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Study on theory of safety forecast mode in highway tunnel construction

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ABSTRACT: Safety forecast models were affected by many factors in previous highway tunnel construction and safe construction could not be guaranteed. From the viewpoint of similarity coefficient, a cluster method based on fuzzy equivalence relation is utilized to analyze these factors theoretically. The advantages of the method presented in this work is analyzed through numerical examples. The results obtained from the method meet the construction requirements. The Fuzzy cluster method applies successfully to tunnel construction.

1 INTRODUCTION

Different from the other decks construction, highway tunnel construction is a relatively inaccessible deck and carried out underground most of the time. Owing to these two factors, its construction safety is decisive in the entire project. Therefore, it is necessary to establish safety forecast model. Safety forecast in highway tunnel construction mainly denotes safety measures taken when the tunnel passes through fragile geological rock stratum. For instance, when tunnel crosses coal seam, oil shale and the rock stratum containing pitch, or passes these geology environment nearby through cracked surrounding rock, jointing development , there can be gas . If the gas density in tunnel has reached explosion limit and the gas contacts with fire, explosion will happen, which will bring great harm and loss to tunnel construction; On the other hand, tunnel construction will be affected by factors such as dust produced in boring process and surrounding rock obdurability. In previous construction, these factors were handled by mechanical equipment solely or by construction experience. However, there would be errors from many aspects, which had some negative influence on construction. Using clustering method based on Fuzzy Equivalence relation, some objects with potential danger in construction are reasonably classified. Fuzzy relation between these objects is established. Safety forecast modes of these objects are given according to system-cluster graph. Reflexivity, symmetry and transitivity of fuzzy equivalence relation is fully used and unavoidable problems in previous safety forecast mode are overcome.

2 INTRODUCTION TO FUZZY CLUSTERING METHOD

Clustering analysis is a discipline which study on classification of things. Its objective is to classify the target samples and variables into some groups by utilizing some mathematical methods, making every individual in each group of close relationship, whereas relationships of individuals among different groups are relatively afar. Since things in reality mostly have fuzzy characteristics, it is natural to introduce fuzzy method into clustering analysis. Fuzzy cluster methods mainly fall into two categories: one is cluster method based on fuzzy equivalence relation, the other is non-cluster method.

2.1 Fuzzy Equivalence Relation[1]

Assume R is fuzzy relation in U, if

①For $\forall\ u \in U$, there exist $\mu_{\underset{\sim}{R}}(u,u)=1$, then $\underset{\sim}{R}$ is reflexive

②For $\forall\ u_i, u_j \in U$, there exist $\mu_{\underset{\sim}{R}}(u_i,u_j)=\mu_{\underset{\sim}{R}}(u_j,u_i)$, then $\underset{\sim}{R}$ is symmetric;

③For $\forall\ u_i, u_j$, $u_k \in U$, there exist $\mu_{\underset{\sim}{R}}(u_i,u_k) \geq \mu_{\underset{\sim}{R}}(u_i,u_j) \wedge \mu_{\underset{\sim}{R}}(u_j,u_k)$, then $\underset{\sim}{R}$ is transitive.

If $\underset{\sim}{R}$ is fuzzy relation which satisfies reflexivity and symmetry, $\underset{\sim}{R}$ is fuzzy compatibility relation. The fuzzy compatibility relation which satisfies transitivity is called fuzzy equivalence relation.

2.2 λ Cut Set

If $\underset{\sim}{R}$ is fuzzy equivalence relation on U, and membership function is $\mu_{\underset{\sim}{R}}(u_i,u_j)$, R_λ is called the λ cut set of $\underset{\sim}{R}$ (λ∈[0, 1]),

$R_\lambda=\{(u_i,u_j) \mid \mu_{\underset{\sim}{R}}(u_i,u_j) \geq \lambda,\ u_i,u_j \in U\}$,

where R_λ is common subset on $U \times U$, and if R_λ is the λ cut set of fuzzy equivalence relation $\underset{\sim}{R}$ in U, R_λ is the equivalence relation in U.

2.3 Formula of Similarity Coefficients Based on Fuzzy Equivalence Relation

Quantity multiplication

$$r_{ij} = \begin{cases} 1 & i = j \\ \left(\sum_{k=1}^{m} x_{ik} \cdot x_{jk}\right) / M & i \neq j \end{cases} \tag{1}$$

where M is a positive number selected appropriately, which satisfies

$$M \geq \max_{i,j}\left(\sum_{k=1}^{m} x_{ik} \cdot x_{jk}\right)$$

The absolute cosine value of the included angle

$$r_{ij} = \frac{\left|\sum_{k=1}^{m} x_{ik} \cdot x_{jk}\right|}{\sqrt{\left(\sum_{k=1}^{m} x_{ik}{}^2\right) \cdot \left(\sum_{k=1}^{m} x_{jk}{}^2\right)}} \tag{2}$$

The maximum and minimum similarity coefficients

$$r_{ij} = \frac{\sum_{k=1}^{m} \left(x_{ik} \wedge x_{jk}\right)}{\sum_{k=1}^{m} \left(x_{ik} \vee x_{jk}\right)} \tag{3}$$

The arithmetic average of the minimum similarity coefficients

$$r_{ij} = \frac{\sum_{k=1}^{m}\left(x_{ik} \wedge x_{jk}\right)}{\frac{1}{2}\sum_{k=1}^{m}\left(x_{ik} + x_{jk}\right)} \tag{4}$$

Statistical correlation coefficients

$$r_{ij} = \frac{\sum_{k=1}^{m}\left|x_{ik} - \bar{x}_i\right| \cdot \left|x_{jk} - \bar{x}_j\right|}{\sqrt{\left[\sum_{k=1}^{m}\left(x_{ik} - \bar{x}_i\right)^2\right] \cdot \left[\sum_{k=1}^{m}\left(x_{jk} - \bar{x}_j\right)^2\right]}} \tag{5}$$

$$where\, \bar{x}_i = \frac{1}{m}\sum_{k=1}^{m} x_{ik}, \bar{x}_j = \frac{1}{m}\sum_{k=1}^{m} x_{jk}.$$

The geometrical average of the minimum similar coefficient

$$r_{ij} = \frac{\sum_{k=1}^{m}\left(x_{ik} \wedge x_{jk}\right)}{\sum_{k=1}^{m}\left(x_{ik} \cdot x_{jk}\right)} \tag{6}$$

3 THE APPLICATION OF THE CLUSTERING METHOD BASED ON FUZZY EQUIVALENCE RELATION IN SAFETY FORECAST MODE OF HIGHWAY TUNNEL'S CONSTRUCTION

3.1 Determining the Safety Forecast Mode in Tunnel Construction

The procedure of determining the safety forecast mode in tunnel construction is as follows,

(1) According to the real-time measuring data of those dangerous objects in the tunnel, determine how dangerous they are;

(2) Establish mathematical model based on those group data;

(3) Determine the safety forecast mode according to the mathematical model [2].

To realize the above goal, first of all, real-time measuring data of the potential dangerous objects must be collected as samples, and the data should be representative in illustrating their danger.

Here 3 index are used: X1 denotes the initial gushing speed of gas(m^3/min); X2 denotes the amount of drilling powder (kg/m); X3 denotes reciprocal of the rock obdurability coefficient.

Table 1 Real-time measuring data of samples

Sample	Index		
	X_1	X_2	X_3
u_1	10	3.4	0.91
u_2	32	4.3	1.25
u_3	8.5	3.5	1.11
u_4	27	5	1.43
u_5	50	6.6	5
u_6	13	3	0.83
u_7	20	4.8	2
u_8	42	6.8	4.35
u_9	40	6.3	3.33

For all samples, using formula(4) is used to calculate similarity coefficients $r_{ij}\ (i, j = 1,2,....9)$. And a 9×9 matrix $\underset{\sim}{R}$ is obtained. Because $\underset{\sim}{R}$ doesn't meet the requirement of transitivity, "self-multiplying" method is used to get fuzzy equivalence matrix $\underset{\sim}{R}^{*}=\underset{\sim}{R}^{8}$. For difference λ values, classifying result are as follows:

λ=1:{ u_1},{ u_2},…{ u_9}.
λ=0.917:{ u_1, u_3},{ u_2 ,u_4},{ u_5, u_8, u_9},{ u_6},{ u_7}.
λ=0.870:{ u_1 ,u_3, u_6},{ u_2, u_4 ,u_7},{ u_5, u_8, u_9} .
λ=0.771:{ u_1, u_2,… ,u_9}.

3.2 System Clustering Graphing According to λ Value.

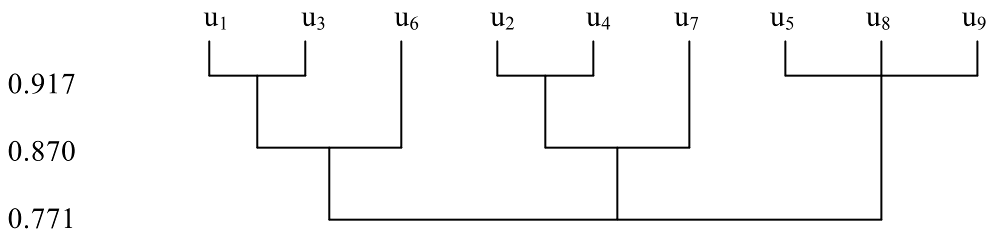

Fig.1 System clustering graph for different λ values

3.3 Numerical Example

According to the data and system clustering graph, it can be seen that when λ at a very low value (0.771), with a relatively low requirement such as gas explosion caused by electrical spark in mechanical operation, and rock collapsing caused by excessive drilling force, it will cause great potential danger for { u5, u8, u9 }. Thus, { u5, u8, u9 } must be classified into severely dangerous group; But for { u2, u4, u7 }, the condition required will be higher compared with that of λ=0.77 to embody its potential danger. For instance, the area of gas explosive density in air will be somewhat less, and explosion will occur only when dust quantity reaches a certain density. Generally, the spontaneity and transitivity of its danger will not so sensitive as λ= 0.771. Thus, { u2, u4, u7 } can be classified into dangerous group; While { u1, u3, u6 } falls into no danger group, whose potential danger can be removed by general appropriate operating method.

From the above analysis it is clear that generally the severely dangerous group such as { u5, u8, u9 } is rare in construction(but small probability occurrence can't be excluded in construction). Hence, regarding the classification where λ = 0.87 as the general case is reasonable. Therefore, this classification can be taken as the safety forecast mode in tunnel construction.

4 CONCLUSIONS

From the above example, it can be seen that cluster method based on fuzzy equivalence relation applies well to highway tunnel construction. It can save labour and money in constructing the tunnel. Meanwhile, it can accurately forecast the potential danger in construction and direct the construction effectively. Hence, the construction can be carried out safely and smoothly.

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