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Abstract. In recent years, with the rapid economic growth, China invested a great deal of time and energy to public infrastructure construction, therefore obtained the rapid development of transportation industry, especially highways and railways. However, in the process of expressway construction, geological disasters are often accompanied by it, especially landslides. Nowadays, China advocates ecological restoration, and some landslides and slopes need effective treatment to restore the ecological environment. This article takes Tawa landslide as an example, and adopts the AHP -fuzzy comprehensive analysis method to optimize different treatment plans, so as to obtain the optimal treatment plan for the landslide.

Keywords: Landslide treatment, AHP-Fuzzy comprehensive analysis method, Scheme optimization

1. Introduction

China has become one of the countries with the highest frequency of geological disasters in the world, especially represented by landslides. It is the most frequent and largest type of geological disaster, and its influence ranks the first among many types of geological disasters in China. The occurrence of landslide is often affected by natural conditions and man-made factors, which makes it a common geological disaster [1, 2]. Landslide treatment design is the core of the treatment work, and it is of great significance to choose an economical and reasonable treatment design scheme [3].

Based on the design of the Tawa landslide treatment project, this paper adopts the AHP-Fuzzy comprehensive evaluation method to construct the evaluation system of the Tawa landslide treatment plan, and then evaluates various plan indicators qualitatively and quantitatively, and finally gives the optimal treatment of the Tawa landslide. The plan and the research results have great reference value for the optimization of similar comprehensive treatment plans for landslides [4].

2. Basic Characteristics of Tawa Landslide and Treatment Plan Design

Tawa landslide is a sliding loess-mudstone mixed landslide. It is the deformation and failure of the original natural slope when part of the rock and soil body slides downward along a curved surface

along the part of its internal engineering with poor engineering properties under gravity conditions. The total volume of Tawa landslide is 170×104 m^3, and the thickness is about 7.0～20.0m. It is characterized by thinner middle and upper parts and both sides, and thicker lower parts, and can be defined as a middle mega-landslide according to the size of the landslide, or as an old landslide according to the age of its formation.

According to the characteristics of the landslide excavation project in each section and the stability analysis of each section of the landslide, combined with the corresponding engineering geological conditions, three different treatment schemes are designed.

Scheme I (M_1): cut and slope release + anti-slide piles + anchors + drainage works + slope protection + foot protection

Scheme II (M_2): cut and slope release + anti-slide piles + anchor frames + anchor frames + drainage works + slope protection + foot protection

Scheme III (M_3): cut and slope release + anchor cable + anchor bolt + drainage works + slope protection + foot protection

3 .AHP-Fuzzy Comprehensive Analysis Method Evaluation Models

The analytic hierarchy process and fuzzy comprehensive analysis method combine the analytic hierarchy process and the fuzzy comprehensive evaluation method to evaluate the problem. This method can avoid the discrepancy between the decision result and the actual situation caused by a single method of evaluation, so as to make a correct evaluation of the alternatives [5, 6, 7].

Taking Tawa landslide as the research object, in order to determine the factors affecting the landslide management scheme, the hierarchical evaluation index system is used to determine the weighting of each factor, and the combination of the system and the fuzzy comprehensive evaluation method is used to determine the evaluation system of the landslide management scheme. The specific evaluation steps are as follows.

3.1 Problem conceptualization

There is a wide variety of influencing factors in engineering examples, and conceptualizing the research question requires a general summary of the specific problem.

3.2 Build a hierarchical model

According to the actual situation, the hierarchical structural model is constructed after clarifying the relationship between the influence factors, which is divided into three levels, namely the target layer, the criterion layer and the solution layer [10]. The structural model is shown in Figure 1.

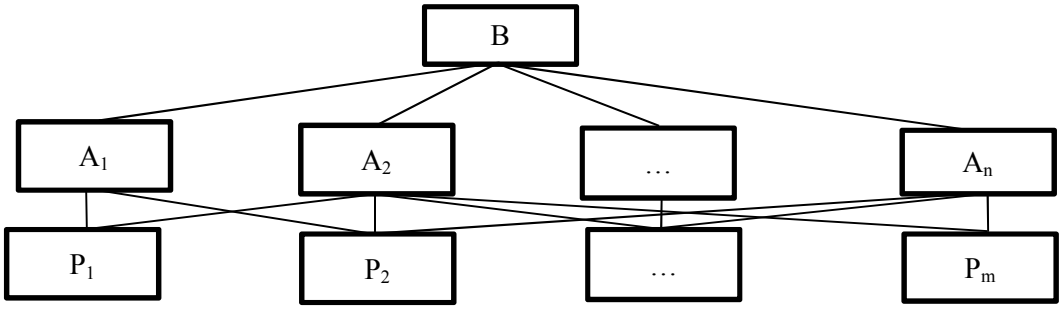

Figure 1. Multi-level structure model

3.3 Construct a pairwise comparison judgment matrix

The judgment matrix is constructed according to the importance of each influencing factor in the criterion layer to an element of the target layer，of which the basic form is shown in Table 1.

Table1. The basic form of the judgment matrix

A	B_1	B_2	…	B_n
$\mathbf{B_1}$	b_{11}	b_{12}	…	b_{1n}
$\mathbf{B_2}$	b_{21}	b_{22}	…	b_{2n}
…	…	…	…	…
$\mathbf{B_n}$	b_{n1}	b_{n2}	…	b_{nn}

In the fuzzy hierarchical analysis, by comparing various influence factors, the quantitative value is finally used to indicate the degree of influence, which is often in the form of 0.1~0.9 scale [11], as shown in Table 2.

Table2. 0.1~0.9 Scale form and meaning

Scale	Definition	Description
0.5	Equally important	Two factors are equally important
0.6	Slightly important	Comparing two factors, one factor is slightly more important than the other
0.7	Obviously important	Comparing the two factors, one factor is obviously more important than the other
0.8	Much more important	Comparing two factors, one factor is more important than the other
0.9	Extremely important	Comparing two factors, one factor is extremely important than the other
0.1,0.2 0.3,0.4	Inverse comparison	If the factor a_i is compared with a_j to get $r_{ij,}$ the judgment obtained by comparing the factor a_i with a_j is $r_{ij}=1-r_{ji}$

Among them, $a_{ij}=0.5$ means that two factors have the same importance when compared; $a_{ij}\in(0.1,0.5)$ means that the importance of factor i is greater than factor j; $a_{ij}\in(0.5,0.9)$ means that the importance of factor j is greater than factor i.

Based on the meaning of the scale, the following matrix is obtained by comparing the factors with each other.

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

3.4 Weight formula of fuzzy complementary matrix

Definition 1 Set matrix$R=(r_{ij})_{n\times n}$, where:

$0\le r_{ij}\le 1$,（i=1,2,…,n;j=1,2,…,n）

Then R is the fuzzy matrix.

Definition 2 Set matrix$R=(r_{ij})_{n\times n}$, where:

$r_{ij}+r_{ji}=1$,（i=1,2,…,n;j=1,2,…,n）

Then R is the fuzzy complementary matrix.

Definition 3 Complementary matrix$R=(r_{ij})_{n\times n}$, satisfying：∀i,j,k

$$r_{ij}=r_{ik}-r_{jk}+0.5 \tag{1}$$

Since the above formula is relatively cumbersome, the following relatively simple methods can be used:

Theorem 1 For matrix $A=(r_{ij})_{n\times n}$, sum by row:

$r_i = \sum_{k=1}^{n} a_{ik}$,(i=1,2,…,n), perform mathematical substitution:

$$r_{ij} = \frac{r_i - r_j}{2(n-1)} + 0.5 \tag{2}$$

Find the fuzzy consistency matrix $R = (r_{ij})_{n\times n}$.

For the sorting vector $W = (W_1, W_2, \dots, W_n)^T$,where：

$$W_i = \frac{\sum_{i=1}^{n} a_{ij} + \frac{n}{2} - 1}{n(n-1)} \tag{3}$$

3.5 Check consistency

Use the "compatibility index" method to verify whether each weight is reasonable.

For the n-order fuzzy complementary matrix Gn, set$A = (a_{ij})_{n\times n}$、$B = (b_{ij})_{n\times n} \in$ Gn, the distance between A and B is：$\|A - B\| = \sum_{i=1}^{n}\sum_{j=1}^{n}|a_{ij} - b_{ij}|$, denoted as $\rho(A, B) = \|A - B\|$。

Definition 4 Set$A = (a_{ij})_{n\times n}$、$B = (b_{ij})_{n\times n} \in$Gn, then say that A,B are perfectly compatible, and if ρ(A,B)=0, that is,∀i,j∈N, there is a_{ij}=b_{ij}.

Definition 5 The fuzzy judgment matrices $A = (a_{ij})_{n\times n}$、$B = (b_{ij})_{n\times n}$, then their compatibility is：

$$FC(AB) = \sum_{i=1}^{n}\sum_{j=1}^{n}|a_{ij} + b_{ij} - 1| \tag{4}$$

Definition 6 The compatibility index of fuzzy matrices A and B is:

$$I(A, B) = \frac{1}{n^2} FC_{(AB)} \tag{5}$$

Definition 7 The weight vector of A:$W = (W_1, W_2, \dots, W_n)^T$

$\sum_{i=1}^{n} W_i = 1$, w_i≥0(i=1,2,…,n), let $W_{ij} = \frac{W_i}{W_i + W_j}$(∀i,j=1,2,…,n), the judgment matrix is:

$$W^* = (W_{ij})_{n\times n} \tag{6}$$

If $I(A, W^*) \le \alpha$（α=0.1）, then the judgment matrix is satisfied and consistent.

Steps to test whether the fuzzy complementary matrix is satisfactory and consistent:

1）Test the satisfactory consistency of m matrices

$$I(A_K, W^{(k)}) \le \alpha, k = 1,2, \dots, m$$

2）Check whether the judgment matrix is compatible

$$I(A_K, A_L) \le \alpha, k \ne l, k, l = 1,2, \dots, m$$

Judge whether the fuzzy complementary matrix meets the above two requirements. If it meets, it means that its weight vector distribution is reasonable. The weight formula is expressed as:

$$W = (W_1, W_2, \dots, W_N) \tag{7}$$

Where:

$$W_i = \frac{1}{n}\sum_{k=1}^{n} W_i^{(k)}, i = 1,2, \dots, n \tag{8}$$

4. Optimization of landslide treatment plan

4.1 Impact factors of landslide treatment plan

The treatment plan in this paper selects three main evaluation factors: economic X1, risk X2, and treatment effect X3. After the discussion of the designers, three plans (M1, M2, M3) are formed, and the above three plans are optimized.

4.2 The Hierarchical Model of Tawa Landslide Treatment Plan

The hierarchical model of the landslide treatment plan is shown in Figure 2.

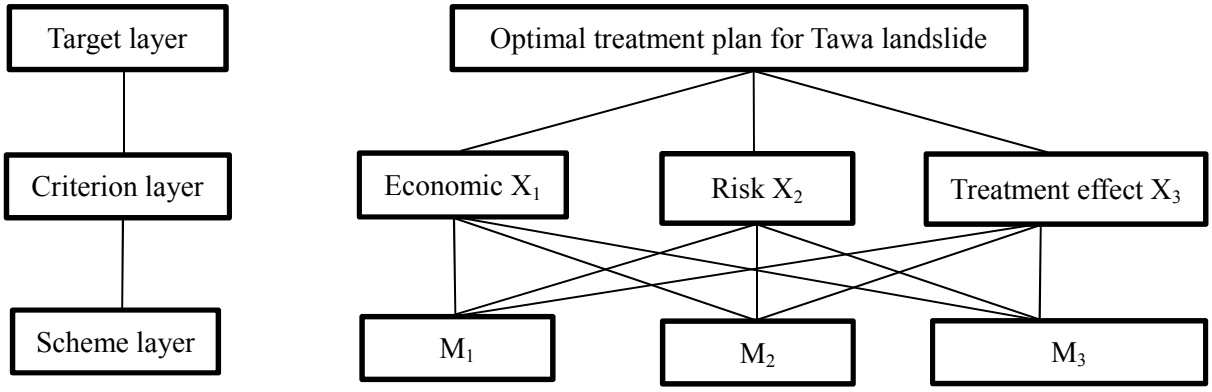

Figure 2. Diagram of Hierarchical Structure Model of Evaluation System for Tawa Landslide Treatment

4.3 Determination of the weighting matrix

After comprehensive evaluation, the weighted fuzzy complementary matrix of the three factors of economy (X_1), risk (X_2) and governance effect (X_3) is obtained.

Weighted fuzzy complementary matrix A_1:

$$A_1 = \begin{bmatrix} 0.5 & 0.4 & 0.4 \\ 0.6 & 0.5 & 0.4 \\ 0.6 & 0.6 & 0.5 \end{bmatrix}$$

According to formula (3), the weight vector is obtained:

$$W_1 = (0.2894 \quad 0.3313 \quad 0.3793)$$

According to formula (6), the judgment matrix of A_1 is:

$$W_1^* = \begin{bmatrix} 0.5000 & 0.4663 & 0.4328 \\ 0.5337 & 0.5000 & 0.4663 \\ 0.5672 & 0.5337 & 0.5000 \end{bmatrix}$$

According to (4) and (5), the compatibility index of A1 and W_1^* is:

$I(A_1, W_1^*)$=0.0369＜0.1, which means that the weight W_1 is distributed reasonably.

Weighted fuzzy complementary matrix A_2:

$$A_2 = \begin{bmatrix} 0.5 & 0.4 & 0.5 \\ 0.6 & 0.5 & 0.4 \\ 0.5 & 0.6 & 0.5 \end{bmatrix}$$

According to (3), the weight vector is obtained: $W_2 = (0.3122 \quad 0.3314 \quad 0.3565)$

According to formula (6), the judgment matrix of A_2 is:

$$W_2^* = \begin{bmatrix} 0.5000 & 0.4851 & 0.4669 \\ 0.5149 & 0.5000 & 0.4817 \\ 0.5331 & 0.5183 & 0.5000 \end{bmatrix}$$

According to (4) and (5), the compatibility index of A_2 and W_2^* is:

$I(A_2, W_2^*)$=0.0448＜0.1, which means that the weight W_2 is distributed reasonably.

Check the consistency of fuzzy matrices A_1 and A_2: $I(A_1, A_2) = 0.0225 < 0.1$,Therefore, it is assumed that the A_1 and A_2 matrices are compatible.

According to equations (7) and (8), the weight vector is:

$$W = \left(\frac{1}{2}(0.2894 + 0.3122) \quad \frac{1}{2}(0.3313 + 0.3314) \quad \frac{1}{2}(0.3793 + 0.3565)\right)$$
$$= (0.3008 \quad 0.3314 \quad 0.3679)$$

4.4 Determination of the index matrix

According to the three indicators of economy (X_1), risk (X_2) and treatment effect (X_3), and compare each impact factor with each other according to Table 2, the judgment matrix R of the three schemes is obtained.

Economy (X_1) Fuzzy judgment matrix

$$R(E_1) = \begin{bmatrix} 0.5 & 0.4 & 0.35 \\ 0.6 & 0.5 & 0.4 \\ 0.65 & 0.6 & 0.5 \end{bmatrix}$$

According to equation (3), we have the alignment vector:

$$E_1 = (0.2775 \quad 0.3908 \quad 0.3324)$$

According to formula (6), the judgment matrix of $R(E_1)$ is:

$$E_1{}^* = \begin{bmatrix} 0.5000 & 0.4153 & 0.4551 \\ 0.5847 & 0.5000 & 0.5405 \\ 0.5449 & 0.4595 & 0.5000 \end{bmatrix}$$

According to (4) and (5), the compatibility index of $R(E_1)$ and $E_1{}^*$ is:

$I(R(E_1), E_1{}^*)$=0.0403＜0.1, which means that the weight E_1 is distributed reasonably.

Risk (X_2) fuzzy judgment matrix

$$R(E_2) = \begin{bmatrix} 0.5 & 0.6 & 0.7 \\ 0.4 & 0.5 & 0.65 \\ 0.3 & 0.35 & 0.5 \end{bmatrix}$$

According to equation (3), we have the alignment vector:

$$E_2 = (0.2998 \quad 0.3668 \quad 0.3335)$$

According to equation (6), the judgment matrix of $R(E_2)$ is:

$$E_2{}^* = \begin{bmatrix} 0.5000 & 0.4497 & 0.4735 \\ 0.5503 & 0.5000 & 0.5240 \\ 0.5265 & 0.4760 & 0.5000 \end{bmatrix}$$

According to (4) and (5), the compatibility index of $R(E_2)$ and $E_2{}^*$ is:

$I(R(E_2), E_2{}^*)$=0.0227＜0.1, which means that the weight E_2 is distributed reasonably.

Treatment effect (X_3) fuzzy judgment matrix

$$R(E_3) = \begin{bmatrix} 0.5 & 0.65 & 0.7 \\ 0.35 & 0.5 & 0.6 \\ 0.3 & 0.3 & 0.5 \end{bmatrix}$$

According to equation (3), we have the alignment vector:

$$E_3 = (0.2958 \quad 0.4023 \quad 0.3025)$$

According to equation (6), the judgment matrix of $R(E_3)$ is:

$$E_3{}^* = \begin{bmatrix} 0.5000 & 0.4238 & 0.4946 \\ 0.5762 & 0.5000 & 0.5708 \\ 0.5054 & 0.4292 & 0.5000 \end{bmatrix}$$

According to (4) and (5), the compatibility index of $R(E_3)$ and $E_3{}^*$is:

$I(R(E_3), E_3{}^*)$=0.0434＜0.1, which means that the weight E_3 is distributed reasonably.

According to the above three fuzzy judgment matrices, the weight vectors of the three design schemes of each factor can be obtained from formula (3):

$$E_1 = (0.2775 \quad 0.3908 \quad 0.3324)$$
$$E_2 = (0.2998 \quad 0.3669 \quad 0.3336)$$
$$E_3 = (0.2958 \quad 0.4023 \quad 0.3025)$$

Its composition weight judgment matrix is:

$$E = \begin{bmatrix} 0.2775 & 0.3908 & 0.3324 \\ 0.2998 & 0.3669 & 0.3336 \\ 0.2958 & 0.4023 & 0.3025 \end{bmatrix}$$

4.5 Preferred outcome of the overall ranking of programmes

The calculation result of the total ranking of the scheme is:

$B = W \oplus R$

$$= (0.3008 \quad 0.3314 \quad 0.3679) \cdot \begin{bmatrix} 0.2775 & 0.3908 & 0.3324 \\ 0.2998 & 0.3669 & 0.3336 \\ 0.2958 & 0.4023 & 0.3025 \end{bmatrix}$$

$$= (0.2916 \quad 0.3871 \quad 0.3218)$$

The above algorithm is a weighted average algorithm, the total weight of treatment plan one and treatment plan three is 0.2916 and 0.3218 respectively, while the total weight of treatment plan two is 0.3871. According to the hierarchical analysis principle, the higher the total weight, the better the treatment plan is considered [12]. Therefore, it can be judged that the treatment plan 2 is the best scheme, and the order of the three treatment schemes is: scheme 2 > scheme 3 > scheme 1. The final treatment plan chooses the comprehensive treatment plan of cutting slope + anti-slide pile + anchor frame + anchor cable frame + drainage engineering + slope protection + slope toe protection, which has achieved good results in the treatment of Tawa landslide.

5. Conclusion

Based on the design of the Tawa landslide treatment project, this paper uses the AHP-Fuzzy comprehensive evaluation method to optimize the selection of the treatment plan. Finally, through the analysis of the comprehensive evaluation vector, it is concluded that the second option is the optimal treatment plan, as follows:

(1) The most critical step is to establish a reasonable hierarchical structure model when using the AHP-Fuzzy comprehensive evaluation method to evaluate the landslide treatment plan. The evaluation method in this article mainly considers the three factors of economy, safety, and treatment effect. Through the comparison of each factor, the importance of each factor is determined and the judgment matrix is constructed. Use index weights to check whether the weight matrix is reasonable and consistent, to determine whether the weights are distributed reasonably, and then to get the total weight of each plan. The higher the total weight, the better the treatment plan.

(2) Using the AHP-Fuzzy comprehensive evaluation method to analyze the Tawa landslide treatment plan in the article, and get the comprehensive evaluation vector of the plan set, so that it can be judged that the treatment plan 2 is the best plan, and it has achieved good results in practical applications. This method can make a more scientific, accurate and well-founded judgment, and its application in the field of landslide treatment is feasible.

(3) It has broad prospects for the optimization research of landslide treatment plan using the AHP-Fuzzy comprehensive evaluation method, and it also has certain reference significance for other similar comprehensive evaluation work. The AHP-Fuzzy method can be combined with other methods to be widely used in multi-objective decision analysis.

(4) In the process of optimizing the selection of landslide treatment schemes, there are often many influencing factors, and the influencing factors considered in this paper are relatively few. When solving practical problems, comprehensive consideration should be made in many aspects, so that the results obtained will be more ideal.

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