Analysis of the effectiveness of landslide stabilization in a near-dam reservoir area

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Abstract. The geological conditions of the landslide area in a near-dam reservoir area of a water conservancy hub project are complicated, and the stability problem of the landslide body is prominent, which is not only directly related to the safety of the adjacent office building and highway, but also poses a threat to the normal operation of the water conservancy hub. According to the latest geological data of the landslide area, the results of the stability calculation of the landslide body are analyzed, and the reinforcement design scheme of circular chair type anti-slide piles & prestressed anchor cables is proposed for the landslide body to solve the problem of anti-slide stability of the landslide body. Numerical analysis results show that: the safety factor under each working condition after reinforcement is within the permissible range and meets the relevant normative requirements, the landslide body has good control effect on deformation after reinforcement, and the reinforcement measures can provide certain reference value for the design and construction of similar projects.

Keywords: Landslide; Reinforcement measures; Anti-slide pile; Anchor rope; Numerical analysis.

1. Introduction

In recent years, complex geological structure and factors such as rainfall and earthquakes have led to frequent landslide disasters in China, resulting in huge losses, and in-depth study of landslide prevention and reinforcement is of great significance. At present, the study of landslide stability and formation mechanism is a research hotspot, a large number of theoretical studies and engineering practice shows that the formation of landslides is a result of the internal factors such as the nature of the rock and soil body that compose the slope, the structural structure and the shape of the slope, and the external factors such as the role of water, earthquakes and the influence of human factors [1-6].

Anti-slide pile support structure can effectively reduce the landslide hazard and maintain the stability of the landslide body [7,8]. However, some projects under complex conditions can’t meet the design requirements by only using anti-slide piles for support. Based on comparing the ways of reinforcing the landslide body studied by the previous researchers, taking into account that the pull-anchor type support structure has the characteristics of low cost, short construction period and easy to control the deformation of the landslide body [9-11]. According to the actual project, the reinforcement design scheme of circular chair type anti-slide piles & prestressed anchor cables is proposed for the landslide body, the anti-slide piles are set at the leading edge of the landslide body, and several rows of anchor cables are added at the top of the anti-slide piles at the side of the trailing edge of the landslide body. The finite element software is used to establish the model for analysis, and the Mohr-Coulomb model is selected as the intrinsic model of the soil body, and the numerical analyses of the natural working condition, rainfall working condition and seismic working condition are carried out respectively.

2. Project Overview

This landslide area is located in Gansu Province, a water conservancy hub project near the dam reservoir area, the landslide body from the guide hole inlet of about 600m, from the dam axis of about 1.1km, and in the landslide body downstream near the edge of the side of the construction of office buildings and other facilities, the landslide body of the middle of the 2240m elevation of the nearby construction of the rerouting highway. The reservoir of the water conservancy hub project is a typical valley-type reservoir, with a designed normal storage level of 2202m, a backwater length of about 53.4km, and the river channel occupies almost the entire valley bottom, and the leading edge of the landslide below the normal storage level elevation has been completely submerged underwater, as shown in Fig. 1. The stability problem of this landslide is not only directly related to the safety and normal operation of office buildings and highways, but also threatens the safety and normal operation of the water conservancy hub.

Fig. 1 Aerial view of the landslide area

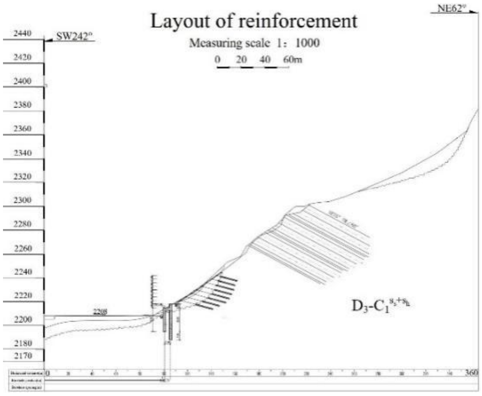


Fig. 2 Layout of reinforcement of landslide

The area of this landslide stabilization is the downstream area of the landslide, i.e. the back part of the office building, the strip is 90-206m wide, the top and bottom is wide and the middle is narrow, in the shape of a bone, which is the current stable area. The landslide area is located in the back side of the office building on the slope, an area of 39,300m2, the square volume of 650,700m3. 300-330m in length, 90-206m in width, the plane shape of the irregular double hump; the back edge of the body of the landslide in this area is 2393m in elevation, and the front edge of the body of the landslide to the back of the office building, the elevation of the elevation of the 2246m, the elevation difference of 147m; the slopes of the body of the landslide are slower, generally 20°-28°, the average of about 25°, after the office building slope body slightly steeper 30°-34°, after the office building slopes many times cut slope load reduction after the status quo, the landslide body after the edge of the rupture wall slopes 50°-73° ranging from the back edge of the steep cliff geomorphology and the more gentle slopes; after the edge and downstream boundary basically extends to the steep cliffs of the composition of gray rock, the landslide area has been a number of times slopes to reduce the load, cut the slopes of the governance of the wrong platform demarcation, the leading edge to the back of the office building.

Field investigation shows that the surface material of the landslide body in this area mainly consists of the debris of cherts from the steep bank slopes at the back edge, and the debris of sand and shale blocks as well as the material from the fault zones underneath the landslide body. According to the exploration borehole disclosure, the maximum thickness of the original landslide body can be up to 50m-55m, later after cutting the slope load reduction treatment, the current thickness of up to 32.0m; constitute the area of the landslide body of the undulating lithology for the Upper Devonian - Lower Carboniferous Uniform (D3-C1) sandstone, shale, in the back of the Upper Carboniferous - Lower Permian Uniform (C3-P1) of the huge thick layer of graywacke to form the bedrock precipitous geomorphology, the leading edge of the slope body parts of the A large-scale regional F2 fault is developed at the leading edge of the slope.

3. Designing Measures of Reinforcement Treatments

As shown in Fig. 2, this project landslide reinforcement program is designed as follows: the strong foot design for Φ2.0m@5.0m the round chair anti-slide piles, row spacing 5.0m, the front row of piles is 20.0m long, the back row of piles is 30.0m long, top-of-pile elevation of front row of piles 2215.00 meters, top pile elevation of the back row of piles is 2218.00 meters. Among them, due to the thicker layer of soil in the landslide body accumulation, it adopts anti-slide piles & pre-stressing anchors for the support. The vertical incidence angle of the prestressing anchor cable is 15°, and the vertical and horizontal spacing between the anchor cables is 3m.

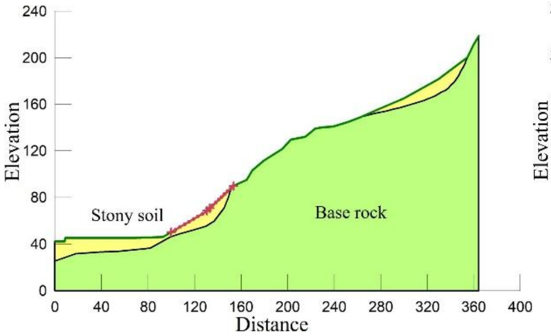
4. Establishment of Numerical Analysis Model

Numerical analysis was carried out using the finite element software Geo-Studio, which has been widely used in the analysis of the geotechnical engineering field in the civil engineering profession. Due to the complexity of the soil itself, only c and φ will generally be provided in the investigation data of the actual project. Coulomb firstly proposed the Mohr-Coulomb model in 1773.As long as the τ value of the force surface of the soil unit reaches the limiting value, the soil body will then tend to the yielding limit state, which is also referred to as the damage state. The damage criterion of Mohr-Coulomb is usually regarded as an elastoplastic model, and the shear bearing capacity of the soil body is emphasized in this model. Due to the above advantages of the Mohr-Coulomb model and its good results in terms of analysis, computation, and accuracy, this model is chosen as the constitutive model for the soil body. The Physical and mechanical parameters of the soil are shown in Table 1.

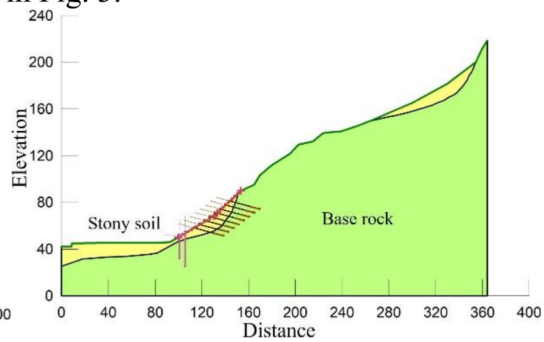
Table 1. Physical and mechanical parameters of the soil

Soil strata	Cohesion (*kPa*)	Internal friction angle (°)	Unit weight (kN/m^3)	Constrained modulus (*GPa*)	Poisson's ratio
Stony soil	20	31	21	0.3	0.36
Base rock	1000	45	26	60	0.24

In order to comprehensively analyze the landslide, numerical analyses of the landslide were conducted for natural, rainfall and seismic conditions before and after reinforcement, and the models before and after reinforcement are shown in Fig. 3.



(a) Pre-reinforcement



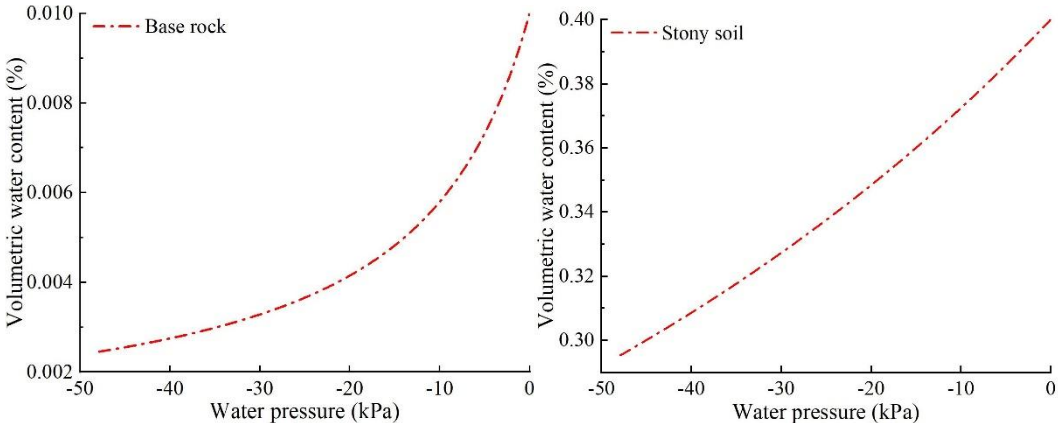
(b) After reinforcement

Fig. 3 Numerical analysis model

The rainfall conditions were calculated for 9 days of continuous rainfall, the specific values of the soil parameters are shown in Table 2, and the hydraulic pressure-volumetric water content relationship for each soil is shown in Fig. 4.

Table 2. Parameters of each soil body under rainfall conditions

Soil strata	Saturated permeability coefficient (*m/d*)	Humidification paths				Rainfall intensity (*mm/d*)
		a	*m*	*n*	θ_s	
Stony soil	1.728	100	1	2	0.4	100
Base rock	0.04	10	1	2	0.01	



（a）Base rock （b）Stony soil

Fig. 4 Hydraulic pressure-volumetric water content relationship of soil body

According to the "China Earthquake Parameter Zoning Map" (GB18306-2015), the peak acceleration of ground shaking in the area where the project area is located is 0.20g, and the intensity of earthquake is VIII. When the proposed static method is adopted to analyze the stability of the landslide under the seismic condition, the seismic acceleration coefficient kh=0.2 is selected, and when the Newmark deformation method is adopted to analyze the displacement of the landslide under the seismic condition, the EI-Centro wave with a peak acceleration of 0.2g is selected as the example waveform, and the time-range curve of seismic wave is shown in Fig. 5.

5. Numerical Analysis Results

5.1 Factor of Safety Under Rainfall Conditions

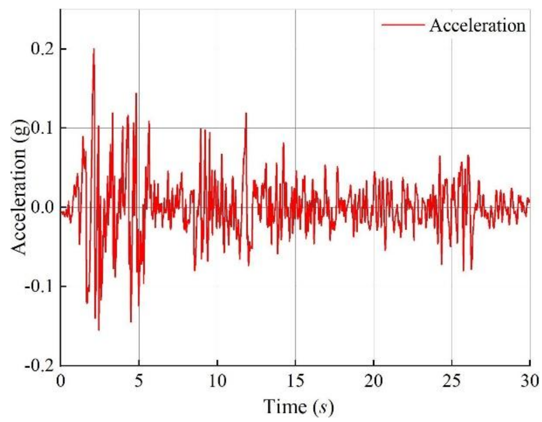


Fig. 5 EI-Centro seismic wave time-range curve

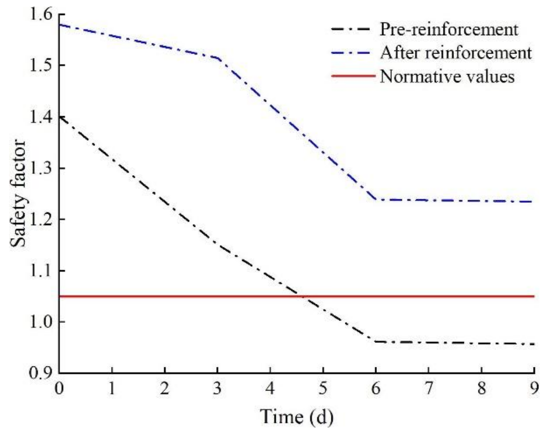
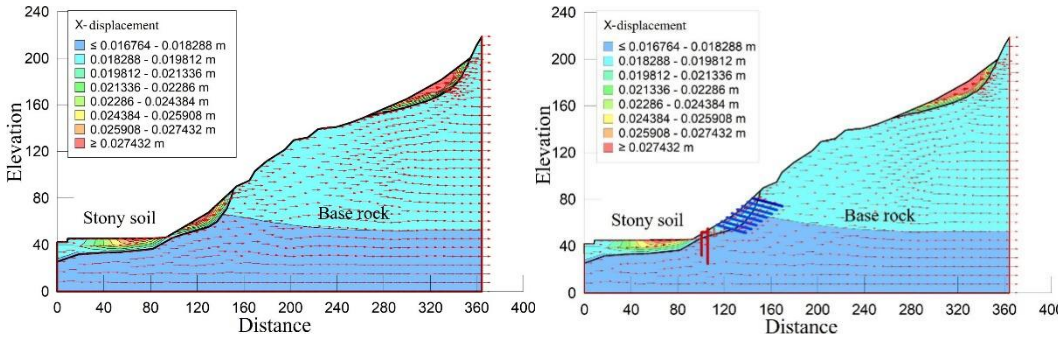


Fig. 6 Rainfall time course curve

As can be seen from Fig. 6, based on the reinforcement measures proposed in this paper, the minimum factor of safety before and after reinforcement decreases with the increase of rainfall duration under rainfall conditions. Before reinforcement, after 5 days of rainfall, the minimum factor of safety is less than the minimum value specified in the code, and the landslide body has the risk of damage. This is due to the fact that as rainfall duration increases, the degree of pore water infiltration increases, and rainfall infiltration reduces the shear strength of the soil on the slope. After reinforcement, the minimum factor of safety increased by 12.75%-31.60% during the 9 days of sustained rainfall and were within the code allowable limits.

5.2 Deformation Under Seismic Conditions



(a) Pre-reinforcement (b) After reinforcement

Fig. 7 Deformation during earthquakes

From Fig. 7, it can be seen that under seismic conditions, the displacement of the landslide body before reinforcement is more than 27.43 mm, while the displacement after reinforcement is about 18.29 mm, which is reduced by 33.32% relative to the pre-reinforcement, and the reinforcement measures significantly reduce the displacement of the landslide body under seismic action.

5.3 Safety Factors for Three Operating Conditions

Table 3. Minimum factor of safety for landslides under various operating conditions

Operating conditions	Pre-reinforcement	After reinforcement	Normative values
Natural conditions	1.401	1.580	1.25
Rainfall conditions (9d)	0.957	1.235	1.05
Seismic conditions	0.995	1.174	1.05

As shown in Table 3, the minimum safety coefficients of the landslides before and after reinforcement under each working condition were calculated. Under natural working conditions, the minimum safety coefficients before and after reinforcement are within the allowable range of the code, and the minimum safety coefficients after reinforcement are increased by 12.78% relative to the pre-reinforcement; under rainfall and seismic conditions, the minimum safety coefficients before reinforcement don't satisfy the code requirements, and the minimum safety coefficients after reinforcement meet the allowable range of the code, and the minimum safety coefficients after reinforcement are increased by 10.95% and 28.99% relative to the pre-reinforcement.

6. Conclusion

This paper is based on a water conservancy hub project near the dam reservoir area landslide reinforcement project reality, design circular chair anti-slide piles & prestressed anchor cable reinforcement program, before and after the reinforcement of the landslide body in the natural conditions, rainfall conditions and seismic conditions of the three conditions of numerical analysis, and reached the following conclusions:

(1) Under natural working conditions, the minimum factor of safety (MFS) before and after reinforcement are within the allowed range of the specification, and the MFS after reinforcement is increased by 12.78% compared with that before reinforcement, and the design scheme of reinforcement makes the landslide body more stable under natural working conditions.

(2) Under the rainfall condition, the minimum factor of safety before and after reinforcement decreased with the increase of rainfall duration. Before the stabilization, the safety coefficient of the landslide was lower than the standard value after the rainfall lasted for 5 days. After reinforcement, the minimum factor of safety increased by 12.75%-31.60% within 9 days of continuous rainfall, and the reinforcement measures enabled the minimum factor of safety to reach above the normative value during continuous rainfall.

(3) Under the seismic condition, the displacement of the landslide body before and after reinforcement was reduced by about 33.32%, and the reinforcement measures made the

displacement of the landslide body under the seismic action reduced significantly, and fully realized the combined effect of the prestressing anchors and anti-slide piles, which could effectively control the deformation of the landslide body.

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