Dynamic construction safety evaluation of weathered granite slope based on attribute identification theory

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Abstract: Given the characteristics of multiple factors and complex mechanisms affecting the safety of weathered granite slopes during construction, this paper puts forward the evaluation standard of the normal degree of the attribute of the slope safety monitoring unit based on the attribute recognition theory, and establishes the safety dynamic evaluation model of weathered granite slope construction based on safety monitoring. Based on the automatic safety monitoring data in the construction period of the slope, the dynamic safety assessment of the slope construction is realized, which lays a foundation for the safety risk control of the slope construction.

1. Introduction

The safety state of the highway slope changes continuously with time and space. The factors affecting the safety of the slope are numerous and complex. The system analysis method should be used to evaluate the safety status of the slope. Slope safety evaluation methods such as finite element analysis [1], numerical simulation evaluation method based on expert scoring [2], neural network inversion numerical simulation method [3, 4], extension theory and grey system theory for slope evaluation method [5], etc., does not consider the slope deformation, which is the most intuitive parameter reflecting the safety of the slope. There are different degrees of defects, and it is difficult to dynamically reflect the process of slope safety change.

2. Slope safety attribute identification method

In order to establish the connection between each metric and qualitative evaluation, based on the attribute set and attribute measurement space concept, the attribute recognition theory model based on attribute recognition criterion is established [6] to dynamically evaluate the weathered granite slope construction safety. In the slope safety monitoring, a variety of deformation monitoring techniques are used [7] to monitor the slope deformation. The attribute identification method from the perspective of weathered granite slope safety is adopted.

2.1 Slope safety attribute measurement space

Suppose that the set of all research objects x_i that affect slope security is X, and the corresponding attribute set is F, then X is called object space, and F is attribute space. If an element in X satisfies $x_i \in C$, it means that it has a C attribute, and the available value indicates the degree of having attribute C, and its value range is defined in the 0-1 interval. Let $C_1, C_2 \cdots C_k$ be relatively independent attribute sets in attribute space F. If $F = C_1 \cup C_2 \cup \cdots \cup C_k$ is satisfied, then $(C_1, C_2 \cdots C_k)$ is the partition of attribute space F, and if C_1 is satisfied, $C_1 > C_2 > \cdots > C_k$ or $C_1 < C_2 < \cdots < C_k$ is called $(C_1, C_2 \cdots C_k)$ as an ordered segmentation of the attribute space F [6, 8].

The safety state of the slope and the normal state of the slope monitoring unit are respectively defined as the attribute measurement space, and are classified into four types of attribute sets according to different states: normal C_1, basic normal C_2, mild abnormal C_3, and severe abnormal C_4.

2.2 Attribute identification criteria

The attribute measure of a measured value x_{ij} in the slope safety evaluation object space X is, abbreviated as $u_{ij}(c_j)$ ($i = 1, 2, \cdots n$, $j = 1, 2, \cdots k$); there is an attribute index in the object space l_i ($i = 1, 2, \cdots n$), which consists of measured values $x_{i1}, x_{i2}, \cdots, x_{ik}$, so there are attribute measures u_{ij} ($j = 1, 2, \cdots k$) in the attribute index, and the comprehensive attribute measure $u_{ij}(C)$ is calculated by the formula (1), abbreviated as u_i [6, 8].

$$\mu_i = \mu_{xi}(C) = \sum_{j=1}^{k} (W_j \times u_{ij}) \quad (1)$$

where w_j is the attribute index weight coefficient.

The slope security attribute set is divided into four categories (C_1, C_2, C_3, C_4), and the slope safety is dynamically evaluated using confidence criteria and indicator scoring criteria.

(1) Confidence criteria for slope safety assessment

Assuming that ($C_1, C_2 \cdots C_k$) is an ordered segmentation class in the slope safety attribute space F and γ is the set confidence, then the indicator attribute set is:

if $C_1 > C_2 > \cdots > C_k$

$$S_0 = \min\left\{ s : \sum_{j=1}^{s} \mu_{xi}(C_j) \geq \gamma, 1 \leq s \leq k \right\} \quad (2)$$

if $C_1 < C_2 < \cdots < C_k$

$$S_0 = \max\left\{ s : \sum_{j=1}^{s} \mu_{xi}(C_j) \geq \gamma, 1 \leq s \leq k \right\} \quad (3)$$

It can be seen from the above that l_i belongs to C_{s0}. The value of confidence γ is generally $0.5 < \gamma < 1$. The empirical value of the slope safety confidence is between 0.6 and 0.7.

(2) Slope safety evaluation index scoring criteria

The attribute scoring method is used to define the relationship between the strengths and weaknesses of different indicators with the same attribute in the evaluation of confidence criteria. Therefore, the higher the attribute score, the stronger the attribute strength. It is assumed that the attribute score of the attribute set C_i is n_i, and when there is $C_1 > C_2 > \cdots > C_k$, there are $n_1 > n_2 > \cdots > n_k$; when $C_1 < C_2 < \cdots < C_k$ exists, there are $n_1 < n_2 < \cdots < n_k$. Therefore, the attribute score value Q_X of the indicator l_i in the object space is as shown in equation (5).

$$Q_X = \sum_{i=1}^{k} [n_i \times \mu_X(C_i)] \quad (4)$$

The scoring criteria stipulate that when $Q_{X1} > Q_{X2}$ exists, the attribute of the indicator l_1 is stronger than the indicator l_2, and it is recorded as $l_1 > l_2$. Similarly, according to the attribute score, the attribute score interval of each attribute evaluation level can be divided, for example, the score interval of C_i is $(n_{i-1}, n_i]$, $i > 1$.

3. Safety dynamic evaluation of weathered granite slope construction based on safety monitoring

3.1 Monitoring unit attribute normality evaluation

The weathered granite slope has the characteristics of rock and soil structure, many factors affecting construction safety and many construction safety monitoring indicators. Its safety monitoring includes surface displacement, internal displacement, and structure deformation, anchor (rod) stress, groundwater and rainfall (Fig. 1).

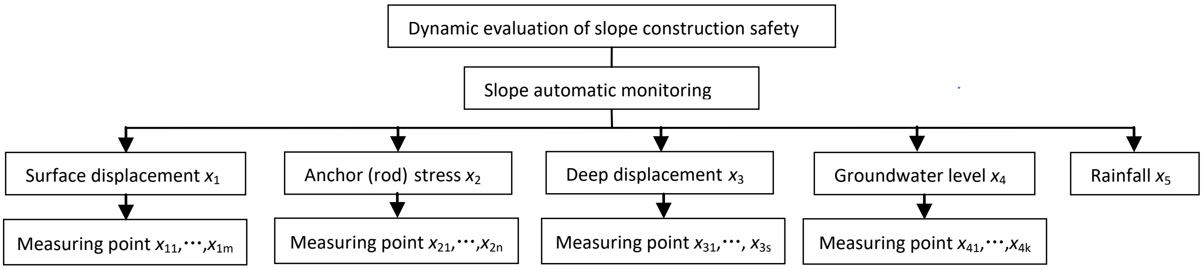

Fig. 1 Dynamic safety evaluation model for slope construction based on automatic safety monitoring

3.2 Safety Dynamic Evaluation Model of Slope Construction Based on Attribute Recognition Theory

Based on the dynamic analysis and evaluation of the normal state of the slope monitoring units, the safety evaluation model of the slope construction is established according to the attribute recognition theoretical model [9, 10] (Fig. 1). The safety of slope is evaluated dynamically based on automatic safety monitoring.

(1) Slope safety monitoring data matrix X

The monitoring data matrix of the safety monitoring indicator object space X consisting of the integrated monitoring unit X_{ij} $(i=1,2,\cdots,k$, $j=1,2,\cdots,n)$ is:

$$X = \begin{matrix} l_1 \\ l_2 \\ \vdots \\ l_m \end{matrix} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1k} \\ x_{21} & x_{22} & \cdots & x_{2k} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mk} \end{bmatrix}$$

(2) Attribute classification standard matrix F

The attribute space F is established according to each monitoring attribute object, where $(C_1, C_2 \cdots C_k)$is the ordered division of the attribute space F $(C_1 > C_2 > \cdots > C_k)$. The classification criteria a_{ij} $(j=1,2,\cdots,k)$ of each indicator $(i=1,2,\cdots,m)$ are known, and thus the classification standard matrix is:

$$F = \begin{bmatrix} C_1 & C_2 & \cdots & C_k \\ a_{11} & a_{12} & \cdots & a_{1k} \\ a_{21} & a_{22} & \cdots & a_{2k} \\ \vdots & \vdots & \cdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mk} \end{bmatrix}$$

Taking the standard deviation of the slope monitoring data as the feature evaluation quantity, the slope surface displacement evaluation standard is established according to the 3σ principle, in which the sample standard deviation s is taken as the standard error σ, the sample average μ is taken as the mean value E; and 1σ is the level I (The normal control value is 2σ as the control value of level II (basic normal), 3σ as the control value of level III (mild abnormality), and finally the monitoring warning value as the control value of level IV (severe abnormality).

Taking the surface displacement monitoring data of a weathered granite slope in Guangzhou as an example, according to the existing slope surface displacement data, the standard deviation of the surface displacement monitoring points (Fig. 2a) and the mean value are obtained by using the Laida criterion. Fig. 2b), the normalized evaluation interval of the surface displacement of the slope is [2.481, 4.932, 7.383, 20.0]. Similarly, the normalized evaluation interval of the deep displacement is [0.173, 0.313, 0.452, 2.0], and the structure tilt is [0.094]. , 0.167, 0.240, 5.0], and the rainfall was [2.760, 5.168, 7.576, 150.0].

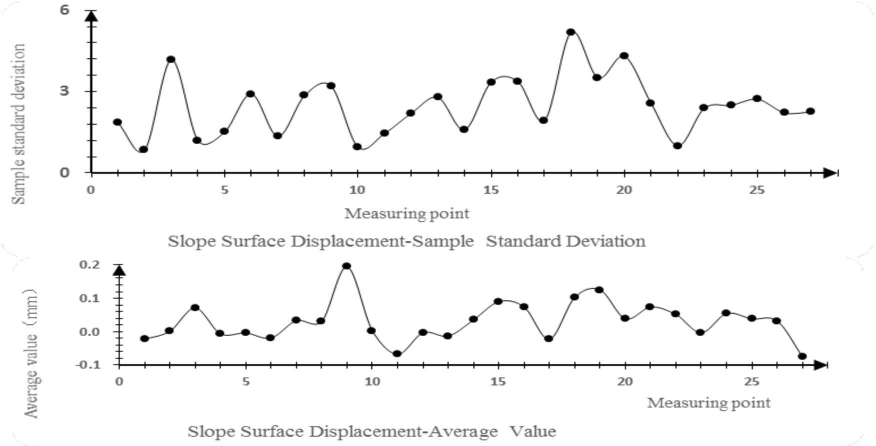

Fig. 2 Displacement of the slope surface - sample standard deviation and average

(3) Single indicator attribute measurement matrix

According to the monitoring data X and the attribute classification standard F, an attribute measurement matrix (single indicator attribute measurement matrix u_i) of each attribute indicator is established. Assuming that a certain measured value X_{ij} of the slope monitoring data has the attribute C_h, its attribute measure is u_{ijh}. Assuming $a_{j1} < a_{j2} < \cdots < a_{jk}$, the attribute measure is as in equation (5).

$$\begin{cases} when\left|x_{ij}\right| \le a_{j1}, \mu_{i1} = 1, \mu_{in} = 0, 2 \le n \le k \\ when\left|x_{ij}\right| \le a_{jk}, \mu_{ik} = 1, \mu_{in} = 0, 1 \le n \le k-1 \\ when \quad a_{jt} \le \left|x_{ij}\right| \le a_{jt+1}, \mu_{it} = \left|x_{ij} - a_{jt+1}\right| / \left|a_{jt+1} - a_{jt}\right|, \mu_{it+1} = \left|x_{ij} - a_{jt}\right| / \left|a_{jt+1} - a_{jt}\right| \\ u_{in} = 0, n > t+1, and \quad N < t, 1 \le t \le k-1 \end{cases} \tag{5}$$

(4) Weight coefficient

The weight coefficient mainly includes the slope safety comprehensive weight coefficient Q and the attribute index weight coefficient q (equation (7)). The slope safety comprehensive weight coefficient Q establishes a relationship between various similar indicators and the comprehensive evaluation of slope construction safety; the attribute index weight coefficient q establishes a relationship between multiple monitoring units of the same type and the type of monitoring indicators (equation (7)). Using the analytic hierarchy process, combined with 10/10 ~ 18/2 (Table 1) [8] to construct the judgment matrix P (equation (6));

Table 1 The interval 10/10 to 18/2 is divided into scales

Scale	E	M	S	V	A
10/10~18/2	1.00	1.50	2.33	4.00	9.00

By calculating the maximum eigenvalue of the matrix P and its corresponding unit eigenvector, the consistency ratio CR is tested. When CR=CI/RI<0.10 of the judgment matrix, the judgment matrix can be considered to be consistent and the weight distribution is reasonable. Otherwise, the judgment matrix should be adjusted; each component of the maximum unit eigenvector is the weight distribution of the index evaluation element, thereby determining the weight coefficient Q of each monitoring index.

$$P = \begin{bmatrix} \mu_{11} & \mu_{12} & \cdots & \mu_{1n} \\ \mu_{21} & \mu_{22} & \cdots & \mu_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \mu_{n1} & \mu_{n2} & \cdots & \mu_{nn} \end{bmatrix} \quad (6)$$

For example, the weight calculation of surface displacement C_1, deep displacement C_2, structural inclination C_3, and rainfall C_4 in the weathered granite slope automatic monitoring system in the engineering case is taken as an example.

The unit eigenvector corresponding to the maximum eigenvalue of the judgment matrix P is calculated by MATLAB as [0.7775 0.4965 0.3253 0.2079], so CR=CI/RI=0.001<0.10, and the weight distribution of the judgment matrix P is reasonable. From this, the weight relationship of (C_1, C_2, C_3, C_4) in the monitoring system is obtained as Q=[0.430, 0.275, 0.180, 0.115].

In addition, the surface displacement, deep displacement or anchor cable (rod) stress in the attribute index are composed of multiple monitoring units, so the attribute index weight coefficient qij is calculated according to formula (7); based on this formula (8) The integrated monitoring unit X_{ij} is calculated, thereby constructing a monitoring data matrix X.

$$q_{ij} = \left|x_{ij}\right| \Big/ \sum_{j=1}^{k} \left|x_{ij}\right| \quad (7)$$

where q_{ij} is the weight coefficient of evaluation factor for i-th row and j-th column, X_{ij} is measurement data of the i-th row, j-th column evaluation factor.

$$X_{ij} = \left|x_{ij}\right|^2 \Big/ \sum_{j=1}^{k} \left|x_{ij}\right| \quad (8)$$

(5) Confidence criterion

The confidence γ of setting the safety of weathered granite slope is 0.6-0.7, and the safety of this kind of slope construction is evaluated by comprehensive attribute measurement matrix (Equation (2) and (3)).

3.3 Comprehensive evaluation of weathering granite slope construction safety

The safety quantitative evaluation of weathered granite slope construction is divided into slope safety comprehensive evaluation and monitoring unit normality evaluation; the normality of each monitoring unit in slope safety monitoring is quantitatively evaluated by attribute normality evaluation standard, and the attributes of multiple monitoring indicators are calculated. The dynamic analysis and evaluation of the safety status of this type of slope construction.

1) Monitoring unit attribute normality evaluation

The attribute normality P_{ij} of each monitoring unit is calculated by the standardized evaluation interval of each monitoring index and formula (9), and finally the normality of the monitoring unit is evaluated according to the normalized 0-1 interval in Table 2.

Table 2 Slope safety index attribute evaluation standard

Evaluation of standardized values	Standardized 0-1 interval	Evaluation classes
a_{i1}	$[V_1,V_2]$=[1.0,0.8]	normal
a_{i2}	$[V_2,V_3]$=[0.8,0.6]	Basically normal
a_{i3}	$[V_3,V_4]$=[0.6,0.3]	Mild anomaly
a_{i4}	$[V_4,V_5]$=[0.3,0.0]	Severe anomalies

$$\begin{cases} when\left|x_{ij}\right| \le a_{i1}, p_{ij} = 1 \\ when\left|x_{ij}\right| \ge a_{ik}, p_{ij} = 0 \\ when \quad a_{it} \le \left|x_{ij}\right| \le a_{jt+1}, p_{ij} = V_t + \left|x_{ij} - a_{it}\right| \Big/ \left|a_{jt+1} - a_{it}\right| (V_{t+1} - V_t), 1 < t < k \end{cases} \tag{9}$$

2) Comprehensive evaluation of slope construction safety

(1) Confidence criterion method

Calculate the corresponding single-index attribute measurement matrix μ_{ij} by formula (5) and the monitoring data matrix, and calculate the slope safety comprehensive attribute measurement matrix μ_i by combining the comprehensive index weight coefficient Q and formula (2). The confidence level γ is set to 0.7, and the attribute category of the attribute indicator is calculated according to the confidence criterion and the formula (2) or the formula (3).

(2) Attribute index scoring method

Distinguish the attribute strength between the same attribute categories by rating the attribute indicators, and evaluate the slope security attribute level; calculate the monitoring attribute indicators according to the above comprehensive attribute measurement matrix and formula (4). The Q_i is scored to thereby assess the slope safety attribute level. According to the four monitoring indicators and the Table 2 in the monitoring system of the weathered granite slope, the slope safety standardization evaluation interval based on the index scoring method is established (Table 3).

Table 3 Slope safety evaluation criteria based on attribute index scoring method

Rating level	Scoring interval
Normal	$[Q_4,Q_3)=[4,3)$
Basically normal	$[Q_3,Q_2)=[3,2)$
Mild abnormality	$[Q_2,Q_1)=[2,1)$
Severe anomaly	$[Q_1,0]=[1,0]$

4. Conclusion

The attribute recognition theory model is combined with the slope safety monitoring to establish a safety dynamic evaluation model for slope construction based on safety monitoring, which realizes the dynamic evaluation of slope construction safety.

(1) In order to realize the dynamic evaluation of the property normality of the safety monitoring unit of weathered granite slope construction, the attribute normalization evaluation standard of the slope safety monitoring unit is established by using the attribute recognition theory and mathematical statistics method, and the slope is realized. Dynamic assessment of the normality of the monitoring unit.

(2) The weighted relationship between attribute index and slope safety is constructed by analytic hierarchy process. S safety dynamic evaluation model of weathered granite slope construction based on safety monitoring is established using the attribute recognition theory model, and the dynamic assessment of highway slope safety is realized during construction process.

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References

[1] Bai Shi. Evaluation of slope stability based on finite element method [J]. Jiangxi building materials, 2016(10):234.

[2] Cai Aiping, Au Yufei. A simple model for evaluating the stability of rock slope based on expert rating [J]. Geotechnical engineering, 2008(03):59-60.

[3] Jiang Ping. Research on stability analysis method of soil slope in seasonal frozen region based on real-time displacement monitoring [D]. Jilin University, 2012.

[4] Zhang Wei. Study on slope safety evaluation index based on field monitoring [D]. Chongqing Jiaotong University, 2015.

[5] Li Kegang. Stability analysis and deformation prediction of rock slope [D]. Chongqing university, 2006.

[6] Cheng Gansheng. Theoretical model of attribute recognition and its application [J]. Journal of Peking University (natural science edition), 1997(01):14-22.

[7] Qin Xiushan, Xhang Da, Cao Hui. Research status and development trend of high-steep slope monitoring technology for open stope [J]. China mining industry, 2017,26(03):107-111.

[8] Zhao Zhifeng. Research on safety evaluation theory and method of high rock slope based on displacement monitoring information [D]. Hohai University, 2007.

[9] Xiao Yanchun, Zhang Zhang, Chen Shuang. Comprehensive evaluation of atmospheric environmental quality in wuhan by applying attribute recognition theory: 2013 annual meeting of the Chinese academy of environmental sciences, kunming, yunnan, China, 2013[C].

[10] Zhao Zhifeng, Yang Fan. Comprehensive safety evaluation of rock slope based on attribute identification theory [J]. Journal of disaster prevention and reduction engineering, 2008(02): 256-260.