

Analysis of Intelligent Monitoring and Early Warning in High Side Slope Areas

Wanqi Wang*

Postgraduate Department, China Academy of Railway Sciences Corporation Limited, Beijing,
100081, China

*Corresponding Author e-mail: wangwanqi@rails.cn

Abstract. As a large amount of excavation, filling and compaction are required during the construction of railroad projects, and slope cutting is also required in special terrain areas, which destroys the original geological environment balance of the soil, and under the influence of environmental and engineering factors, geological disasters such as landslides and collapses are easily induced. In this paper, a scientific method of slope stability discrimination is firstly proposed on the basis of monitoring and early warning. By combining two methods of engineering displacement monitoring and numerical simulation analysis for monitoring and early warning, it circumvents the problem of using a single method with poor accuracy and improves the efficiency of the early warning system. Compared with the traditional monitoring and early warning, this paper proposes the method of linkage early warning, which summarizes the factors that have a great influence on the stability of slope and obtains the corresponding prediction information in advance, and applies the data to the numerical simulation to obtain the stability change of slope, so that the early warning can be released in advance and the countermeasures can be taken to reduce the loss.

Keywords: High side slope; Stability; Intelligent monitoring; Early warning.

1. Introduction

For landslide safety monitoring and landslide geohazard prevention and early warning technologies during construction, scholars at home and abroad have continuously applied new technologies to propose new methods. Mingtao Jia et al [1] developed a slope displacement analysis system that can value the characteristic points of the slope surface, and analyzed the stability of the slope body through the displacement data; Tao et al [2-3] embedded the anchor cable of NPR material into the Newtonian force change monitoring and early warning system, and integrated the information release and interaction to realize the whole process of landslide monitoring; Jianyong Liu et al [4] designed a multi-sensor fusion landslide geohazard prediction early warning platform; Wang Di et al [5] designed a set of intelligent early warning system for slope monitoring using BDS high-precision differential positioning technology and traditional point stability analysis method and image movement discrimination technology; Wu Kai et al [6] developed remote monitoring software using GPRS to complete displacement data collection and analysis; Xie Mowen et al [7] developed a GIS system for landslide safety monitoring using ArcGIS ; Wu Zhenjun et al [8] also developed a landslide monitoring management and analysis system using GIS platform; Wang Jiajia et al [9] developed a landslide hazard prediction system based on Web-GIS technology, which is mainly used to assess landslide hazards.

The above scholars' researches covered the aspects of landslide monitoring data collection, network transmission, data analysis and data distribution, and achieved corresponding results, but linked early warning was rarely mentioned. The subsystems of linked warning are independent of each other due to surface displacement, microseismic, landslide dynamics, etc. Therefore, it is easy to form information silos, which causes problems such as difficulty in determining the comprehensive warning level. To address this situation, we need to solve the problem of integration and fusion analysis of multi-source monitoring data. The domestic research in this field is still in the initial stage. Most scholars focus on the study of slope monitoring using a single data source [10-12], and a few scholars predict the slope deformation trend [13-14]. To this end, in this paper, data from a multi-

source data chain monitoring system are used to fuse and analyze the monitoring data of the slopes along the railroad line of the Lake-Hangzhou line. The results show that the fusion analysis of multi-source information under the premise of better interconnection can better ensure the comprehensiveness of slope monitoring information and the accuracy of results.

2. Engineering Background

The area along the side slopes of the Ho-Hang railroad is located in the subtropical monsoon zone, with four distinct seasons, abundant rainfall, hot and humid climate in summer, cold and dry in winter, and pleasant weather in spring and autumn. The average annual temperature is 17.8°C, the average relative humidity is 70%, the annual precipitation is 1454mm, and the annual sunshine time is 1765h. The average monthly temperature and precipitation in Hangzhou are shown in Figure 1.

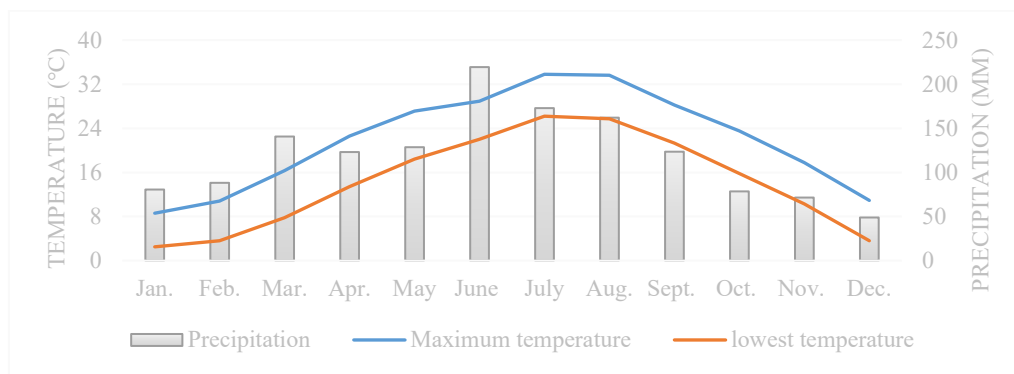


Figure 1. Monthly average temperature and precipitation from 2011 to 2020 (Hangzhou)

There are many slopes along the Lake - Hangzhou Railway, which also include several high slopes. DK124+898.02~DK125+188.06 Shunyi deep graben and DK127+698.18~DK127+788.53 deep graben roadbed, the relative height difference of the roadbed is 70~100m, the maximum center excavation depth is about 35m, the maximum slope height is about 44m high slope. The rock joints and fissures are developed, the lithology is more broken, and there is the risk of slope collapse.



Figure 2. High side slope

3. Determination of slope stability

For the assessment of slope stability, we adopt the method of multi-indicator quantification and weighting accumulation, which integrates the factors affecting slope stability, such as precipitation, earthquake, drainage, support, slope height, slope angle, etc., and quantifies these factors in a unified way and considers them comprehensively.

According to the slope engineering and relevant specifications, the stability warning of slope is divided into five grades, namely, extremely stable, stable, basically stable, unstable and extremely unstable [15]. Since the stability of slope is related to the engineering environment (rainfall and seismic intensity, etc.) and engineering measures (slope height, slope angle, drainage, support, etc.)

of slope, it is necessary to unify these judgment factors, and finally get the evaluation index by quantification and weighting accumulation respectively, and determine the slope status according to the evaluation index.

Table 1. Table of slope stability warning evaluation level

Evaluation Level	Evaluation Index
Extremely stable	1.0-0.8
Stable	0.8-0.6
Basically stable	0.6-0.4
Unstable	0.4-0.2
Extremely unstable	0.2-0

By reviewing the norms, engineering analogies, monitoring data analysis and some monitoring and warning thresholds proposed in the literature, the criteria for taking the slope warning indicators relative to the slope stability classification were listed [16]. The data are quantified uniformly by polarization, as shown in the following table. (The quantification for drainage and support conditions is converted into measurement data according to the actual situation)

Table 2. Uniform quantification table

Grading	Daily rainfall \mm	Monthly cumulative rainfall \mm	Maximum Seismic Intensity	Slope height \m	Slope angle \(\(^{\circ}\)
Extremely unstable	0	0	0	0	0
Unstable	0~0.5	0~0.43	0~0.125	0~0.2	0~0.25
Basically stable	0.5~0.75	0.43~0.64	0.125~0.375	0.2~0.45	0.25~0.5
Stable	0.75~0.9	0.64~0.8	0.375~0.625	0.45~0.3	0.5~0.67
Extremely stable	0.9~1	0~1	0.625~1	0.3~1	0.67~1
Graded		Drainage		Support	
Extremely Unstable		0		0	
Unstable		0.25		0.25	
Basic Stable		0.5		0.5	
Stable		0.75		0.75	
Extremely stable		1		1	

The hierarchical analysis method and the information entropy method were selected, and a combination of these two methods was used to calculate the early warning indicator weights (as shown in Table 3).

Table 3. Comprehensive weighting table

Indicators	Daily rainfall	Monthly cumulative rainfall	Maximum Seismic Intensity	Slope height	Slope angle	Drainage	Support
Weights	0.17	0.115	0.205	0.11	0.135	0.12	0.135

The evaluation index was calculated based on the data of each indicator and the weight ratio of each indicator, and the evaluation was performed according to the situation divided in Table 2.

$$A = \sum_{i=1}^n Y_i * X_i \tag{1}$$

Where A is the early warning index, Yi, Xi are the indicator data and indicator weights respectively

4. Weather linkage warning design

4.1 Influence of precipitation on slope stability

The stability of slopes is disturbed by many external factors, such as rainfall, which causes changes in the stability of slopes. In practice, slope instability in many areas is directly or indirectly caused by rainfall. From the relevant statistical data, most of the slope instability problems in China are related to rainfall, especially after heavy rainfall, a large number of landslides and crumbling slope instability can occur, and the losses are heavy. [17]

In order to study the relationship between precipitation and slope stability, a small slope model is made, and precipitation is simulated by sprinkling water, and the intensity of precipitation is controlled by the amount of sprinkling water for experimental research.

Experimental model: A model slope made of remodeled soil with known parameters, size 30cm*20cm, height 15cm. by conversion its contact surface is about 0.06 square meters, then not sprinkled with 60ml of water is equivalent to 1mm of precipitation.

Experimental procedure: Gradual increase in increments of 5 mm in the 0 - 100 mm rainfall interval.

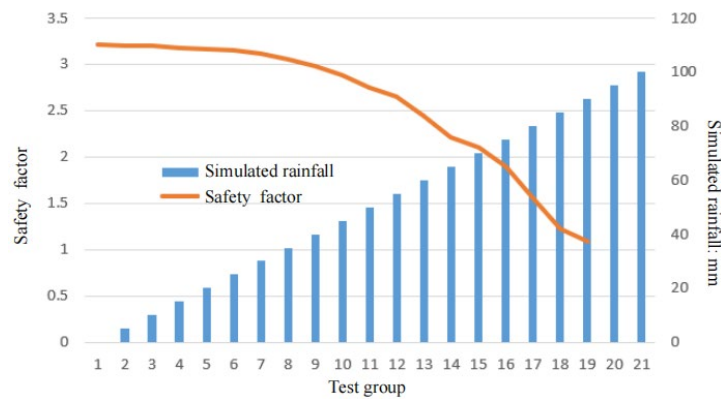


Figure 3. Simulated experimental K value variation graph

According to the experimental results, it can be seen that the stability of the slope is closely related to the precipitation. Therefore, in order to achieve a more accurate and timely monitoring system, weather linkage warning is developed.

4.2 Linkage warning design

Weather linkage warning, i.e. obtaining regional meteorological data from the official platform of China Meteorological Network, combined with the data information obtained from the system, predicts the stability of the slope in the future period.

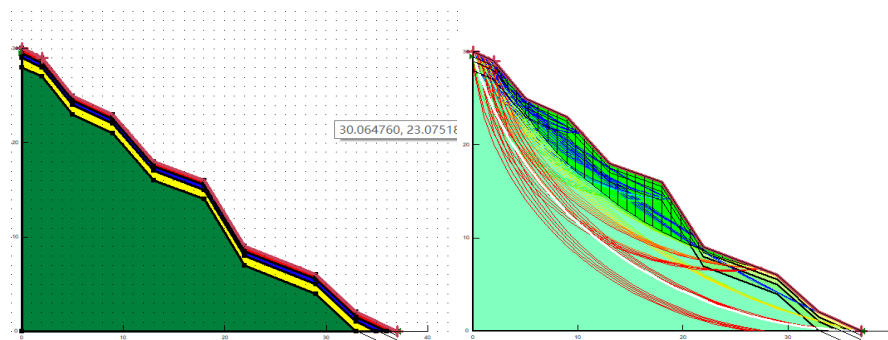


Figure 4. Slope section model and potential sliding surface analysis results

The prediction calculation of K value needs to calculate the c and ϕ values for a period of time in the future. Since the c and ϕ values vary greatly under different environments, the infiltration experiment combined with the historical data in the system monitoring data is used to obtain the

relationship between c and ϕ values and water content and the water content of different soil layers as a function of precipitation. According to the results obtained from the infiltration experiment, it is known that water infiltrates in the soil after precipitation and gradually infiltrates from the surface layer, and the water content of the soil varies at each depth, so the model can be divided into different areas according to the depth when building the model.

Table 4. Regional division table

Depth	Region Naming
0--0.5	a
0.5--1	b
1--2	c
2--h/2	d
h/2--h	e

Since the soil in area e is stable and almost not affected by external forces, it is considered in the study that its state absolute stability parameters will not change. Soil samples at different locations in five levels a, b, c, d and e were taken for research and measurement. The variation of water content of each soil layer was obtained as shown in Figure 6.

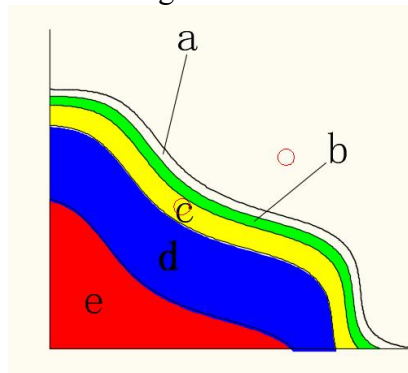


Figure 5. Schematic diagram of regional division

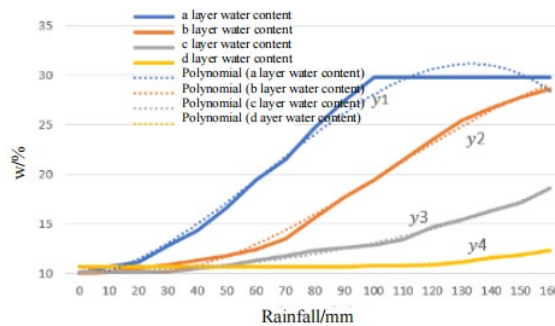


Figure 6. Variation of water content of each soil layer

The water content functions for each soil layer under different rainfall conditions were obtained as follows.

Table 5. Table of water content function

	Relationship formula
a layer water content function	$y_1 = -0.0162x^3 + 0.3588x^2 - 0.3107x + 9.6279$
b layer water content function	$y_2 = -0.0082x^3 + 0.2816x^2 - 1.4141x + 11.865$
c layer water content function	$y_3 = 0.0007x^3 + 0.0155x^2 + 0.0172x + 10.056$
d layer water content function	$y_4 = 0.0014x^3 - 0.0252x^2 + 0.1239x + 10.554$

Predicting the safety coefficient of slope through the model in slope\W module requires importing the c and ϕ values of slope soil, and using triaxial shear experiment to determine the cohesion and internal friction angle of soil. c and ϕ of slope soil are important factors to deduce the stability

coefficient k , and the water content, c and ϕ values are different under different external force conditions (mainly considering rainfall), so here the c and ϕ values of slope A and B are obtained through multiple tests in Therefore, the changes of c and ϕ values of slopes A and B under different water content conditions were obtained through several tests. The process is to use the obtained soil samples to configure 21 types of soil samples with water content ranging from 10% to 30% in the laboratory, three copies of each type, to conduct triaxial shear experiments to obtain the major and minor principal stresses, and to make Mohr circles and tangents to obtain the c and ϕ values under different water content conditions and take the average values. From the c and ϕ values, the stability coefficient K can be calculated by the software model, and the relationship between rainfall and stability coefficient K can be obtained by combining the above two corresponding relations, and then the influence of future weather conditions on slope stability can be predicted.

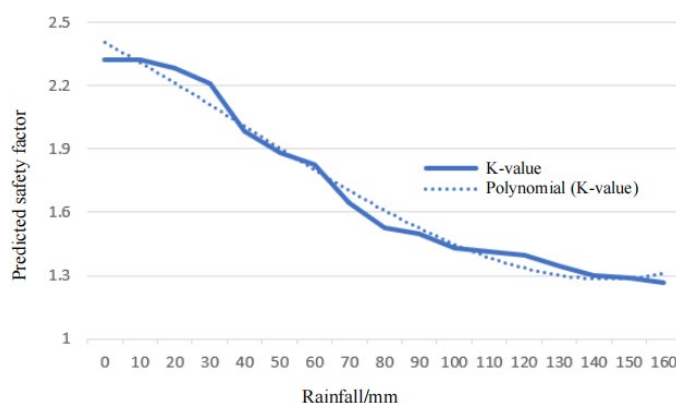


Figure 7. Safety factor prediction chart

From this, the future slope stability can be predicted based on the fitted equation $y = 0.00033 x^3 - 0.00497 x^2 - 0.07932 x + 2.48682$ combined with the obtained weather conditions.

5. Conclusions

This paper establishes a new type of slope monitoring and early warning system for the problems of low accuracy, large information lag, inaccurate judgment basis and single structure of monitoring system which cannot adapt to monitoring of large area. Some innovative methods and means of slope monitoring are proposed.

(1) Slope classification based on stability assessment

In this paper, we summarize various configuration conditions of the slope itself and the natural environment conditions in which the slope is located. We propose a screening method by combining the specification requirements and the opinions of experts in various literature, and obtain an evaluation data through data dimensionless processing and weight distribution, so as to classify the stability of the slope into five grades.

(2) Linkage warning measures

In order to create sufficient time for responding to accidents and to improve the time scale of warning, linkage warning measures are introduced. For example, we can add rainfall conditions to the slope model according to the weather forecast in geostudio software to get the stability change, and use it as the base data to release the warning information.

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