correlation coefficient will be 0.

The formula for calculating correlation coefficient is given as:

$$\mathrm{r_{xy}} = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sqrt{n\sum_{i=1}^{n} x_i^{\ 2} - \left(\sum_{i=1}^{n} x_i\right)^2}\sqrt{n\sum_{i=1}^{n} y_i^{\ 2} - \left(\sum_{i=1}^{n} y_i\right)^2}} \qquad (1)$$

When $x_i = y_i$, $r_{xy} = 1$, the equation (1) shows that the variables X and Y are completely correlated.

Further more, the value of the correlation coefficient r_{xy} tells the degree of interrelation, between two variables and two time series of one variable at two different moments. The correlation coefficient $r_{xy} = 1$ means that the two signals completely similar or one single keeps invariant. Therefore, the correlation coefficient between two signals, which came from one monitoring variable during different monitoring times, shows the change degree of monitoring variable. Also, the correlation coefficient between real-time signal and standard signal of monitoring variables shows the degree about real-time signal deflects from the standard signal.

The degree of real-time sampled signal holistic deflecting from the standard signal can be obtained by calculating the correlation coefficient. However, the information of the location where the deflection starts is unknown, which is important for analyzing [6-7].It will arose some problems to process the signal from the monitoring system based on distributed optical fiber sensing using the method mentioned above.

Generally speaking, for the security monitoring of dams, we take time series under stable running condition as the standard signal X, if no seepage occurs, the value of X become fixed. So, by calculating the correlation coefficient of X and Y of the segment, the value of the correlation coefficient will be 0, which it is not helpful to identify the symptom of hidden hazard in dams.

2.2 Improved correlation coefficient method based on MATLAB wavelet

The function of xcorr can be employed to calculate the correlation coefficient of two signals in MATLAB toolbox. The data from the monitoring system based on distribute optical fiber sensing continuously change with time. After pre-process of denoising and eliminating error for the data, some new series are for further calculation by interpolating appropriately in the series [8]. The signal measured under the standard condition is defined as standard signal $x(t)$, and the others are defined as common signal $y(t)$. The correlation coefficient between $x(t)$ and $y(t)$ can be calculated by using the improved correlation coefficient method based on MATLAB wavelet. Idiographic process is explained as follows:

First, for the signal series $x(t)$ and $y(t_j)$, taking n as a fixed value to calculate the correlation coefficient between $x_{i+n}(t)$ and $y_{i+n}(t)$ by using the formula 1, and then the degree of signal $y(t_j)$ deflecting from the standard signal $x(t)$ at point $i+\frac{n}{2}$ can be got. Here, j is time series , n is step length, and j =1,2,3…, i =0,1,2…., n=1,2,3….

Second, suppose $i=i+1$ and $n=n+1$, repeat the step one until finish all the segments of the signals.

Third, for all possible j, repeat the above two steps until the signal X with all signal y_j are calculated, the information therefore, signal Y deflecting from the standard signal at each time point are obtained.

By calculating the correlation coefficient, while X or Y keep stable, the data at that segment should be increased to $\frac{k\sigma}{n+1}$ one by one, k=1, 2… n, where σ is temperature resolution. That can help to get the accurate relationship of X and Y.

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3. EXPERIMENT AND ANALYSIS

The system based on distributed optical fiber sensing is used to monitor the running situation of the earth and rockfill dams, which can continuously measure the internal temperature along the optical fiber for estimating the degree of the security of dams. A simulating kit is designed to simulate seepage flow of dams for symptom extraction in short time. It consists of flow control valve, flow meter, buffer zones and seepage model [9], the experimental simulator is shown in Fig.1.

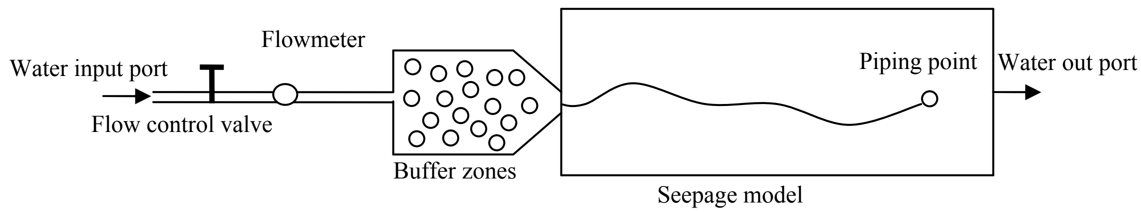


Fig. 1. Simulator device

The optic fiber sensors with location marked are installed in the seepage model. The temperature data of the monitoring system is acquired automatically by the special software and stored in one-dimension array. The configuration of the optical fiber sensors are shown in Fig.2.

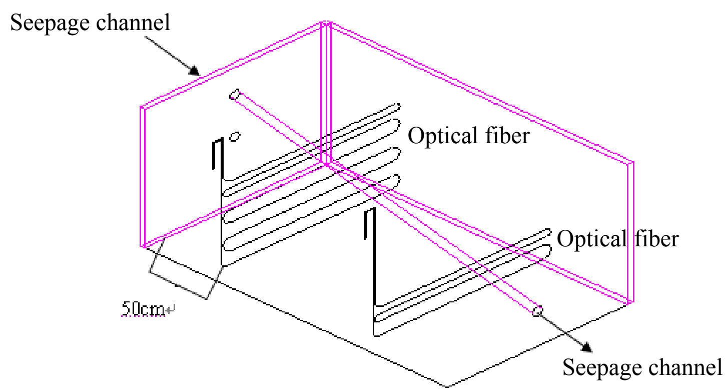
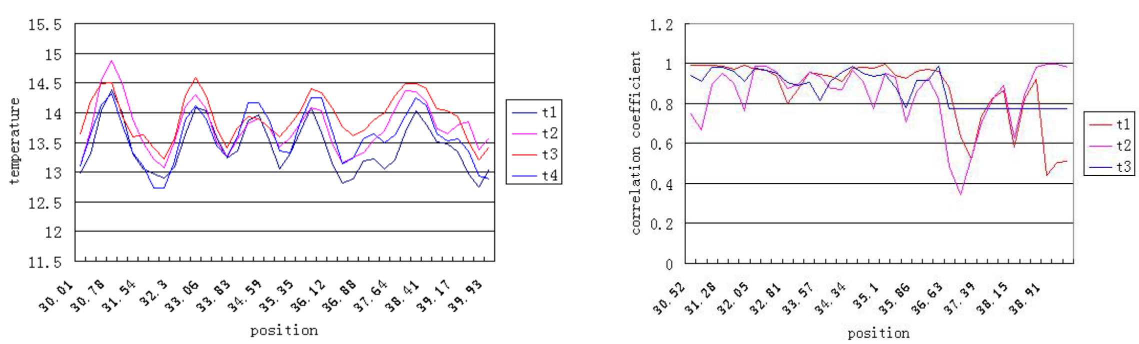


Fig. 2. Arrangement of optic fiber in seepage model

In Fig.2, the arrowhead denotes the direction of the seepage channel. In this experiment, the surface temperature of the earth is 12.0℃, the temperature of the atmosphere is 12.5℃, the temperature of the water source is 14℃. The sampling time is 7 minutes. A segment from 30m to 40m was selected to analyze as an example since this segment is near the water outlet port with visible happened seepage. The serieses at four different times on this segment are used to analyze, shown in Fig.3 (a).



(a) Results before processing

(b) Results after processing with improved method

Fig. 3. Result of monitoring

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In Fig.3 (a), the curves show that the seepage may occur at the segments with 30m and 32.3m and the segment from 36.9m to 38.1m with small temperature difference of 2℃ between the earth and the water source. However, it is difficult to judge the degree of the seepage.

Suppose the series sampling at earlier time as X and others as Y , n=5, after pre-process of denoising, eliminating error, the correlation coefficient between two series can be calculated by the improved correlation coefficient method based on MATLAB wavelet. The processed signal is shown in Fig.3 (b).

In Fig.3 (b), it is clear that the degree of signals at 30.1m and 36.6m to 40.0m greatly deflected from the standard signal, it is to say that the seepage with some degree surely happened at this place. On the top of the simulator, the leakage subsidence within an area with the diameter of 0.6m is observed around the position of 40m along the optical fiber.

4. CONCLUSION

Some measured temperature data from the disturbed optical fiber sensing system are analyzed with proposed the improved correlation coefficient method based on MATLAB wavelet. The degree of the seepage is effectively identified for the simulated seepage in a dam simulator. It is helpful to quickly know the location and the degree of the seepage and make early warning timely. Together, the method provides a tool for telling the trend of the failure with similar data.

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