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Prevention and Control Measures and Analysis of Bedding Landslides in Marl Slopes in Guilin City

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Abstract

Bedding-parallel landslides in marl slopes in the Guilin area are prone to occur under the combined effects of dip-slope structural conditions, rainfall infiltration, and engineering disturbances, exhibiting significant structural control characteristics and distinct regional engineering geological features. Taking bedding landslides in marl slopes of Guilin as the research object, this study analyzes the fundamental characteristics of marl and the failure features of bedding rock slopes, and further investigates the main controlling factors of landslide formation. The results indicate that the development of weathering-induced fractures, unfavorable dip-slope topographic conditions, continuous rainfall-induced softening, and slope excavation disturbances are the primary factors triggering slope instability. On this basis, commonly used prevention and control measures, including slope cutting and unloading, retaining structures, combined reinforcement, vegetation protection, and drainage systems, are systematically summarized. Furthermore, two treatment schemes—anchor bolt with wire mesh and shotcrete support, and prestressed anchor cable frame beam with vegetation—are proposed based on engineering practice. A comprehensive comparison between the two schemes is conducted in terms of stability, construction conditions, economic efficiency, and ecological compatibility. The results show that Scheme I exhibits better overall stability and long-term support performance, whereas Scheme II has certain advantages in economic efficiency and environmental compatibility. It is suggested that the treatment of bedding landslides in marl slopes in Guilin should follow an integrated approach of “drainage-reinforcement-protection-monitoring”, so as to provide a reference for landslide prevention and control in similar regions.

Subject Areas

Civil Engineering

Keywords

Marl, Bedding Landslide, Formation Mechanism, Control Measures, Support Scheme

1. Introduction

Bedding landslides are a common and highly hazardous type of geological disaster in rock slopes. Their occurrence is closely related to bedding orientation, weak interlayers, fracture development, groundwater activity, and external disturbances. Previous studies have shown that bedding rock slopes, when controlled by unfavorable structural planes, often exhibit pronounced bedding-controlled sliding characteristics. The failure process is characterized by the coexistence of progressive deformation and sudden instability, and may involve tensile cracking at the rear edge, formation of a continuous sliding surface, and overall sliding under the influence of rainfall, earthquakes, reservoir level fluctuations, and engineering excavation [1]-[6].

Among them, Guo Shuangfeng *et al.* [1] pointed out that faults and bedding structural planes jointly control creep-tensile cracking deformation and failure; Zhang Ke *et al.* [2] suggested that bedding landslides generally undergo stages of initial deformation, rear-edge tension cracking, shear sliding, and overall penetration; Tang Yusheng *et al.* [3] revealed the controlling role of strain softening in weak interlayers on the progressive failure of landslides; Zhao Yuanping *et al.* [4] analyzed the initiation mechanism of bedding rock landslides under seismic loading; Ding Geyuan *et al.* [5] discussed the mechanical mechanism of buckling-type bedding landslides; and Deng Yonghuang *et al.* [6] summarized the development pattern of bedding rock landslides under different dip angles from a regional statistical perspective.

In addition to the inherent structural conditions of slopes, rainfall infiltration, groundwater activity, and engineering disturbances are also important triggering factors for bedding landslides. Zhu Zhiming *et al.* [7] showed that continuous rainfall and poor drainage of accumulated water at the rear edge can lead to lubrication of the sliding zone, softening of rock and soil, and reduction in slope stability. Wang Yu *et al.* [8] pointed out that the coupling effect of slope toe excavation and rainfall accelerates the strength degradation of weak interlayers and promotes the formation of sliding surfaces. Zhu Sainan *et al.* [9], based on studies in the Three Gorges Reservoir area, found that reservoir water level fluctuations and deterioration of the fluctuation zone significantly affect the continuous deformation and development trends of large-scale bedding landslides. Therefore, the occurrence of bedding rock landslides is generally the result of the combined effects of internal structural conditions and external hydrological, dynamic, and engineering factors.

In terms of prevention and control, previous studies generally agree that comprehensive measures should be adopted rather than a single method. Wei Qianshan *et al.* [10] proposed an integrated treatment model of "toe counterweight + slope cutting and unloading + anti-slide pile support + slope surface protection + comprehensive drainage", and verified its effectiveness. Lin Xuan *et al.* [11] suggested that anti-slide support combined with surface drainage and crack sealing can effectively reduce slope displacement and shear deformation. Overall, slope cutting and unloading, retaining structures, anchor (cable) reinforcement, slope surface protection, and drainage measures have become the main technical approaches for the treatment of bedding rock landslides.

Marl slopes, as used in this paper, refer to slopes developed in marl strata or marl-dominated weathered rock masses. Bedding-parallel landslides refer to landslides whose deformation and failure develop preferentially along bedding-controlled weak planes. Marl slopes in the Guilin area are highly susceptible to bedding-parallel landslides due to the combined effects of rainfall, weathering, karstification, and engineering disturbances. Marl is prone to weathering and softening, with well-developed fractures and significant strength reduction upon water exposure, leading to prominent stability problems in such slopes. Based on this, this study summarizes the main controlling factors and commonly used prevention and control measures, and compares two treatment schemes, in order to provide a reference for landslide mitigation in similar regions.

This study is an engineering case-based paper focusing on bedding landslides in marl slopes in Guilin. It follows a technical framework of characteristic analysis, mechanism identification, and scheme comparison. Based on the regional geological setting, field investigation, engineering survey data, and parameters from the Fenghuangshan landslide case, the paper analyzes the formation mechanism and major controlling factors of bedding landslides in marl slopes, and compares two representative treatment schemes. The main contribution of this study lies in integrating mechanism analysis with engineering prevention and control, thereby providing a useful reference for the treatment of similar bedding landslides in karst mountainous areas.

2. Geological Mechanism Analysis

2.1. Basic Characteristics of Marl

Marl is a transitional sedimentary rock between carbonate rocks and clay rocks, characterized by a muddy or fine-grained structure. In the field, it can be identified based on outcrop color, bedding features, and its reaction with dilute hydrochloric acid. Under microscopic observation, marl exhibits distinct differences from limestone in terms of grain composition, compaction characteristics, and the development of stylolites. In terms of composition, marl mainly consists of calcite and clay minerals, with minor components such as dolomite, quartz, and organic matter. Due to the coexistence of soluble components and insoluble impurities, marl is prone to dissolution under water-rock chemical interactions, which leads to microstructural degradation, crack propagation, and a reduction in mechanical strength. These characteristics determine that marl rock masses are susceptible to softening and fragmentation, and generally exhibit poor stability in engineering practice.

2.2. Structural and Failure Characteristics of Bedding Slopes

A bedding slope (dip slope) refers to a slope in which the dip direction of the rock strata is generally consistent with the slope aspect. Based on lithology, stratigraphic combination, dip angle, and layer thickness, bedding slopes can be classified into different types. The failure modes of bedding slopes are complex and include planar sliding, sliding-tensile cracking, sliding-bending, sliding-compression-induced tensile cracking, and toppling failure. Among these, sliding-tensile cracking and sliding-bending failures are the most representative. Studies have shown that the stability of bedding slopes is strongly controlled by bedding plane conditions. Factors such as excavation methods, slope angle, bedding orientation, development of structural discontinuities, and groundwater conditions all play significant roles in influencing slope stability. Therefore, bedding characteristics are the key controlling factor distinguishing bedding rock slopes from other types of slopes.

2.3. Formation Conditions and Main Controlling Factors of Bedding Landslides in Marl Slopes in Guilin

Guilin is characterized by abundant rainfall and intense weathering-dissolution of rock masses, and bedding landslides in marl slopes are therefore relatively common in this region. Taking the Fenghuangshan landslide in Pingle County as an example, the slope is covered by Quaternary residual clay and underlain by the upper member of the Middle Devonian Xindu Formation marl, mainly composed of strongly weathered and moderately weathered marl. The measured bedding attitude is approximately 155˚∠18˚, which is generally consistent with the slope aspect, indicating a typical dip-slope condition. The landslide has an elevation difference of about 25.5 m between the rear and front edges, a longitudinal length of about 40 m, a transverse width of about 80 m, and a natural slope angle of about 20˚ - 30˚. After artificial excavation, the front edge locally formed a near-vertical free face. Groundwater in the site mainly consists of Quaternary pore water and bedrock fissure water, while the moderately to slightly weathered layers have relatively poor permeability. The mean annual rainfall in the area is 1563.8 mm, with the rainy season mainly concentrated from April to August, during which intense and prolonged rainfall events are common.

Comprehensive analysis indicates that bedding landslides in marl slopes in Guilin are mainly controlled by four factors, namely: engineering geological conditions, topographic and geological structural conditions, rainfall, and human engineering activities. Field investigation and the engineering case show that marl is strongly weathered and highly fractured, and locally softens and disintegrates upon wetting, which facilitates the formation of weak structural planes. The dip-slope structure, together with fracture cutting, provides favorable conditions for sliding along bedding planes. Rainfall infiltration along fractures and bedding planes readily softens the weathered layer and the sliding-zone soil, thereby reducing the shear strength of the slope. In addition, excavation at the slope front disturbs the original stress equilibrium and accelerates fracture propagation and slope deformation. Overall, slope failure in Guilin marl slopes results from the combined effects of weathering-induced fracturing, dip-slope structure, rainfall infiltration and softening, and engineering disturbance.

3. Classification of Support Measures for Marl Landslides

3.1. Slope Cutting and Unloading

This method is commonly used for stabilizing push-type landslides, in which the rear part of the sliding mass pushes the front part downslope, but is generally not applicable to traction-type landslides, which are typically initiated by unloading or failure at the slope toe/front edge and then retrogressively propagate upslope, or to internal slope failures. The design of this method is based on stability calculations and must also be adapted to local geological conditions.

This measure is suitable for weathered marl bedding slopes in Guilin where sufficient room is available at the slope front for regrading, and where shallow to medium-depth translational deformation dominates so that unloading can effectively reduce the driving force; however, it is generally unsuitable as a stand-alone measure for slopes with obvious rear-edge tensile cracking, strong free-face conditions at the toe, or pronounced traction-type failure characteristics. (See **Figure 1**)

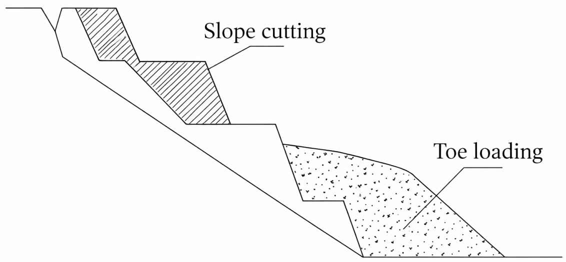

Figure 1. Schematic diagram of slope cutting and unloading.

3.2. Retaining Structures

Retaining walls increase the anti-sliding force of the sliding mass by their self-weight, thereby resisting the thrust of the landslide. They are commonly used for shallow landslides with loose and fragmented materials, where the sliding bed is relatively strong and has a high bearing capacity. However, they are generally not suitable for landslides with weak sliding beds or where the sliding surface tends to develop upward or downward. (See **Figure 2**)

This measure is suitable for bedding slopes with relatively shallow sliding masses, adequate space for construction at the slope toe, and relatively high bearing capacity of the sliding bed, especially where the slope consists mainly of fragmented and loose weathered marl; however, it is not appropriate for slopes with weak sliding beds, potential upward or downward extension of the sliding surface, or significant groundwater influence.

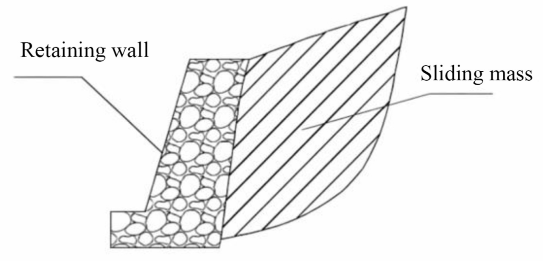

Figure 2. Schematic diagram of retaining structure.

3.3. Combined Reinforcement

In engineering practice, a single reinforcement method often has certain limitations. When a single method cannot achieve the desired stabilization effect, combined reinforcement measures can be adopted according to site-specific geological conditions and engineering requirements. Common combined reinforcement methods include anchor bolts combined with slope cutting and unloading; reinforced concrete piles combined with anchor bolts; and drilled steel rail anti-slide piles. (See **Figures 3-5**)

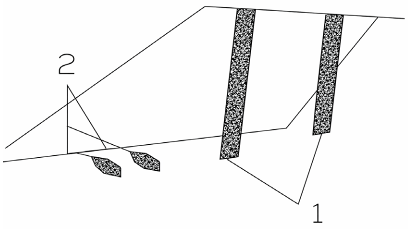

Figure 3. Reinforced concrete piles with anchor bolts (1—reinforced concrete pile; 2—anchor bolt).

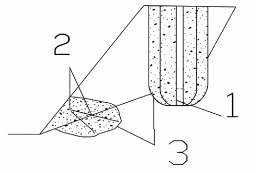

Figure 4. Reinforced concrete piles and anchor bolts with rock grouting zone (1—reinforced concrete pile; 2—anchor bolt; 3—grouting zone).

This measure is suitable for marl bedding slopes in Guilin that are affected simultaneously by weathering fractures, dip-slope structure, rainfall infiltration, and engineering disturbance, and for which a single treatment method cannot meet stability requirements; in contrast, it is generally unnecessary for slopes of limited scale and minor deformation that can be adequately stabilized by a single treatment measure.

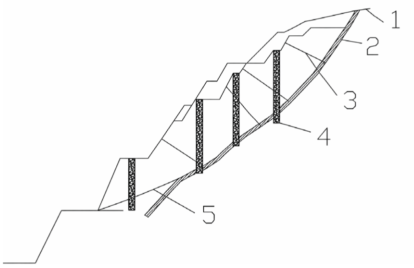

Figure 5. Combined system of drilled anti-slide piles, anchor bolts, and slope cutting (1—original slope; 2—lamprophyre; 3—prestressed anchor bolt; 4—drilled anti-slide pile; 5—smooth joint surface).

3.4. Vegetation Protection

Studies have shown that wind speed measured on exposed highway slopes is approximately 8 times higher than that on grassland and 15 times higher than that in forested areas. Higher wind speeds generally intensify wind erosion, which is unfavorable for moisture retention. When combined with poor soil conditions and large temperature differences, complex microclimates may form, posing significant threats to slope stability. In recent years, with increasing environmental awareness and improved living standards, vegetation-based slope protection has developed rapidly. On slopes suitable for plant growth, planting appropriate vegetation can not only improve the landscape and restore ecological balance disturbed by construction, but also protect slopes from wind erosion and rainfall-induced erosion, aligning with the concept of green slope protection. The influence of vegetation on slope stability mainly involves two mechanisms: hydrological and mechanical.

1) Hydrological Mechanism

The hydrological effect of vegetation refers to the interception of rainfall by plant canopies, which reduces the splash erosion of soil particles. Meanwhile, vegetation enhances water retention and delays surface runoff, thereby reducing soil erosion. In addition, the litter layer (fallen leaves and branches) acts as a filter and buffer, similar to a sponge, which slows, disperses, and filters surface runoff, preventing further development of sheet erosion and gully erosion.

2) Mechanical Mechanism

According to the root anchorage theory, shallow roots mainly provide reinforcement, while deep roots provide anchorage. These characteristics are consistent with modern anchorage support principles. Herbaceous plants have high vegetation coverage but shallow and easily degradable root systems, thus providing significant reinforcement effects. In contrast, shrubs and trees have well-developed root systems with strong soil-binding capacity, offering significant anchorage effects. The reinforcement effect of shallow roots contributes to resisting overturning. When external forces tend to induce overturning of the slope, vegetation and soil act as an integrated system, making it difficult for roots to be pulled out without damage. The anchorage effect of deep roots becomes significant when sliding tends to occur, as deep roots act similarly to anchor bolts, effectively restraining slope deformation.

This measure is suitable for surface protection of marl bedding slopes with relatively gentle gradients, evident shallow weathering, and ecological restoration demands; however, it should not be used alone on steep slopes, actively deforming slopes, or slopes subject to strong surface runoff erosion and seepage effects.

3.5. Drainage Measures

The rainfall is one of the primary factors affecting slope stability, which has been widely recognized in slope stability studies. However, the mechanism of rainfall-induced instability is complex and depends on rainfall intensity, rainfall pattern, infiltration conditions, and local climatic and environmental factors. In general, the effects can be summarized into two aspects: Rainwater infiltration raises the groundwater level within the slope, increases moisture content, and reduces the overall mechanical strength of the slope; Seepage water increases the unit weight of the slope mass, thereby increasing gravitational forces and reducing slope stability.

Drainage measures mainly include: 1) surface drainage of subgrade; 2) pavement drainage; 3) installation of drainage ditches or subdrains; 4) subgrade drainage systems.

This measure is applicable to all kinds of marl bedding slopes in Guilin that are significantly affected by intense rainfall and fracture-controlled infiltration, and it should be prioritized as a key control measure; however, for slopes where a distinct sliding zone has already developed and deformation continues, drainage alone is generally insufficient as the sole treatment method.

4. Slope Support Schemes in Guilin

Based on the regional geological data, field investigations, and geotechnical survey reports of the project area, together with the preceding analysis of the landslide formation mechanism, slope geological structure, and stability conditions, the slope treatment should primarily aim to improve overall stability, control deformation associated with bedding-parallel sliding, and ensure the safety of buildings and structures located at the slope toe, while also taking into account constructability, economic efficiency, and environmental compatibility. Considering that the potential sliding of this slope is mainly controlled by weak structural planes within the weathered marl, and that the slope is characterized by a pronounced free face at the front as well as significant rainfall infiltration effects, the selection of treatment schemes should also comprehensively consider construction space constraints and drainage requirements. On this basis, two slope protection and reinforcement schemes are proposed: Scheme I involves slope cutting followed by anchor bolts, wire mesh, and shotcrete, supplemented by a drainage system and monitoring measures; Scheme II adopts prestressed anchor cables (or anchor bolts) with frame beams and vegetation, also supplemented by a drainage system and monitoring measures.

4.1. Scheme I: Protection and Reinforcement Engineering

Scheme I is primarily intended to improve overall slope stability and ensure long-term support performance. It is suitable for slopes with a pronounced free face at the front, high safety requirements, and sufficient conditions for slope trimming and surface reinforcement works. In view of the susceptibility of weathered marl bedding slopes to rainfall infiltration and shallow sliding, this scheme adopts a combined approach of slope cutting and unloading, anchor bolts with wire mesh and shotcrete, together with drainage protection, so as to enhance the integrity of the slope mass and control further deformation.

4.1.1. Drainage Engineering

1) Layout of Drainage System

The layout of the drainage system is an indispensable component in the treatment of landslide instability. The purpose of drainage design is to reduce the infiltration of rainfall and surface water into the slope mass. A well-designed drainage system ensures efficient discharge of surface water, thereby significantly reducing the adverse effects of water on slope stability. According to site conditions, an interception ditch is arranged at the rear edge of the newly formed slope crest after slope cutting to intercept surface runoff from the upper slope. In addition, interception ditches are arranged on the berms (platforms) of the slope, which are connected to the existing drainage system of the site (hospital drainage system), ensuring smooth surface water discharge.

2) Design of Drainage System

Table 1. Design results of surface drainage engineering of scheme one.

Ditch Section and Location	Design Discharge (m^3/s)	Design Flow Velocity (m/s)	Cross-Sectional Area (m^2)	Design Rectangular Dimensions	
				Height (m)	Width (m)
Slope Crest	0.062	0.5	0.25	0.5	0.5
Slope Toe	0.108	0.5	0.25	0.5	0.5
Berm Interception Ditch	0.054	0.3	0.09	0.3	0.3

To prevent surface water from infiltrating into the subsurface and affecting slope stability, an interception ditch is installed at the rear edge of the newly formed slope crest after slope cutting to capture runoff from the upper slope. Interception ditches are also arranged along the slope berms and connected to the existing drainage system, ensuring smooth drainage and minimizing adverse impacts on the slope mass. Based on the topography, geomorphology, and watershed boundaries of the slope area, the catchment division and layout of drainage ditches are determined. The cross-section of the drainage ditch is designed as a rectangular section. The hydraulic design and optimization results of the geometric dimensions of each drainage ditch section are presented in **Table 1**.

3) Structural Design of Drainage Engineering

Channel lining: To prevent erosion and seepage, the ditch bottom is lined with C20 concrete with a thickness of 0.1 m. The side walls of the ditch are constructed using M7.5 mortar masonry, with a lining thickness of 0.24 m. The surface of the ditch is plastered with M10 cement mortar with a thickness of 15 mm.

4.1.2. Anchor Bolt with Wire Mesh and Shotcrete Engineering

1) Calculation of Anchor Cable Cross-Sectional Area

$$A_g = \frac{kN}{f_{ptk}} \tag{1}$$

where:

k—safety factor;

N—design axial load of the anchor cable;

f_{ptk}—design tensile strength of the material.

2) Calculation of Anchorage Length

$$L_a = \frac{kN}{\pi D f_{rb}} \tag{2}$$

where:

D—diameter of the anchorage body;

f_{rb}—design bond strength between the anchorage body surface and the surrounding rock/soil mass.

$$l_a = \frac{kN}{\xi n \pi d f_b \psi} \tag{3}$$

where:

ξ—working condition coefficient of bond strength between steel strands and cement mortar;

n—number of steel strands;

d—diameter of steel strands;

f_b—design bond strength between mortar and steel strands;

ψ—influence coefficient of anchorage length on bond strength.

To prevent the rolling of weathered and fragmented rock blocks, which may threaten the safety of people and property at the slope toe, anchor bolts combined with wire mesh and shotcrete are adopted for slope surface protection. HRB235-grade steel bars with a diameter of φ25 mm are used as anchor heads. For the first-stage slope, the designed pull-out capacity of anchor bolts is 50 kN with a length of 6.0 m. For the second-stage slope, anchor bolts are arranged in a staggered (quincunx) pattern, with a length of 9.0 m and a designed pull-out capacity of 60 kN.

The spacing is 2.0 m × 2.0 m in both horizontal and vertical directions, and the inclination angle of the anchor bolts is $\theta = 25^\circ$. The borehole diameter is φ90 mm, and the holes are grouted with M25 cement mortar. A single layer of φ8@200 steel wire mesh is installed on the slope surface, followed by spraying C20 concrete with a thickness of 10 cm. Expansion joints are arranged along the slope at intervals of 15 - 20 m, with a joint width of 25 mm, filled with asphalt hemp fiber or asphalt mastic.

4.2. Scheme II: Protection and Reinforcement Engineering

Scheme II, while satisfying the basic stability requirements of the slope, places greater emphasis on ecological restoration, adaptability to construction conditions, and economic efficiency. It is suitable for slopes where construction conditions are relatively constrained, environmental disturbance should be minimized, and slope landscape effects need to be considered. In response to the pronounced shallow deformation and rainfall erosion commonly observed in weathered marl bedding slopes, this scheme adopts prestressed anchor cables (or anchor bolts) with frame beams and vegetation, combined with drainage protection, so as to integrate structural support, slope protection, and ecological compatibility.

4.2.1. Drainage Engineering

1) Layout of Drainage System

According to site conditions, an interception ditch is arranged at the rear edge of the newly formed slope crest after slope cutting to intercept surface runoff from the upper slope. In addition, interception ditches are arranged on the berms of the slope and connected to the existing drainage system (hospital drainage system), ensuring effective surface water discharge.

2) Design of Drainage System

To prevent surface water from infiltrating into the subsurface and affecting slope stability, an interception ditch is arranged at the rear edge on the left side of the slope crest to intercept runoff from the upper slope. The interception ditch is connected to the existing drainage system to ensure smooth drainage and reduce adverse impacts on the slope. Based on the topography, geomorphology, and watershed boundaries of the slope area, the catchment division and layout of drainage ditches are determined. The cross-section of the drainage ditch is designed as a rectangular section. The hydraulic design and optimization results of the geometric dimensions of each drainage ditch section are shown in Table 2.

Table 2. Design results of surface drainage engineering of scheme two.

Ditch Section and Location	Design Discharge (m^3/s)	Design Flow Velocity (m/s)	Cross-Sectional Area (m^2)	Design Rectangular Dimensions	
				Height (m)	Width (m)
Slope Crest	0.062	0.5	0.25	0.5	0.5
Slope Toe	0.108	0.5	0.25	0.5	0.5

3) Structural Design of Drainage Engineering

Channel lining: To prevent erosion and seepage, the ditch bottom is lined with C20 concrete with a thickness of 0.1 m. The side walls are constructed using M7.5 mortar masonry, with a lining thickness of 0.24 m. The ditch surface is finished with M10 cement mortar with a thickness of 15 mm.

4.2.2. Prestressed Anchor Cable Frame Beam Engineering

1) Layout of Prestressed Anchor Cable Frame Beam

To ensure the overall stability of the slope and mitigate the adverse effects of weathering and rainfall erosion, a prestressed anchor cable frame beam system is designed for effective protection based on the actual conditions of the Fenghuangshan landslide in Pingle County, Guilin. The anchor cables and frame beams work together as an integrated system, providing overall reinforcement for the entire slope. The anchor cables mainly resist tensile (pull-out) forces, while the frame beams primarily function to resist surface weathering and rainfall erosion. This combined point-surface reinforcement approach effectively enhances slope stability.

2) Design of Prestressed Anchor Cable Frame Beam

The designed pull-out capacity of a single anchor cable is 650 kN. The anchorage length is 6.0 m, and the total length is 18.0 m, with a spacing of 2.0 m × 2.0 m. The inclination angle (dip angle) of the anchor cable is 25˚ relative to the horizontal. The borehole diameter is φ150 mm, and the holes are grouted with M30 cement mortar. The frame beam adopts a cast-in-place reinforced concrete structure with a cross-section of 600 × 400 mm. The concrete strength grade is C25. The longitudinal reinforcement consists of six HRB335 steel bars with a diameter of φ16 mm, while the stirrups are HPB235 steel bars with a diameter of φ8 mm at a spacing of 200 mm.

5. Scheme Comparison

Scheme I adopts anchor bolts combined with wire mesh and shotcrete after slope cutting and unloading. In this support system, anchor bolts can significantly enhance slope stability, providing good safety performance. The construction process is relatively simple, efficient, and of moderate difficulty. The combination of anchor bolts and shotcrete with wire mesh offers good integrity and reliability for slope support. In addition, natural slope cutting simplifies the construction process. However, this scheme also has some disadvantages. As a concealed support system, post-construction inspection and monitoring of anchor bolts are relatively difficult, and unexpected failures such as local collapse may occur without obvious precursors. During shotcrete construction, it is difficult to precisely control the water-cement ratio, and the construction environment is often harsh, posing potential health risks to workers. Moreover, artificial slope cutting may cause considerable disturbance to the natural environment and potentially induce secondary hazards.

Scheme II adopts a prestressed anchor cable (or anchor bolt) frame beam system combined with vegetation. The frame structure itself mainly serves as a load-transferring system, while the anti-sliding resistance is primarily provided by anchor cables or anchor bolts at the frame joints. This technique has advantages such as flexible layout, diverse structural forms, convenient adjustment of cross-sections, and good conformity with the slope surface. The anchor cable (or bolt) frame beam with vegetation exhibits good overall integrity and provides a certain degree of stability. Furthermore, it offers a more natural appearance and integrates well with the surrounding environment, avoiding abrupt visual impacts and conforming to the concept of green slope protection. However, its long-term stability is inferior to that of the anchor bolt with shotcrete system, and thus it is less commonly applied in large-scale high slopes. Through comprehensive comparison, both schemes cause relatively limited environmental disturbance and have minimal impact on land use after construction. Landscape facilities can be arranged on the slope surface to improve the driving environment. Scheme I demonstrates superior overall stability, better control of local deformation, and more durable support performance compared to Scheme II, although it involves higher costs. Scheme II has advantages in economic efficiency and construction techniques, and causes less environmental disturbance, aligning well with green engineering concepts. Hereafter, Scheme II may be adopted under constrained conditions. However, when conditions permit, Scheme I is recommended from the perspective of long-term stability and support performance.

6. Conclusions

1) Marl in Guilin is characterized by easy softening, low strength, and well-developed fractures. Under the combined effects of dip-slope structure, rainfall infiltration, and engineering disturbances, bedding landslides are prone to occur, exhibiting significant structural control characteristics.

2) The treatment of bedding landslides in marl slopes should follow the principle of combining engineering reinforcement with drainage measures. Comprehensive approaches, including slope cutting and unloading, anchor (cable) reinforcement, retaining structures, and drainage protection, should be adopted to improve overall slope stability.

3) The two proposed treatment schemes each have their own advantages. Scheme I provides better stability and long-term support performance, while Scheme II shows advantages in economic efficiency and ecological compatibility. In practical engineering, the selection should be made based on specific site conditions.

Conflicts of Interest

The authors declare no conflicts of interest.

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