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Research on Optimization of Prevention and Control Measures for High Slopes along Mountainous Highway

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KEYWORDS

Highway Slope;
Fuzzy Comprehensive Evaluation;
Midas Gts Nx;
Micro-Pile Reinforcement

ABSTRACT

Highways, as critical transportation infrastructure, not only ensure the daily production and livelihood of residents but also serve as key support for promoting regional economic development and implementing the rural revitalization strategy. However, during the construction and operation of some mountainous highways, insufficient attention to slope stability issues and the lack of systematic protective design and treatment have led to frequent geological hazards such as slope instability and landslides. These incidents severely compromise road safety and endanger the lives and property of nearby residents. To systematically investigate scientific prevention and control solutions for high slopes along mountainous highways, this paper selects a typical high slope on a mountainous highway as the research subject. Based on its geological conditions and deformation characteristics, three feasible treatment measures are proposed: micro-pile reinforcement, double-row pile support, and steel flower pipe grouting technology. By introducing the fuzzy comprehensive evaluation method, a multi-dimensional analysis is conducted, considering factors such as engineering investment, construction duration, environmental impact, and technological maturity. The results indicate that the micro-pile reinforcement scheme offers the best overall performance. Furthermore, numerical simulation of this optimal scheme using the finite element software Midas GTS NX verifies that its deformation control effectiveness and safety factors under both natural and rainstorm conditions meet standard requirements, demonstrating notable treatment effectiveness. This study provides a reliable technical approach and practical reference for similar slope engineering projects.

INTRODUCTION

Mountainous highways are important infrastructure for the production and daily life of rural residents and form the basis for the rapid development of rural revitalization[1]. Currently, rural tourism roads and key traffic routes in some domestic mountainous areas are under construction or planned. The stability of slopes along these highways is crucial not only for the safe operation

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(a) Slope Face (Looking East) **(b) Slope Face (Looking West)**

Figure 1 | Topography and Geomorphology of the Slope Area

of the roads but also for the lives and property of nearby residents.

Various slope treatment measures are now relatively mature and widely used, such as soil nailing walls, retaining walls, anti-slide piles, anchor rods, and anchor cables. Therefore, when undertaking slope treatment, the problem of scheme selection is inevitable. The problem of scheme selection in construction projects is essentially a multi-objective decision-making problem. Many experts and scholars have conducted a series of studies on this and achieved fruitful results. Qiao Jiangang et al[2] used fuzzy theory and fuzzy comprehensive evaluation to establish a fuzzy comprehensive evaluation method for the protective effect of highway slopes in mountainous areas. Zhang Xiaoling et al[3] established a two-layer fuzzy evaluation DRASTIC model based on Analytic Hierarchy Process (AHP), which can well reflect the spatial continuity of groundwater vulnerability. Wu Xiaowei et al[4] used AHP to systematically analyze key indicators such as driving habits, traffic volume, economy, safety, and efficiency in Kenya, constructing a comprehensive evaluation model for highway intersection schemes, providing references for local highway at-grade intersection design. Mao Ye[5] used the entropy weight method to establish a comprehensive evaluation method for geological disaster treatment targeting all parties involved in the project (survey, design, construction, supervision, and construction units). Wei Liang et al[6] constructed an optimal decision-making model for karst cave treatment schemes using a genetic algorithm. Deng Zongping et al[7] applied the cloud model-TOPSIS method for qualitative indicator quantification and calculation of combined subjective and objective weights, used in the comparison and selection of highway route alternatives. P. Xia et al[8] proposed a slope stability evaluation method combining group decision theory, AHP, and fuzzy comprehensive evaluation. X.L. Yao et al[9] proposed a cloud model-improved multi-level fuzzy comprehensive evaluation method for landslide risk, capable of addressing uncertainties in landslide preparation and occurrence, greatly improving the effectiveness of landslide evaluation results, providing an effective reference for landslide disaster prevention. C.G. Lai et al[10] used game theory and an FCE-based evaluation model to assess flood risk in the Dongjiang River Basin, providing a reference for flood control and mitigation applications in the basin.

Substantial achievements have been made using the fuzzy comprehensive evaluation method domestically and internationally. Based on this, this paper focuses on high slopes along mountainous highways, establishing an evaluation system for selecting the optimal prevention and control measure scheme from six aspects: engineering investment, construction period, construction difficulty, environmental impact, construction safety, and technological maturity. The fuzzy comprehensive evaluation method is used to quantify the indicators and determine the optimal treatment scheme[11][12][13].

PROJECT OVERVIEW

Geographical Location and Basic Conditions

The slope is located in Section Yangyun Road, Group 3, Sanduhe Village, Zigui County, within the Three Gorges Reservoir area. It is situated on the north slope at chainage K5+100~K5+215m of Yangyun Road, with a slope aspect of 336°, an average gradient of 21°. The slope crest is Yangyun Road at an elevation of 667m. The slope face consists of terraced farmland, overall approximating a rhombus shape, with a generally concave slope surface morphology. There are four residential households on the right side of the slope face. The current condition of the slope face is shown in **Figure 1**.

A field investigation conducted in January 2024 revealed that cracking had occurred along the centerline of the road at the slope crest, extending from west to east. The cracks measured approximately 10 cm in width and had a depth of about 0.3 m (**Figure 2**). Additionally, localized collapses were observed on the slope face (**Figure 3**). No evidence of surface subsidence

Figure 2 | Road Cracking

Figure 3 | Local Collapse at Slope Toe

was detected during the survey. According to information obtained from local residents, the cracking on the road at the slope crest initially appeared between July and August 2023 and has persisted and progressively developed since that time.

Hydrogeological Conditions

The slope area belongs to a subtropical continental climate, characterized by warm and humid conditions with relatively abundant annual rainfall, averaging about 1450mm[14]. The annual rainfall in Zigui County varies significantly, prone to droughts or floods, with heavy rains mainly concentrated from April to October, and the most frequent rainstorm days occurring in July and August[15].

The strata in this slope area mainly include Quaternary colluvial-deluvial depositsconsisting of boulders with soil ($Q_4^{ecol+dl}$)、Quaternary alluvial-proluvial silty clay (Q^{al+pl})、Quaternary organic soil (Q^{pd})、and Permian Maokou Formation (P_1m) limestone.

Quaternary Colluvial-Deluvial Deposits ($Q_4^{ecol+dl}$)

Mainly distributed at the slope crest, south side of the road, comprising boulders with soil, varying in thickness from 0 to 10m. It is thicker at the junction between the rural road and the mountain at the slope crest, thinning out along the road towards both sides. The colluvial-deluvial layer is brown-yellow, reddish-brown, etc., with loose structure and good permeability. It is mainly composed of colluvial-deluvial materials, containing numerous boulders and rock fragments, with particle sizes ranging from 1 to 30mm, angular to subangular, mostly limestone fragments.

Quaternary Alluvial-Proluvial Silty Clay (Q^{al+pl})

The stratum on the slope face is Quaternary alluvial-proluvial silty clay, reddish-brown, brown-yellow, etc., mainly distributed below the cultivated topsoil on the slope face north of Yangyun Road, with a overall distribution.

Quaternary Organic Soil (Q^{pd})

Organic soil, gray, bluish-gray, with high water content, existing as interlayers within the silty clay.

Permian Maokou Formation Limestone (P_1m)

The Permian Maokou Formation limestone ($P < sub > 1 < /sub > m$) is gray, light gray, thick-bedded massive microcrystalline limestone containing chert nodules. Joints and fissures are developed. The core recovery rate is high, and the rock core is relatively complete, with a recovery rate of 80% to 95% and an RQD of about 85%. The rock hardness is classified as moderately hard rock, the integrity is relatively complete, and the basic quality grade is III.

ANALYSIS AND COMPARISON OF PREVENTION SCHEMES

Analysis of Prevention Schemes

Through field investigations and analysis of exploration data, it has been determined that slope deformation is still developing, with local slope surface collapse occurring during the creep process, although the deep sliding surface has not yet fully connected. To curb further deformation of the slope, promptly restore road traffic, and ensure the safety of surrounding residents' lives and property as well as the operational safety of the highway, three reinforcement schemes are proposed based on the deformation characteristics of the slope and experiences from similar engineering projects. These schemes are: micro-piles combined with lattice anchor cables, double-row pile support with anti-slide piles, and steel flower pipe grouting.

Scheme 1: Micro-Pile Reinforcement.

Micro-piles with a section of φ150 are arranged along the road axis at the slope crest, spaced at 1m intervals, with a length of 25m. A reinforced concrete cap is designed at the top of the micro-piles. Two rows of micro-piles aligned with the road direction are arranged at the middle and toe of the slope. The slope face is protected using anchor cable concrete lattice

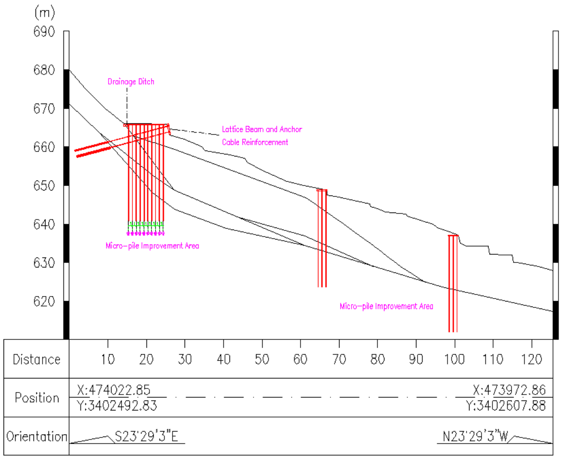


Figure 4 | Layout Profile of Scheme 1

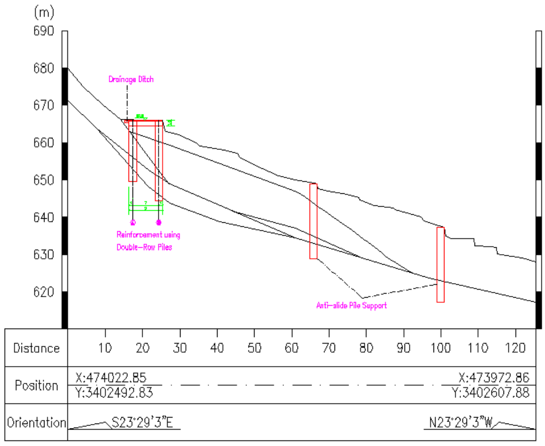


Figure 5 | Layout Profile of Scheme 2

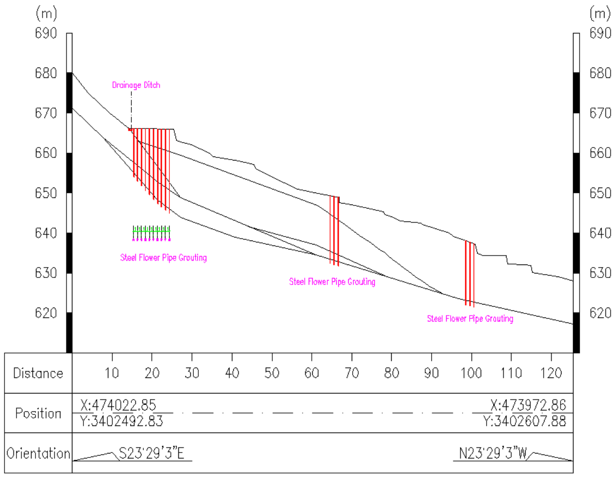


Figure 6 | Layout Profile of Scheme 3

beams. The lattice beams have horizontal and vertical spacings of 3m, with a vertical spacing of 1.5m. The anchor cables use Φ15.24 steel strands, 25m long, installed at an angle of 15°. A typical treatment cross-section is shown in **Figure 4**.

Scheme 2

Double-Row Pile Support. Piles near the mountain are 20m high with a cross-section size of 1.5×2m, totaling 25 piles. Piles farther from the mountain are 25m high with a cross-section size of 1.5×2m, totaling 25 piles. Horizontal connecting beams of 1.5×1.5m are set between the piles. A cap beam of 1.5×2m is set atop the piles. The transverse pile spacing is 6m, and the longitudinal spacing is 5m. The concrete for the pile shafts, cap beams, and connecting beams is C40. The reinforcement cover thickness for the anti-slide piles is 70mm, and for the cap beams and connecting beams, it is 50mm **(Figure 5)**.

Scheme 3

Steel Flower Pipe Grouting Support. This involves drilling and installing 108mm steel flower pipes, followed by pressure grouting using cement slurry with a water-cement ratio of 0.8:1 made from 42.5 grade ordinary Portland cement. The grouting pressure is controlled between 0.5 and 0.8 MPa per meter. Grouting is performed at the slope crest, middle, and toe **(Figure 6).**

Scheme Comparison

A comparison of the three prevention measures from the perspectives of engineering investment and construction period is shown in **Table 1**. From an economic perspective, Scheme 1 should be chosen. If considering the construction period, Scheme 3 should be selected. In traditional scheme comparisons, the factors are not quantified, which may still lead to difficulties in final scheme selection.

FUZZY COMPREHENSIVE EVALUATION METHOD

Traditional scheme comparison and selection primarily revolved around two major factors: construction duration and project cost. However, with the evolution

Table 1 | Comparison of Prevention Schemes

Scheme	Engineering Investment / 10,000 CNY	Construction Period / Month
1	698.25	4
2	1599.40	5
3	811.00	3

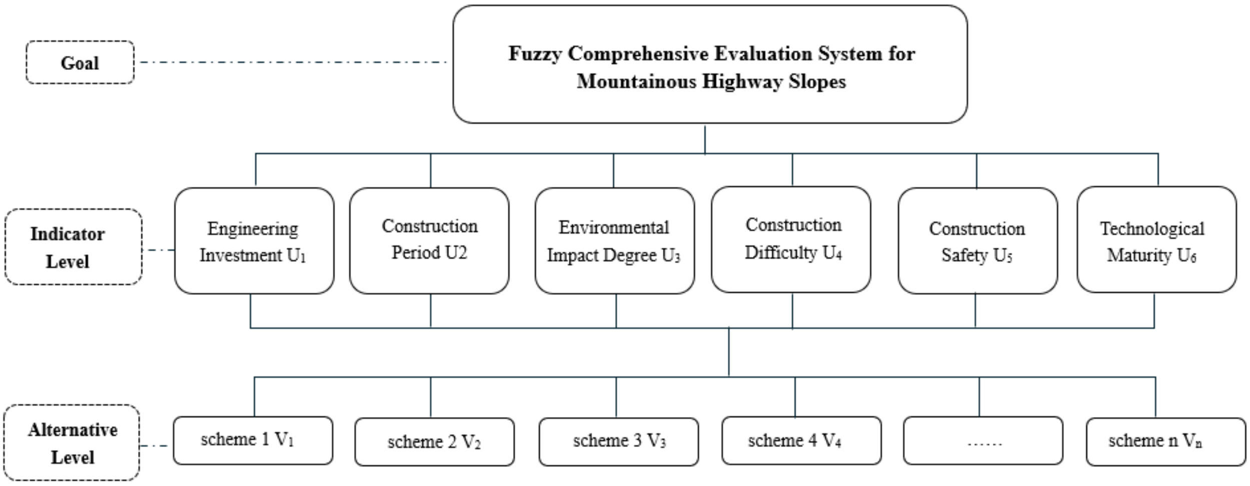


Figure 7 | Evaluation Indicator System for Selecting the Optimal Scheme for High Slope Prevention Measures on Mountainous Highways

of the era and technological advancements, the green concept has gained widespread acceptance and taken root in public consciousness. Consequently, the environmental impact of construction activities can no longer be overlooked. Furthermore, a successful engineering project is the result of effective collaboration among all stakeholders. Therefore, during project design, it is essential to consider not only the feasibility of the scheme but also the difficulty level of its construction. To address this multifaceted challenge comprehensively, the fuzzy comprehensive evaluation method is adopted. This method enables the systematic quantification of various influencing factor indicators[16]. Drawing on insights from other relevant literature and tailoring the approach to the specific context of this project, the indicators for the fuzzy comprehensive evaluation in this study encompass the following six key factors: Engineering Investment (U_1), Construction Period (U_2), Environmental Impact Degree (U_3), Construction Difficulty (U_4), Construction Safety (U_5), and Technological Maturity (U_6). These evaluation indicators form the factor set $U = (U_1, U_2, U_3, U_4, U_5, U_6)$. The corresponding set of the three schemes is the scheme set $V = (V_1, V_2, V_3)$ [17] (**Figure 7**).

Constructing the Fuzzy Judgment Matrix

Assume the fuzzy judgment matrix B is a k-th order square matrix on the scheme set $V = (V_1, V_2, V_3)$,

$$B_k = (B_{ij}^k)_{m\times m}$$

where, b_{ij} represents the relationship between scheme V_i and scheme V_j under a certain factor U_k. The elements b_{ij} in the matrix are defined as follows:

$$b_{ij} = \begin{cases} 0, & \text{when } V_i \text{ is inferior to } V_j \\ 0.5, & \text{when } V_i \text{ is equal to } V_j \\ 1, & \text{when } V_i \text{ is superior to } V_j \end{cases} \tag{3-1}$$

Thus, the fuzzy judgment matrix is expressed as follows:

$$B_k = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1m} \\ b_{21} & b_{22} & \cdots & b_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ b_{m1} & b_{m2} & \cdots & b_{mm} \end{bmatrix} \tag{3-2}$$

where $k = 1,2,\ldots,N$

Sum the rows of B_k, denoted as:

$$v_i = \sum_{j=1}^{m} b_{ij}^k \tag{3-3}$$

where $i = 1,2,\ldots,m$

Perform mathematical transformation:

$$v_{ij}^{k} = \frac{v_i - v_j}{2m} + 0.5 \quad (3\text{-}4)$$

Establish the fuzzy consistent matrix $R_K = (V_{ij}^{k})_{m\times n}$:

$$R_k = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1m} \\ v_{21} & v_{22} & \cdots & v_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mm} \end{bmatrix} \quad (3\text{-}5)$$

where $k = 1,2,\ldots,N$

Establishing the Membership Degree Matrix and Decision Matrix

Based on the fuzzy consistent matrix R_K, calculate the membership degree matrix S using the square root method. The element S_i^k in matrix S is the relative membership degree of scheme V_i under target U_k.

$$S_i^k = \frac{\bar{S}_i}{\sum_{i=1}^{m} \bar{S}_i} \quad (3\text{-}6)$$

where: $\bar{S}_i = \left(\prod_{j=1}^{m} v_{ij}^{k}\right)^{\frac{1}{m}}$,and $i = 1,2,\ldots,m$

Employing the expert scoring method, the weight vector $W = W_1, W_2, \ldots, W_n$ was calculated. The weights within this vector reflect the relative importance or proportional contribution of each influencing factor within the evaluation system[18].Subsequently, the weighted decision matrix, which incorporates these calculated weights to adjust the original decision data, can be expressed by the following formula.

$$T = S \cdot W^T = (S_{ij)_{m\times n}} \cdot w_{1\times n}^{t} \quad (3\text{-}7)$$

$$T_i = \sum_{k=1}^{n} w_k S_i^k \quad (3\text{-}8)$$

The merit of each scheme is reflected by comparing the size of T_i. A larger value indicates a better scheme, whereas a smaller value indicates a poorer comprehensive rating. Thus, the optimal prevention measure scheme can be determined.

OPTIMIZATION OF PREVENTION MEASURES

Establishing the Factor Set

Based on the previously mentioned influence factor indicator set $U = (U_1, U_2, U_3, U_4, U_5, U_6)$ and the scheme set $V = (V_1, V_2, V_3)$, the evaluation table for the influencing factors of each scheme is established (**Table 2**). The evaluation of factors for each scheme follows: Good > Fair > Poor.

Where: Engineering Investment (U_1), Construction Period (U_2), Environmental Impact Degree (U_3), Construction Difficulty (U_4), Construction Safety (U_5), Technological Maturity (U_6)

Calculating the Fuzzy Matrices

Based on the above table and formulas (3-1), (3-2), six fuzzy judgment matrices are obtained:

$$B_1 = \begin{bmatrix} 0.5 & 1 & 1 \\ 0 & 0.5 & 1 \\ 0 & 0 & 0.5 \end{bmatrix} \quad B_2 = \begin{bmatrix} 0.5 & 1 & 0 \\ 0 & 0.5 & 0 \\ 1 & 1 & 0.5 \end{bmatrix}$$

$$B_3 = \begin{bmatrix} 0.5 & 1 & 1 \\ 0 & 0.5 & 0 \\ 0 & 1 & 0.5 \end{bmatrix} \quad B_4 = \begin{bmatrix} 0.5 & 1 & 1 \\ 0 & 0.5 & 0 \\ 0 & 1 & 0.5 \end{bmatrix}$$

$$B_5 = \begin{bmatrix} 0.5 & 1 & 0 \\ 0 & 0.5 & 0 \\ 1 & 1 & 0.5 \end{bmatrix} \quad B_6 = \begin{bmatrix} 0.5 & 0 & 0 \\ 1 & 0.5 & 0 \\ 1 & 1 & 0.5 \end{bmatrix}$$

Calculate the corresponding fuzzy consistent matrices R_k according to formulas (3-3), (3-4), and (3-5):

$$R_1 = \begin{bmatrix} 0.500 & 0.667 & 0.833 \\ 0.333 & 0.500 & 0.667 \\ 0.167 & 0.333 & 0.500 \end{bmatrix} \quad R_2 = \begin{bmatrix} 0.500 & 0.667 & 0.333 \\ 0.333 & 0.500 & 0.167 \\ 0.667 & 0.833 & 0.500 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0.500 & 0.833 & 0.667 \\ 0.167 & 0.500 & 0.333 \\ 0.333 & 0.667 & 0.500 \end{bmatrix} \quad R_4 = \begin{bmatrix} 0.500 & 0.833 & 0.667 \\ 0.167 & 0.500 & 0.333 \\ 0.333 & 0.667 & 0.500 \end{bmatrix}$$

$$R_5 = \begin{bmatrix} 0.500 & 0.667 & 0.333 \\ 0.333 & 0.500 & 0.167 \\ 0.667 & 0.833 & 0.500 \end{bmatrix} \quad R_6 = \begin{bmatrix} 0.500 & 0.333 & 0.167 \\ 0.667 & 0.500 & 0.333 \\ 0.833 & 0.667 & 0.500 \end{bmatrix}$$

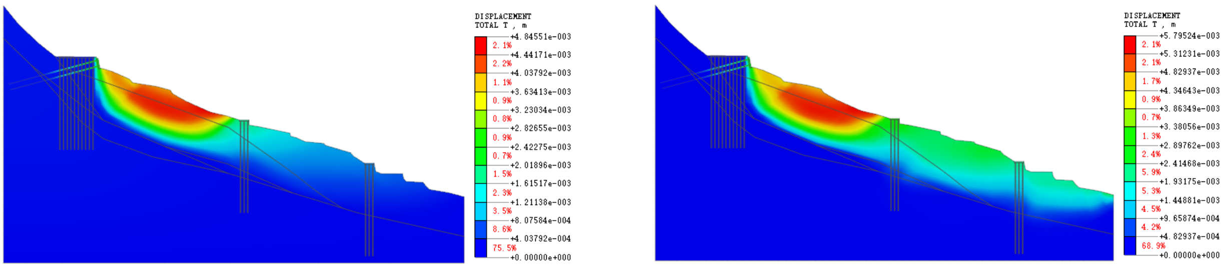
Calculate the multi-objective relative membership degree matrix S according to formula (3-6):

Table 2 | Evaluation Table of Influencing Factors for Each Scheme

Scheme	Indicators of influencing factors					
	U_1	U_2	U_3	U_4	U_5	U_6
V_1	Good	Fair	Good	Good	Fair	Poor
V_2	Fair	Poor	Poor	Poor	Poor	Fair
V_3	Poor	Good	Fair	Fair	Good	Good

Table 3 | Expert Scoring Table

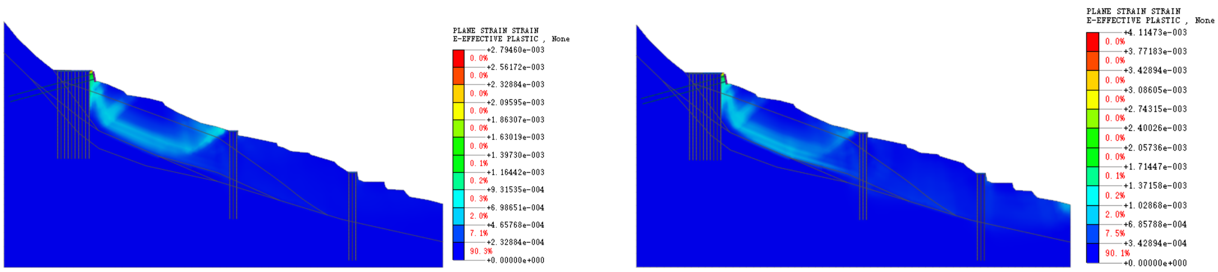
Expert	U1 (Engineering Investment)	U2 (Construction Period)	U3 (Environmental Impact Degree)	U4 (Construction Difficulty)	U5 (Construction Safety)	U6 (Technological Maturity)
1	9	9	7	6	5	3
2	10	8	8	7	6	2
3	9	9	6	7	6	3
4	9	10	8	5	6	4
5	10	9	7	7	5	2
6	8	8	8	6	4	3
7	10	8	7	6	7	2
8	9	9	8	8	6	5
9	9	10	7	5	6	5
10	9	8	6	6	7	4



(a) Total Slope Displacement after Reinforcement under Natural Condition

(b) Total Slope Displacement after Reinforcement under Rainstorm Condition

Figure 8 I Displacement Nephogram after Reinforcement



(a) Plastic Zone Nephogram after Reinforcement under Natural Condition

(b) Plastic Zone Nephogram after Reinforcement under Rainstorm Condition

Figure 9 I Plastic Zone Nephogram after Reinforcement

$$S = \begin{bmatrix} 0.454 & 0.335 & 0.454 & 0.454 & 0.335 & 0.211 \\ 0.335 & 0.211 & 0.211 & 0.211 & 0.211 & 0.335 \\ 0.221 & 0.454 & 0.335 & 0.335 & 0.454 & 0.454 \end{bmatrix}$$

Based on experience from similar projects, the expert scoring method was used to rate the influence degree of the six factors.For this project, a panel of ten distinguished experts specializing in the fields of economics and technology was invited and assembled. These experts were tasked with conducting evaluations and providing ratings based on six critical aspects, namely: engineering investment, construction period, environmental impact, construction difficulty level, construction safety, and technological maturity. The comprehensive scoring data collected from these experts, which reflects their professional assessments across these defined criteria, has been systematically compiled and is presented in detail in **Table 3**.

Based on the expert scoring table, the total scores for each influencing factor were calculated and subjected to normalization processing. The resulting weight vector for each influencing factor is as follows:

$$W = (0.2266, 0.2167, 0.1733, 0.1552, 0.1429, 0.0813)$$

Then, according to formula (3-7), calculate the decision matrix:

$$T = S \cdot W^{\mathrm{T}} = (0.3896, 0.2483, 0.3603)$$

Optimal Scheme Selection

Because $T_1 > T_3 > T_2$, therefore, for this project, considering the six factors of engineering investment, construction period, environmental impact degree, construction difficulty, construction safety, and technological maturity comprehensively, the micro-pile support scheme is superior to the double-row pile support and steel flower pipe grouting reinforcement schemes.

FINITE ELEMENT SIMULATION

A two-dimensional slope model was established using the finite element software Midas GTS NX to perform numerical simulation analysis on the slope reinforced with micro-piles. The analysis focused on examining the deformation behavior of the reinforced slope and calculating its stability safety factor, thereby evaluating the effectiveness of the optimal prevention measure.

For a typical cross-section, a two-dimensional model was developed comprising 4,482 nodes and 8,735 elements. After reinforcement, and under the natural condition, the vehicle load from the lane was applied. The deformation area was primarily concentrated in the farmland located in the middle and upper portions of the slope, as shown in **Figure 8(a)**. Under the rainstorm condition, the deformation zone exhibited some expansion and deepening compared to the natural condition, though the primary deformation region remained concentrated in the middle and upper sections of the slope body.

Specifically, for the slope reinforced with micro-piles, the maximum displacement under the natural condition was 4.845 mm, with a corresponding safety factor of 1.369. Under the rainstorm condition, the maximum displacement increased to 5.795 mm, and the safety factor was 1.329. Both the calculated displacements and safety factors under these two conditions meet the safety requirements stipulated in the "Technical Code for Building Slope Engineering" (GB 50330-2013) [19] **Figure 8(b)**.

The nephogram illustrating the plastic zone distribution of the reinforced slope under natural conditions is presented in **Figure 9(a)**. Analysis reveals that the primary deformation area is concentrated in the middle and upper sections of the slope mass. Crucially, the plastic zone in these regions is not fully connected or continuous, indicating that a complete failure mechanism has not developed.For comparison, **Figure 9(b)** displays the plastic zone nephogram under rainstorm conditions. When contrasted with Figure 9(a), it is observed that the plastic zone under the rainstorm scenario exhibits signs of deepening and expansion, reflecting the adverse effects of increased pore water pressure and reduced soil shear strength due to rainfall infiltration. However, a critical finding is that the plastic zone still remains non-continuous and does not form a fully connected shear surface.

This observed behavior under both natural and more critical rainstorm conditions leads to two significant conclusions. Firstly, it demonstrates that the reinforcement using micro-piles is effective in enhancing the slope's overall stability and preventing the formation of a coherent failure mechanism. Secondly, it validates that the prevention scheme selected through the fuzzy comprehensive evaluation method is both rational and feasible, as the numerical simulation results confirm its satisfactory performance in improving slope stability.

CONCLUSION

This paper takes the slope along the Yangyun Road section in Sanduhe Village, Zigui County, within the Three Gorges Reservoir area, as the research object. Employing the fuzzy comprehensive evaluation method, a comprehensive assessment was conducted on three prevention and control measures: micro-piles combined with lattice anchor cables, double-row piles combined with anti-slide piles, and steel flower pipe grouting. Subsequently, the finite element software Midas GTS NX was utilized to simulate the optimal reinforcement scheme. The main conclusions are as follows:

1) An evaluation index system for selecting the optimal scheme for high slope prevention measures along mountainous highways was established. The fuzzy comprehensive evaluation method was applied to quantify the evaluation indicators and compute the decision matrix. The calculation results demonstrate that the micro-pile reinforcement scheme is superior to both the steel flower pipe grouting scheme and the double-row pile support scheme, thus it can be identified as the optimal solution.
2) The evaluation indicators are scientific and reasonable, evaluating the slope treatment scheme comprehensively from six aspects: engineering investment, construction period, construction difficulty, environmental impact degree, construction safety, and technological maturity. The evaluation results reflect the engineering reality well.
3) Midas GTS NX finite element software was used to simulate the optimal slope prevention measure. The simulation results meet the requirements of current codes, verifying the feasibility and applicability of the fuzzy comprehensive evaluation method in selecting the optimal prevention measures for slopes along mountainous highways.

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