Geologic Hazard Forecasting Model Application in a HPP Based on Prototype Monitoring

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Abstract. Based on geological hazard monitoring data at dam site of a HPP, slope and debris flow forecasting models of short term are studied practically. An advanced gray model is proposed for dangerous rock mass sloping disaster and tested with displacement monitoring data at high slope. A critical rainfall model and a storm intensity index are used to evaluate risk of single debris flow at dam site. The hazard forecasting conclusion might be generated by means of comprehensive analysis with the models and key monitoring indexes, so as to promote reliability and timeliness of the forecasting results.

1. Introduction

After large-scale reconstruction of the original topography in the construction process of hydropower projects, geological disasters or secondary disasters will inevitably occur in the construction area, which will bring certain risks to hydraulic structures such as dams and safety belts for the lives and property of local people's lives and property. In recent years, geological disasters such as collapse, landslide or debris flow have occurred in many large and medium-sized hydropower station construction areas, some of which have caused different levels of casualties and economic losses. Through post-disaster investigation, it is found that some geological disasters can be greatly reduced if monitoring is in place and early warning is timely before they occur. Therefore, based on the prototype monitoring data of hydropower projects, it is an important subject with practical guidance to study and establish a scientific and reliable geological disaster prediction model to provide practical technical support for disaster emergency early warning for engineering construction units.

There has been long-term practical experience at home and abroad in monitoring, early warning and prevention of geological disasters. In 1985, the US Geological Survey and the National Weather Service jointly established a landslide and debris flow early warning system in the San Francisco Bay area [1]. The system mainly makes judgments based on rainfall intensity, permeability of rock and soil mass, water content and meteorological changes, and the early warning results are broadcast through the Meteorological Center. Hong Kong, China, also established a landslide and debris flow meteorological early warning system as early as 1984 [2], mainly using rain gauges to carry out real-time rainfall monitoring and landslide early warning. In the study of geological disaster prediction models, scholars at home and abroad have proposed dozens of prediction models and methods for different types of disasters. For example, there are three types of prediction models for landslide disaster: deterministic model, statistical model and nonlinear model [3]. The statistical model mainly adopts mathematical processing and statistical methods to fit and analyze the slope deformation monitoring data, and the...
modeling process is relatively simple and practical. Deterministic models need to quantify various parameters, and then use mathematical and physical methods to carry out accurate analysis. Although its physical meaning is relatively clear, in practical applications the algorithm design is rather complicated, which is not convenient for software programming. Non-linear models generally need to prove their feasibility through landslide confirmatory prediction. Although they have certain advantages in theory, they have not yet been fully tested by engineering [4]. The prediction methods of debris flow disaster include macro precursor method, analogy analysis method, cause and effect method, statistical analysis method, etc., which can be selected according to the characteristics of local debris flow activities and monitoring data in practice.

From the actual situation of hydropower projects, geological disasters often occur under very bad weather and geological conditions, and some still occur during people's rest time. Under such a background, it is often difficult to effectively discover and grasp the abnormal changes and development trends of hidden dangers of disasters in real time, whether it is mass observation and mass preparedness or macro precursor inspection. Therefore, according to the geological disaster prevention goal of scientific prediction and timely warning, it is necessary to use prototype monitoring data to model and analyze the development status of landslide and debris flow geological disasters in pregnant disaster areas, which can be used as the evaluation basis for disaster prediction and emergency warning. Considering the site conditions of hydropower stations and the characteristics of potential hazards, it is necessary to select suitable prediction models according to different types of disasters. On this basis, a geological disaster monitoring and early warning system with all-weather, remote monitoring, automatic data processing and analysis, prediction and emergency management functions should be constructed to improve the monitoring level of geological disasters, enhance the early warning and forecasting effect and emergency response capability.

2. Predictive Model Algorithm Design

Based on the monitoring data of high slope dangerous rock deformation and debris flow gully duration rainfall, the landslide prediction model and debris flow prediction model are established respectively.

2.1 Improved Grey Model for Landslide Prediction

The grey system theory [5] put forward by professor Deng Julong in 1982 takes the uncertain system of "small sample and poor information" with "limited number of samples and amount of information" as the research object. Through mining and analyzing the known information, valuable information is extracted to realize correct understanding and effective control of the system operation behavior. In the concrete application of landslide disaster prediction, the slope of the disaster-prone body can be regarded as a grey system. According to the slope deformation duration data monitored on the spot, it can be processed into an increasing time series by appropriate mathematical methods, and then the optimal fitting function approximation can be sought, which can be used as a mathematical model to predict and analyze the landslide deformation.

Considering that GM (1,1) grey model may have large fitting errors when monitoring data are less and fluctuate greatly, log function is used to process the data sequence after equal interval to improve its smooth characteristics. The specific algorithm steps are designed as follows:

STEP 1: Input deformation monitoring data sequence

\[ x=x(t_i) \quad (i=1,2,\ldots,n) \]  

where \( x \) is the monitored deformation and \( t_i \) is the measurement time.

STEP 2: Perform isochronous processing on monitoring data

1) Calculate the average time interval \( \bar{t} \):

\[ \bar{t} = \frac{1}{n-1}(t_n - t_1) \]  

(2) Calculate the deformation value \( y(t) \) of equidistant interval points:
where, $\beta$ is the adjustment coefficient.

STEP 4: Calculate Pending Parameters $a$ and $b$:

$$\begin{bmatrix} a \\ b \end{bmatrix} = [B^T B]^{-1} B^T \cdot U$$  \hspace{1cm} (5)

where, $B = \begin{bmatrix} -z(2), 1 \\ -z(3), 1 \\ ... \\ -z(n), 1 \end{bmatrix}$, $U = [y(2), y(3), ..., y(n)]$

$$z(t) = \frac{y'(t)}{\ln y(t) - \ln y'(t-1)} + \frac{[y'(t-1)]^t}{[y'(t)]^{t-2} [y'(t-1) - y'(t)]}, \hspace{1cm} t= 2, 3, ..., n$$  \hspace{1cm} (7)

STEP 5: Calculate the fitting value of the model:

$$y(n + 1) = e^{y'(n + 1) - \beta}$$  \hspace{1cm} (8)

Among them,

$$y'(n + 1) = \frac{\sum_{i=1}^{n} y'(i) e^{-ai}}{\sum_{i=1}^{n} (1-e^{ai}) e^{-2ai}} \cdot e^{-a} \cdot (1-e^{a})$$  \hspace{1cm} (9)

2.2 Prediction Model of Debris Flow

In the practical application of debris flow prediction, the critical condition of rainfall-runoff is mainly determined. Since runoff is determined by rainfall, the critical value of rainfall is the focus of analysis and research. Prediction Model of Debris Flow is a combination of real-time monitoring rainfall and comprehensive analysis with the critical rainfall value of debris flow occurrence in the region to judge whether debris flow will occur, which is generally suitable for short-term and impending prediction. According to the different time scales, debris flow disaster prediction can be divided into two levels: short-term prediction and real-time prediction. On the one hand, after the rainfall monitoring stations are reasonably arranged, the rainfall thresholds of each station are analyzed and calculated to determine the critical rainfall range for triggering debris flow, and a real-time alarm will be issued once the rainfall reaches the critical rainfall. On the other hand, a critical rainfall criterion for debris flow activity and a disaster-hit rainfall criterion are established, and the occurrence probability of debris flow is judged according to rainfall monitoring data in a source region, and a short-term early warning is issued according to the situation. Short-term forecast refers to judging the possibility of debris flow occurrence in the region or ravine in the next few hours to days according to the historical rainfall process. It is mainly used to guide the disaster reduction and early warning of debris flow in small regions or ravines. A real-time forecast is an impending disaster warning based on on-line monitoring data to assess whether the current rainfall exceeds the monitoring index during the period. Its main purpose is to directly inform the personnel in danger areas in real time so as to evacuate and evacuate in time.

In the application of short-term prediction of debris flow in a single gully, the rainstorm intensity index $R$ of debris flow gully can be calculated according to the formula recommended in “the Code for Investigation of Debris Flow Disaster Prevention Engineering” (DZ/T 0220):

$$R = K(H_{24} + H_{1} + H_{1/6})$$  \hspace{1cm} (10)

Among them, $K$ is the correction factor of antecedent precipitation, $K=1$ when there is no antecedent rainfall and $K>1$ when there is antecedent rainfall. Temporarily take $K = 1.1 - 1.2$; $H_{24}$, $H_{1}$, $H_{1/6}$ ——$24$ h, $1$ h and $10$ min measured maximum rainfall, mm; $H_{24}$, $H_{1}$, $H_{1/6}$ ——critical rainfall amount of $24$h, $1$h and $10$ min, mm, at which debris flow may
occur in this area.

After obtaining the rainstorm intensity index, according to the statistical analysis results of a large number of debris flow disaster monitoring data, the following judgment criteria are adopted to evaluate the possibility of debris flow induced by rainfall in the future period of time:

1. $R < 3.1$, safe rain;
2. $R = 3.1$, rain conditions of possible debris flow;
3. rain conditions with $3.1 < R \leq 4.2$ and debris flow occurrence probability less than 0.2;
4. $4.2 < R \leq 10$, the probability of debris flow is $0.2 \sim 0.8$;
5. Rain with $R > 10$ and debris flow occurrence probability greater than 0.8.

Short-term prediction is mainly applicable to debris flow disaster prediction in the next few days. Its advantage is that it can provide more sufficient early warning time. However, due to the heavy rain intensity index $R$ depending on the accuracy of rainfall data and the reliability of various parameters of the model, certain false positives or false negatives may be caused. In order to make up for the shortage of short-term forecast, a critical rainfall warning criterion can be set at the same time, and the characteristic rainfall threshold value in the debris flow monitoring area is taken as a monitoring index. Once the real-time rainfall monitoring data in situ exceeds the threshold value, an early warning prompt of the corresponding level is triggered, and the early warning information is pushed to relevant personnel through a preset release channel.

3. An Application Example of a Hydropower Station

3.1 General Situation of the Project

The reservoir of a hydropower station has a total capacity of 7.4 billion cubic meters. The project is located in the southwest mountainous area. The river valley is deep, the current is fast, the river channel is narrow, and the geological environment is fragile. The interaction between construction activities and major geological disasters is especially prominent in the project hub area. After investigation, geological disasters developed in the construction area, and three large-scale dangerous rock masses, six landslides, eight collapsed accumulations and five debris flow gullies have been found.

After the construction of the hydropower station began, a large number of monitoring points have been built for each potential geological hazard point in the dam site area: rainfall, mud level, soil humidity, groundwater level and other monitoring have been set up in the debris flow gully on the left bank, and strain, displacement and ground motion monitoring of the high slope rock mass on the right bank of the plunge pool. All monitoring facilities have been fully automated and connected to the on-site geological disaster monitoring information management and early warning platform. Landslide and debris flow anomaly evaluation and trend prediction analysis are conducted through the platform's online monitoring and model base. On the platform (Fig.1), besides generating geological disaster meteorological early warning forecast according to meteorological forecast, landslide collapse prediction based on grey model, improved grey model and debris flow prediction based on critical rainfall model are also developed. Thus forming landslide, collapse and debris flow disaster prediction method library and early warning criterion set in different time scales.
3.2 Prediction of Landslide of High Slope on Right Bank of Water Cushion Pond

According to geological survey, there are many dangerous rock masses on the high slope on the right bank of the plunge pool. In order to monitor the displacement change of the dangerous rock masses, several sets of drawstring displacement meters are arranged in this area. When the dangerous rock block loosens or deforms, the displacement meter can measure its displacement variation in real time and transmit the measured data to the monitoring and early warning platform through the automation system. The improved grey model is used to fit the displacement monitoring data of rock mass, as shown in Figure 2 and Table 1. From the results of modeling analysis, it can be seen that the improved grey model has a good fitting effect for the monitoring data of short-term and small samples. The overall rule of the model process line is basically consistent with the measured value, and the relative error of the model fitting value at most times is within +/-10%. The model is further used to carry out extensive prediction calculation on the displacement from 18:00 to 20:00 on November 3, 2017. Through verification and comparison with the measured values, it is found that the relative error of the predicted values is also about 10%, which basically meets the accuracy requirement of deformation prediction of dangerous rock mass in the monitoring area and provides several hours of advance warning time for on-site emergency response.

![Fig.1 Geological hazard monitoring arrangement and pre-warning interface in a HPP](image)

![Fig.2 Measured displacement and simulating displacement with the advanced gray model course line of typical position at dangerous slope rockmass](image)

| Time               | Measuring Displacement (mm) | simulating values (mm) | Relative Error (%) |
|--------------------|-----------------------------|------------------------|--------------------|
| 2017/10/28 0:00    | 11.8                        | 11.8                   | -0.08%             |
| 2017/10/28 12:00   | 21.5                        | 23.6                   | -9.59%             |
| 2017/10/29 0:00    | 11.8                        | 11.9                   | -1.22%             |
| 2017/10/29 12:00   | 18.6                        | 21.2                   | -13.96%            |
3.3 Debris Flow Forecast
Since the provenance is mainly a single gully rainstorm type debris flow, it is more appropriate to use a short-duration critical rainfall prediction model for prediction. It is generally believed that the rainfall before the debris flow activity is the effective rainfall causing the debris flow activity, and the rainfall after it can only increase the scale and duration of the activity. Therefore, real-time monitoring data are used to establish a critical rainfall criterion and a disaster rainfall criterion for debris flow activity, which are the relationships between short-term rainstorm (10min rainfall intensity, 1h rainfall intensity, 24h rainfall intensity) and previous rainfall. Then, the occurrence probability of debris flow is determined by comparing the rainfall monitoring data of the provenance.

According to the local measured data, a short period of heavy rainfall occurred on July 7, 2017. The accumulated rainfall on that day reached about 40mm and the rainfall intensity reached 23mm in 10min, which all exceeded the red warning index of critical rainfall designed in the region, as shown in Fig. 3. According to the calculation, the rainstorm intensity index \( r \) at this moment is 6.09, and the probability of debris flow is about 40%, which belongs to the alarm rain condition, as shown in Fig. 4. According to the calculation results of the critical rainfall index and rainstorm intensity index prediction model, the gully is at risk of debris flow on the same day or the next day, and the on-site monitoring platform sends out early warning information to relevant personnel in a timely manner through short messages and other means.

Note: The data marked with * are the predicted values of the model.

![Fig.3 Daily rainfall bar of debris flow in typical period](image_url)

| Date         | Time   | Rainfall (mm) | Rainfall (mm) | Change (%) |
|--------------|--------|---------------|---------------|------------|
| 2017/10/30   | 1:00   | 12.3          | 12.5          | -1.88%     |
| 2017/10/30   | 12:00  | 18.6          | 20.4          | -9.80%     |
| 2017/10/31   | 0:00   | 11.8          | 11.3          | 4.04%      |
| 2017/10/31   | 12:00  | 22.1          | 23.2          | -4.88%     |
| 2017/11/1    | 3:00   | 10.8          | 10.6          | 1.55%      |
| 2017/11/1    | 13:00  | 21.5          | 22.0          | -2.29%     |
| 2017/11/2    | 0:00   | 11.8          | 11.9          | -1.18%     |
| 2017/11/2    | 14:00  | 15.7          | 15.9          | -1.21%     |
| 2017/11/3    | 0:00   | 11.2          | 11.0          | 1.76%      |
| 2017/11/3    | 12:00  | 17.5          | 16.3          | 7.09%      |
| 2017/11/3    | 18:00  | 12.9          | 11.6*         | 9.81%      |
| 2017/11/3    | 19:00  | 11.8          | 10.5*         | 10.98%     |
| 2017/11/3    | 20:00  | 11.8          | 10.5*         | 10.79%     |
4. Conclusion

(1) The prediction models of landslide, collapse and debris flow disasters in short-term and impending period are practically studied, and the debris flow disaster prediction model based on critical rainfall and the improved grey prediction model of landslide disaster based on prototype monitoring of slope deformation are established. By taking rain data and displacement monitoring data as model inputs, the risk assessment of slope collapse and debris flow disasters is carried out according to the mathematical prediction and prediction model. Combined with the real-time monitoring index evaluation strategy, the geological disaster prediction conclusion can be comprehensively analyzed and generated, thus effectively improving the reliability and timeliness of early warning results.

(2) A real-time forecasting provides a shorter warning time and is suitable for imminent disaster forecasting, but its accuracy and reliability are higher than those of short-term forecasting. In practical application, the two early warning modes can be combined with each other. When the short-term forecasting model sends out early warning information, it can issue event notification to remind relevant personnel to make emergency preparations. If the real-time forecast also gives an early warning with the passage of time and the development of the rainfall process, the on-site personnel shall be immediately organized to carry out evacuation, emergency rescue and other work according to the alarm level and emergency plan.

(3) At present, landslide and debris flow prediction models and parameters have been established on the ground disaster monitoring platform. However, due to the short monitoring history, the modeling and prediction accuracy for debris flow and landslide geological disasters is limited. In the later stage, various parameters of the geological disaster prediction model can be verified and optimized in combination with various geological disaster monitoring data in the hub area and relevant dam safety monitoring results. At the same time, the applicability of other monitoring and early warning models in similar projects can be further studied in order to enrich and perfect the model base and method base.

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