Performance of rock–soil slope reinforcement and protection effect in cutting slope construction

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Abstract

It is inevitable to excavate slide slope and damage rock slope under the rapid development of expressway. To further remedy ecological environment, correct understanding of side slope stability is essential for the effective reinforcement and protection of rock–soil slope. In this paper, the reinforcement and protection technologies of cutting slopes were introduced firstly, and then the classifications of rock–soil slope reinforcement technologies in China and abroad were compared. Taking the Daqing–Guangzhou Highway as the research subject, three kinds of reinforcement and protection schemes were proposed and analyzed. Combing fuzzy comprehensive judgment with analytic hierarchy process, a supporting model of cutting slopes was established. The analytic hierarchy process was used to determine the weight and the degree of membership was calculated. Finally, the model was applied into the project to carry out evaluation. The results showed that the fuzzy comprehensive evaluation model used in this paper had a good reference value for the future development of cutting slopes.

Keywords: rock and soil slope; cutting slope construction; remediation protection

1 INTRODUCTION

In recent decades, China’s highway construction has made significant progress in both construction level and construction quality. However, with the gradual expansion of the scale of capital construction projects, the attendant geological environmental and technical problems have been more and more complicated. Engineering difficulty is high in mountainous areas and errors in operation can cause soil lateral deformation and even landslides. Besides, floods, heavy rains and weathering can also cause slope deformation and collapses. Many experts and scholars have made some researches to protect soil slope. Mao et al. [1] held that plant roots and soil roots could effectively reinforce soil and protect slope. To determine the performance of green bristlegrass in soil reinforcement and slope protection and its variation characteristics on the belt of water table fluctuation, the tensile strength, anti-scouring property, erosion resistance and shearing resistance of soil root were tested. Finally, they found soil foot could reinforce soil. Su and Liu [2] proposed a design method of slope reinforcement under the action of pre-stressed anchor cable, bolt and anti-slide pile through analyzing the displacement field in the construction process of a rock side soil project using finite element method and found through simulation test that the horizontal displacement of the rock side slope significantly reduced, which effectively enhance the stability of rock side slope reinforced by pre-stressed anchor cables, rock bolts and slide-resistant piles. Gong et al. [3] used soil nailing support method to improve the stability of the slope, performed centrifugal model test of unreinforced side slope and two centrifugal model tests of soil nailing reinforced side slope using a centrifugal machine, and studied the deformation characteristics of loess slope in Southwest China. The centrifugal model test results suggested that soil nailing could greatly enhance the stability of loess slope, and the effect was better when the length of soil nailing was different. Reinforcing the stability of slope soil by reasonably remodeling and utilizing side slopes can satisfy the...
requirement of modern engineering construction security. As the engineering geological conditions are diversified in various regions, considering safety and stability of the slope only can no longer meet the current needs. Therefore, single slope protection should be transformed into comprehensive slope protection, which is more conducive to development [4].

2 CUTTING SLOPE INSTABILITY AND ITS REINFORCEMENT AND PROTECTION TECHNOLOGY

2.1 Cutting slope instability mode
Generally, cutting slope instability modes can be divided into sliding type, collapse type and limited deformation type.

2.1.1 Sliding type
Sliding damage refers to the sliding instability phenomenon of the weak zone of the slope, which can be divided into flat type, arc type, sphenoid type and mixed type, as shown in Table 1.

2.1.2 Collapse type
The high incidence sites of collapse damage are natural steep slopes and steeply excavated slopes. It consists of dumping type and slip type.

2.1.3 Limited deformation type
In the construction process, unloading stress release and adjustment will appear in the slope rock mass, leading to deformation. When encountered the appropriate conditions, the degree of deformation increases and there will be instability damage. In the construction of cutting slopes, there are many artificially excavated and natural high and steep slopes. Slope deformation occurs when there is damage, resulting in unnecessary economic losses. Therefore, it is necessary to reinforce and protect the cutting slopes to reduce the frequency of landslide deformation and make remediation before deformation to win the time for further treatment [5].

2.2 Cutting slope reinforcement technology

2.2.1 International classification
International Institute of Soil Mechanics and Geotechnical Engineering proposed four slope control measures [6], as follows:

- Change the geometric shape of the slope: increase materials in landslide anti-skid area and reduce the slope degree.
- Drainage: surface drainage; vertical well drainage; tunnel and corridor drainage; vacuum drainage; point drainage.
- Support structure: gravity retaining wall; frame retaining wall; cage retaining wall; cast-in-place reinforced concrete retaining wall; reinforced retaining structure; rock slope fixed net.
- Slope internal reinforcement: rock anchor; micro-pile group; soil nail; anchor; heat treatment; frozen; electroosmotic anchor; planting.

2.2.2 Domestic classification
The types of cutting slope control measures in our country can be summarized as four categories: slope reduction, support, reinforcement and drainage.

Slope reduction. According to the slope rate, classification is performed to stabilize the slope, which can destroy the original terrain and landforms. Besides, solving the digging soil problem will lead to soil erosion and destruction of the original natural slope vegetation and landforms.

Support. As for the support measure, it includes retaining wall, anti-slide pile [7] and pre-stressed anchor cable anti-slide pile [8]. The retaining wall is suitable for slopes with low thickness and thrust. If the thrust is relatively large, the anti-slide retaining wall is selected. The anti-slide pile is a laterally loaded cylindrical support member, similar to the cantilever force structure, which can be divided into single pile, row pile and pre-stressed anchor pile. Anti-slide pile position can be set flexibly, but the exposed type anti-slide piles affect the appearance and the reinforcement rate is high, with expensive expenses. Pre-stressed anchor cable anti-slide pile uses resisting power and anchor tension to resist the external slope destructive power. However, compared with the anti-slide pile, its construction process is more complicated, but the duration is relatively short, with small material expenses.

Reinforcement. Bolt reinforcement and lattice reinforcement are mature reinforcement measures that have been widely applied with good effects [9].

Drainage. Drainage systems fall into two categories. First, the ground drainage system can be divided into side ditches, cut ditches, drains and jet slots. Second, underground drainage system is divided into leak ditches, blind ditches and flat holes. According to the local conditions, various drainage measures should be applied with cohesion coherence, making it a complete drainage system.

| Type    | Features                                                                 |
|---------|---------------------------------------------------------------------------|
| Flat    | The structural plane direction is approximately parallel to the slope surface, the slope is inclined and the inclination angle is less than the slope angle |
| Arc     | The failure surface in the slope occurs along the maximum shear stress inside the loose deposit, and the failure surface resembles an arc                                         |
| Sphenoid| The two weak surfaces and the excavation surface form a wedge, and the intersection of the two structural planes is inclined, and the inclination angle is close to or greater than the friction angle |
| Mixed   | Damage formed with two or all three of the above three types              |
2.3 Cutting slope protection technology
Generally, cutting slope protection technology includes engineering protection and plant protection [10]. The engineering protection is divided into protective wall, masonry, cement sand plaster and anchoring and shotcreting slope protection, preventing the occurrence of erosion, shedding and collapse of the slope. Plant protection depends on the adhesion between the rhizome and the soil and the entanglement of the rhizomes to improve the ability of the slope to resist erosion [11]. The current applied vegetation protection methods are: artificial vegetation, planting belt, hydraulic spray sowing, organic matter spray broadcast [12].

2.3.1 Engineering protection technology
Engineering slope protection technology [13] is divided into rubble slope protection and protection wall, masonry skeleton vegetation slope protection, concrete frame grass protection slope and shotcreting slope.

2.3.2 Plant protection technology
Traditional plant protection techniques include: grass cover slope protection, planting belt slope protection, ecological bag green slope protection, contour hedgerow slope protection, vines plant slope protection and geocell protection technology.

2.3.3 New protection technology
At present, China has begun to use new plant protection technologies, such as 3D vegetation net slope protection, hydraulic spray sowing slope protection, ecological cutting wall slope protection, thick layer substrate spraying vegetation slope protection (TBS), SNS flexible protective net, etc. Spraying mixed grass is a new ecological protection technology. First, set the anchor on the slope and connect the wire mesh to the solid slope. Then, the grass, fertilizer, clay and other necessary ingredients are mixed to a certain proportion and sprayed to the slope. After a period of time, the slope can gradually form a green vegetation. The most important part of this method is the mixture of formula: there must be enough pores to enable the plant to grow steadily and the slope should be equipped with the ability to resist rainwater erosion.

3. SLOPE CONTROL PROGRAM SELECTION METHOD

3.1 Fuzzy comprehensive evaluation method
The fuzzy comprehensive evaluation method [14] is a method of quantifying the factors that are unclear or difficult to be quantitatively analyzed. It decomposes the impression factors of the objective things to form statistical indicators systems of different plates. The fuzzy set exchange principle is used to perform conformance operations to determine the credibility of the research objectives.

3.2 Maximum membership method
The element \( v_k \) corresponding to the largest evaluation index \( b_k \) is selected to be the result of the evaluation, \( V = \{ v_k \mid \max b_k \} \). The maximum membership method is based on the contribution of the largest indicator, and the information provided by other indicators is discarded. Moreover, when there are multiple maximum indicators, this method is difficult to determine the evaluation results. Therefore, we consider a new method.

3.3 Weighted average method
Take \( b_k \) as the weight, and the weighted average values of the elements in each evaluation set are the evaluation results:

\[
V = \sum_{k=1}^{n} b_k v_k = \frac{\sum_{k=1}^{n} b_k}{\sum_{k=1}^{n} b_k}.
\]

If the evaluation index is normalized, then:

\[
V = \sum_{k=1}^{n} b_k v_k.
\]

Evaluate the objects and express them with the appropriate numbers. The results are compared and the closest non-quantitative element is the evaluation result. Through a section analysis of the Daqing–Guangzhou Expressway, the scheme which is most suitable for the section is selected.

4 CASE ANALYSIS OF SLOPE CONTROL

4.1 Project overview
The Daqing–Guangzhou Expressway is located in the hilly area, with silty clay on its surface and small thickness. The groundwater type is mainly bedrock fissure water, which is supplied by atmospheric precipitation. The underlayer is composed of the completely weathered and strongly weathered powdery sandy mudstones. According to the type of soil slope, the stability was calculated, and the stability coefficient is 0.976.

4.2 Reinforcement and protection scheme
The slope strata are dominated by the completely weathered and strongly weathered powdery sandy mudstones, with a slope height of less than 40 m. The type of slope has a large proportion and is representative. Three kinds of schemes were designed to carry out this research.

As shown in Table 2, scheme 1 applies bolt reinforcement and slope reduction, combining mixed grass spraying with arched 3D net grass planting. Scheme 2 applies anchor and prestressed anchor cable, combining mixed grass spraying with arched 3D net grass planting. Scheme 3 applies retaining walls and ecological slots to realize vertical greening, combining mixed grass spraying with arched 3D net grass planting.
4.3 Reinforcement and protection scheme options

4.3.1 Establish a fuzzy evaluation model

The combination of analytic hierarchy process and fuzzy comprehensive evaluation method was proposed to determine the research section. Ten experts scored the fuzzy relationship between the various factors, and then the reliable results were obtained based on fuzzy comprehensive evaluation. Based on the evaluation contents of the high slope support scheme and the local natural conditions and construction objectives, we propose an index system that includes technical, economic, environmental and ecological factors.

4.3.2 Determine the weight

We use the analytic hierarchy process to determine the weight. This method is a reasonable and feasible system analysis method, which is easy to operate with high credibility. The technical indicators, economic indicators, environmental indicators and ecological indicators of the calculation results are summarized, as shown in Table 3.

Table 3. Calculation results of the total target layer.

| Best support scheme | Technology | Economy | Environment | Ecology | Wi |
|---------------------|------------|---------|-------------|---------|----|
| Technology          | 1.0000     | 3.0000  | 1.0000      | 3.0000  | 0.3930 |
| Economy             | 0.3333     | 1.0000  | 3.0000      | 3.0000  | 0.2269 |
| Environment         | 1.0000     | 1.0000  | 2.0000      | 2.0000  | 0.2699 |
| Ecology             | 0.3333     | 0.3333  | 1.0000      | 1.0000  | 0.1102 |

Table 2. Supporting scheme.

| Scheme | Slope height | Level 1          | Level 2          | Level 3          | Level 4          |
|--------|--------------|------------------|------------------|------------------|------------------|
| Scheme 1 | 38           | 1:1 Anchor bolt   | 1:1.25 Arched 3D net grass planting | 1:1.25 Arched 3D net grass planting | 1:1.25 Spraying seeds |
| Scheme 2 | 35           | 1:0.75 Anchor bolt Lattice beam | 1:0.75 Anchor frame beam | 1:1 Arched 3D net grass planting | 1:1.25 Spraying seeds |
| Scheme 3 | 30           | 1:0.25 Retaining wall Starting slope | 1:0.75 Spray sowing grass plating | 1:1 Spray sowing grass plating | ———— |

4.3.3 Fuzzy comprehensive evaluation results

Level 1 fuzzy comprehensive evaluation.

In accordance with the steps of fuzzy comprehensive evaluation, the operator $M(\bullet, +)$ is adopted. The following is performed by taking scheme 1 as an example.

\[
B_1 = A_1 \bullet R_1 = (0.3921, 0.0751, 0.1574, 0.2740, 0.1014)
\]

\[
\begin{bmatrix}
0 & 0.2 & 0.5 & 0.3 & 0 \\
0.1 & 0.6 & 0.3 & 0 & 0 \\
0 & 0 & 0.1 & 0.9 & 0 \\
0 & 0.2 & 0.8 & 0 & 0 \\
0 & 0 & 0.4 & 0.6 & 0
\end{bmatrix}
\] (3)

(2) Economic indicator.

\[
B_2 = A_2 \bullet R_2 = (0.5499, 0.2402, 0.2098)
\]

\[
\begin{bmatrix}
0 & 0 & 0.1 & 0.9 & 0 \\
0 & 0 & 0.3 & 0.7 & 0 \\
0 & 0.2 & 0.5 & 0.3 & 0
\end{bmatrix}
\]

\[
= [0 \ 0.04196 \ 0.2320 \ 0.725990]
\] (4)

(3) Environmental indicator.

\[
B_3 = A_3 \bullet R_3 = (0.5714, 0.2857, 0.1429)
\]

\[
\begin{bmatrix}
0 & 0 & 0.2 & 0.8 \\
0 & 0 & 0.4 & 0.6 & 0 \\
0 & 0 & 0.3 & 0.7 & 0
\end{bmatrix}
\]

\[
= [0 \ 0 \ 0.157 \ 0.386 \ 0.457]
\] (5)

Figure 1. Total target weight vector.
(4) Ecological indicator.

\[
B_k = A_k \cdot R_k = \begin{bmatrix} 0.6667 & 0.3333 \\ 0.6 & 0.4 \end{bmatrix} \\
= \begin{bmatrix} 0.0667 & 0.3 & 0.2333 & 0.4 \end{bmatrix}
\]  

Level 2 fuzzy comprehensive evaluation.

\[
B = A \cdot R = \begin{bmatrix} 0.3930 & 0.2269 & 0.2699 & 0.1102 \\ 0.141 & 0.517 & 0.343 & 0 \\ 0.042 & 0.232 & 0.726 & 0 \\ 0 & 0.157 & 0.386 & 0.457 \\ 0.067 & 0.3 & 0.233 & 0.4 \end{bmatrix} \\
= \begin{bmatrix} 0.072 & 0.331 & 0.429 & 0.168 \end{bmatrix}
\]

Evaluation indicator processing.

- According to the maximum membership degree, the evaluation result of scheme 1 is poor.
- Weighted average method. \( V = \{ \text{excellent} (V_1), \text{good} (V_2), \text{average} (V_3), \text{inadequate} (V_4), \text{poor} (V_5) \} \), which is assigned to 0.9, 0.7, 0.5, 0.3, 0.1, respectively, \( V = \sum_{k=1}^{n} b_k v_k = 0.362 \) and the result is inadequate.
- Similarly, the result of scheme 2 can be obtained.

\[
B = A \cdot R = \begin{bmatrix} 0.3930 & 0.2269 & 0.2699 & 0.1102 \\ 0.039 & 0.278 & 0.534 & 149 & 0 \\ 0 & 0 & 0.287 & 0.534 & 0.179 \\ 0 & 0.143 & 0.6 & 0.243 & 0.014 \\ 0 & 0.067 & 0.567 & 0.367 & 0 \end{bmatrix} \\
= \begin{bmatrix} 0.015 & 0.155 & 0.499 & 0.286 & 0.045 \end{bmatrix}
\]

According to the maximum membership degree, the evaluation result of scheme 2 is average. Weighted average method, \( V = 0.4623 \), the evaluation result is average.

Similarly, the result of scheme 3 can be obtained.

\[
B = A \cdot R = \begin{bmatrix} 0.3930 & 0.2269 & 0.2699 & 0.1102 \\ 0.183 & 0.614 & 0.203 & 0 & 0 \\ 0.014 & 0.643 & 0.343 & 0 & 0 \\ 0 & 0.3 & 0.633 & 0.067 & 0 \end{bmatrix} \\
= \begin{bmatrix} 0.076 & 0.471 & 0.398 & 0.056 \end{bmatrix}
\]

According to the maximum membership degree, the evaluation result of scheme three is good. Weighted average method, \( V = 0.613 \), the evaluation result is good. Therefore, scheme 3 is the best scheme.

5 CONCLUSIONS

In this paper, the traditional method of reinforcement and protection of cutting slope was analyzed in detail, and a new method of cutting slope support was put forward. Taking Daqing-Guangzhou Highway as an example, the fuzzy comprehensive evaluation model was used to analyze the problems. The design scheme which is most suitable for the project was selected out finally. The results revealed that it was practical to combine the reinforcement and protection of the cutting slope with the fuzzy comprehensive flat plate model, which has the advantages of convenient operation, high efficiency, high accuracy and satisfactory results. As there are many factors affecting the choice of the road cutting slope support program, how to scientifically choose a reasonable program needs further studies.

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