Research on the Early Warning Threshold of Slope Displacement Rate

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Abstract. Slope is affected by internal structure and external natural and human factors, and the evolution process is quite complicated, which makes it difficult to determine the early warning indicators of slope instability. In view of the complexity of slope deformation, this paper introduces similarity theory, collects and sorts out related engineering data and landslide data of slid slopes in the past, uses engineering analogy to propose a displacement rate warning threshold method, and verifies the effectiveness of this method with engineering examples.

1. Introduction
The slope early warning is based on detailed investigation and in-depth study of the geological and hydrological conditions of the slope, make reasonable judgments and various levels of alarms on the future development trend of slope stability. Slope deformation and failure are complex and changeable. In order to more clearly determine the time of occurrence of landslide, it is necessary to seek for a certain applicable landslide variable warning value, that is, landslide warning criterion value. Because of its simple, intuitive and easy-to-obtain advantages, landslide warning criteria have attracted more and more attention from researchers. At present, the pre-warning criteria are not universal. The criteria are numerous and complex, and there is no uniform classification standard. Therefore, there is no complete theoretical system for the classification research of early warning criteria. There are many studies on the displacement and displacement rate criteria based on the slope deformation mechanism. Because of its mature numerical monitoring methods and easy access to data, more and more attention has been paid to engineering practice.

2. Determination of slope warning threshold

2.1 Engineering analogy
The so-called engineering analogy method is the application of natural history analysis to recognize and understand the geological and hydrological conditions of existing engineering projects, and to compare them with the same or similar conditions of the engineering project to be studied, and to promote or promote some known information of existing projects. Apply to the unknown information of the proposed research project. Engineering analogy plays an important role in scientific research and is widely used. Geotechnical engineering systems are complex, including geological structure of rock and soil, groundwater conditions, lithological structure, evolution mechanism, construction and
excavation, and local hydrological and climatic conditions. This complexity leads to the fact that the simple rock and soil mechanics calculation method cannot meet the reality, and the results often vary greatly. Some geotechnical projects are also successfully designed by using engineering analogy.

2.2. Determining the weights of factors affecting slope failure

Comparing two or more projects with similarity requires a physical index to describe the degree of comprehensive similarity, which is called comparability in engineering. The factors affecting slope instability failure are subdivided into nine comparable factors such as slope angle, fault joint development degree, sliding failure mode, sliding surface depth, rock mass structure, basic rock mass, rainfall, groundwater and excavation and blasting. Each factor is divided into 5 levels according to their different attributes, corresponding to the magnitude of 1 to 5.9 main influence factors. Comparability calculation formula can be used:

$$K_{ij} = \sum_{k=1}^{9} A_k(i, j) w_k, \quad k = 1, 2, \ldots, 9$$  \hspace{1cm} (1)

Among them, $A_k(i, j)$ represents the combined similarity of the i slope and the j slope with respect to the k factor. Obviously, the more similar the magnitude of the K factor between the two slopes, the greater the similarity, and the greater $A_k(i, j)$. $i_k$ and $j_k$ represent $i, j$. The value of slope with respect to the k factor, then $A_k(i, j)$ is calculated as:

$$A_k(i, j) = \frac{\min(i_k, j_k)}{\max(i_k, j_k)}$$  \hspace{1cm} (2)

$W_k$ represents the degree of influence of the k factor on the instability and damage of the slope, that is, the comparable weight of the k factor, which has the following relationship

$$\sum_{k=1}^{9} w_k = 1$$  \hspace{1cm} (3)

The value of each element represents the weight value of the corresponding factor. The judgment matrix is determined by the analytic hierarchy process, and the square root method is used for approximate calculation. After normalization, we get:

$$\bar{W} = (0.073 \ 0.079 \ 0.292 \ 0.133 \ 0.054 \ 0.045 \ 0.135 \ 0.159 \ 0.031)$$

The weight values of similar influencing factors of the slope are shown in Table 1.

| Element                  | Slope angle | Development degree of fault joint | Sliding failure mode | Groundwater | Rainfall |
|-------------------------|-------------|-----------------------------------|----------------------|-------------|----------|
| $w_i$                   | 7.3%        | 7.9%                              | 29.2%                | 15.9%       | 13.5%    |
| Element                 | Basic quality of rock mass | Rock structure                  | Sliding surface depth | Excavation blasting |
| $w_i$                   | 4.5%        | 5.4%                              | 13.3%                | 3.1%        |

2.3. Calculation of landslide comparability

Analyze the topography and geomorphology, geological structure, stratum lithology, hydrological conditions, engineering construction and other data of 14 typical landslides, and comprehensively judge the level of the comparable degree of influence factors of typical landslides, which is similar to determining the magnitude of typical landslide influence factors. The magnitude matrix of the comparability factor of the new slope $i = [i_1, i_2, \ldots, i_9, i_{10}, i_{11}, i_{12}, i_{13}, i_{14}]$, Calculate the comparability $K_{ij}(1 \leq j \leq 14)$ between the new slope $i$ and each typical landslide, find the $j$ corresponding to the smallest $K_{ij}$, and the slope $j$ is the most similar slope of the new slope.
3. Example analysis of slope warning threshold

3.1. Slope comparability analysis
Through the analysis of the geological structure conditions, stratum lithology and hydrological data of a certain expressway section, the grade values of 9 comparable factors that affect the stability of the slope are determined.

3.2. Determination of slope warning value
The factor levels of the study slope and the typical landslide have been determined. The combined similarity $A_{i,j} (i = 1,2,3,...,9)$ between the slope and 14 typical landslides is calculated, and the top 3 similarities are ranked.

| Typical similar slope                  | Comparability |
|----------------------------------------|---------------|
| Xieliupo landslide                      | 0.887         |
| Shale Mountain Landslide               | 0.853         |
| Baishi Township Landslide              | 0.844         |

The sliding speed of the Xieliupo landslide from 2002 to 2010 was 6-15mm/d; the slid body was obviously divided into upper and lower sections. Because the landslide was a large-scale landslide, it had slipped by nearly 45m on the whole, and no serious landslide had occurred. Disasters, but when the sliding speed of the slope is 6-15mm/d, many local slip damages have occurred on the slope. From this, it is determined that the displacement rate of the landslide at the constant velocity deformation stage entering the accelerated deformation stage is 6mm/d, and the displacement rate from the initial acceleration deformation stage to the intermediate acceleration deformation stage is 15mm/d. Using the landslide first-level safety reserve factor $k=1.25$, we get The displacement rate in the later stage of constant velocity deformation is 4.8mm/d. Based on the engineering analogy method, determine the landslide displacement rate early warning threshold and the corresponding level of the slope as shown in Table 3.

| Warning level | Displacement rate warning value |
|---------------|---------------------------------|
| Level 3       | 4.8mm/d                         |
| Level 2       | 6mm/d                           |
| Level 1       | 12mm/d                          |

3.3. Analysis of on-site monitoring results of slope
A fixed inclinometer is embedded on the fourth and second slope platforms to monitor the internal displacement of the slope. The specific monitoring results are as follows:

(1) The horizontal displacement of each measuring point on the fourth-level slope showed a gradual increase trend. Affected by rainfall, the horizontal displacement of the slope had abrupt changes around July 4, 2016, and the measuring points Z4K102, Z4K106, and Z4K112 had sudden changes in the airborne direction Displacement reaches 14mm, 13mm, 19mm, and the maximum deformation displacement in the airborne direction of each measuring point Z4K102, Z4K106, Z4K112 is about 23.7mm, 17.3mm, 32.2mm, and the maximum displacement and deformation rate is 10.2mm/d, 7.5mm/d, 12.8mm/d.

(2) The change trend of the deep displacement of the secondary platform is basically the same as that of the fourth-grade slope. The horizontal displacement of the slope occurred abruptly before and after July 8, 2016 under the influence of rainfall, and the abrupt displacement of the measuring points Z2K101, Z2K105, Z2K109 in the airborne direction reached 12mm , 14mm, 17mm, and the sudden change of horizontal displacement occurred around November 20, 2016, and the sudden displacement in the airborne direction was 3~5mm. The maximum deformation displacement of each measuring point Z2K101, Z2K105, and Z2K109 in the airborne direction is about 21.2m, 24.8mm, and 27.9mm,
respectively. The maximum displacement and deformation rates are 6.3mm/d, 7.6mm/d and 9.2mm/d respectively.

The slopes, slopes, and retaining walls all have different degrees of cracking. Combined with the monitoring data, the slope is mainly affected by rainfall. The strong weathered phyllite softens with water, and the shear strength decreases. In general, the slope in the state of sliding, the early warning value of the displacement change rate is basically consistent with the field monitoring data.

4. Conclusion

Nine factors that affect the similarity of landslides are selected, and each comparable degree factor is graded from 1 to 5 to quantify, and the influence weight of each factor is determined by the analytic hierarchy process. Based on the engineering analogy method, the displacement rate early warning method is proposed. For example, the field monitoring data measurement is basically consistent with the displacement change rate warning value based on similar theory.

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