Study on Deformation Characteristics and Prevention Measures of Ancient Landslide under the Influence of Multi Intensity Cyclic Rainfall

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Abstract: In order to explore the deformation and reactivation characteristics of ancient landslide under the influence of cyclic rainfall with different intensities, taking shaojiazhuang section of Kaili Ring Expressway as an example, the displacement on the top of slope, deep displacement of slope and rainfall activity were collected based on field monitoring method, and the correlation between slope displacement and rainfall activity was analyzed. Furthermore, the applicability of different control measures such as load reduction of slope excavation and anti slide pile under the influence of cyclic rainfall is compared by numerical simulation. The results show that: (1) In the process of rainfall, the influence degree of various factors on slope stability is as follows: the amount of rainfall > groundwater level > short-term rainfall intensity. The change of slope stability under cyclic rainfall can be judged by the ratio s' / s of displacement increase to rebound. When the ratio is less than 15%, landslide and other geological disasters are likely to occur near the measuring point; (2) The deep sliding of ancient landslide mainly occurs between the groundwater level and the weak interlayer such as the strong weathering zone or the ancient sliding zone. The prevention and control of ancient landslide should not only be limited to the shallow landslide, but also comprehensively evaluate the stability of the weak interlayer possibly existing in the deep according to the relationship between the strong weathering zone or the ancient sliding zone and the groundwater; (3) When the distance between the top and toe of slope is far, appropriate excavation load reduction can more effectively control the further development of the displacement of the top of slope, but the setting of anti slide pile at the toe of slope can effectively prevent the deep sliding caused by the failure of weak interlayer inside the slope, and improve the overall stability of ancient landslide. Through the comprehensive prevention and control measures of slope top excavation + slope toe anti slide pile, the deep sliding of slope and shallow landslide can be comprehensively treated.

1. Introduction

The ancient landslide is the product of the long-term complex evolution of the slope. In a broad sense, the landslide which is inactive for a long time and whose last activity time is not clear can be regarded as the ancient landslide[1~2]. Landslides are mostly formed in mountainous landforms, and the gentle platform formed by ancient landslides is often one of the main human settlements in mountainous areas. Usually, ancient landslides have reached a new stable state after a long period of deposition, but a large number of ancient landslides still have the risk of revival under the influence of extreme climate and human engineering activities[3]. Especially for Southwest China, the mountains are rolling and the vegetation is luxuriant. The geomorphic characteristics of the original landslides can not be distinguished under the influence of long-term environmental transformation. The type and scope of ancient landslides are often missed or misjudged in the process of engineering construction[4]. Moreover, the rainy season is long in Southwest China. Under the comprehensive influence of rainfall and engineering activities, ancient landslide revival cases occur from time to time, which brings many problems to local engineering construction and personnel safety.

At present, the research on ancient landslide can be divided into three aspects: (1) the relationship between the evolution of ancient landslide and geological structure and climate; (2) the formation, revival and periodic change characteristics of ancient landslide; (3) the activity characteristics and engineering treatment of ancient landslide[5~7]. In particular, the activity characteristics of ancient landslide and engineering treatment are most closely related to personnel safety and engineering activities. Many scholars have carried out research on it and achieved rich results. Such as Małgorzata et al.[8] took a long-term approach to describe and explain the variability of landslide activity and hazards over apace and time. The results show that the factors affect the stability of landslides not only include rainfall, snowmelt and earthquakes, but also include river erosion, sea abrasion, increased loading and human interference; Shengwen Qi et al.[9] based on the methods of ground survey and geophysical investigation analyzed the structure and scope of ancient landslide and established a recognition and geological model of a deep-seated ancient landslide. Meanwhile, the results also pointes out that the protection of the toe of slope is very important to prevent the reactivation of ancient landslides; Piotr Owczarek et al.[10] through the analysis of the Great Whale River, Nunavik, Canada conduct the points that the landslide is not only affected by the slope shape, physical and mechanical characteristics of the slope and slope cutting, but also significantly affected by the weather, especially rainfall. In addition, the detection of slope deformation and evolution should not be limited to a short period of time of slope displacement with deformation monitoring, but should be through long-term analysis methods; Dongzi Liu et al.[11] explored the influence of long-term water level change on slope stability through indoor model test, and a evolution model of anti slide pile reinforced slope under the influence of long-term water level change was put forward, which provided a new idea for long-term evolution analysis of slope. Until now, the academic community has made a lot of summary on the factors and engineering characteristics affect the stability of ancient landslide[12~14], and clearly pointed out that rainfall is one of the important influencing factors of landslide revival, but there are few studies focusing on the deformation characteristics and revival mechanism of ancient landslide caused by irregular multi intensity cyclic rainfall within a certain period of time, and there is a lack of systematic guidance on the application scope of different reinforcement forms of ancient landslide under rainfall.

Therefore, through on-site monitoring of the ancient landslide in rainy season, based on the displacement of the top of the slope, the displacement of the deep slope and the distribution of rainfall, this paper analyzes the displacement law of the ancient landslide under the influence of multi-intensity cyclic rainfall and the change of slope stability, and explores the reinforcement measures and mechanism of the ancient landslide by numerical simulation, so as to to provide guidance and suggestions for the long-term engineering construction and slope reinforcement measure in rainfall infect area.

2. General Situation of Engineering and Geology

2.1. Project Overview

Figure 1 shows the construction project of Kaili ring expressway. The highway starts from sankeshu town of Kaili city and ends at Machangping, with a total length of 58.47 km. There is a large accumulation in k33+400~k33+680 section. The design adopts the combination of bridge and excavation subgrade to cross the accumulation, the left side of the road is the excavation cutting. The original slope gradient of the excavation section is about 1:1.3, the slope after excavation is still 1:1.3. The highest part of the slope excavation is about 20.7 m. Before the construction of the project, the field investigation found that there were cracks within the scope of the accumulation body, the widest of which was up to 1.89 m, and there was a risk of collapse under the rainfall erosion, which brought some hidden dangers to the production and life safety of the residents above the accumulation body. After comprehensive analysis, it is decided to set a row of anti slide piles at the foot of the slope, with a length of about 20 m and a section size of 2 m × 3 m. The construction period of cutting excavation is from April to June. After entering July, small-scale landslides occurred in some parts of slope cutting under the action of frequent rainfall, but it did not have a significant impact on residents and construction safety. The specific site conditions are shown in Figure 2.

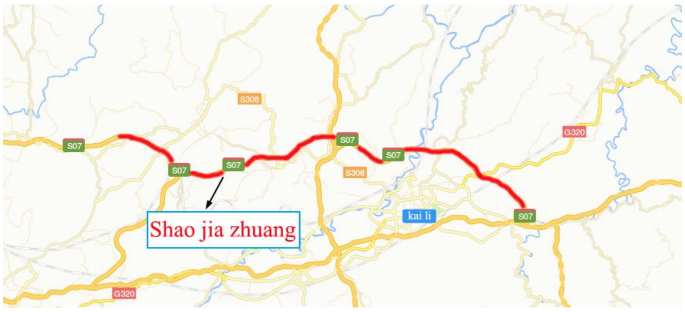


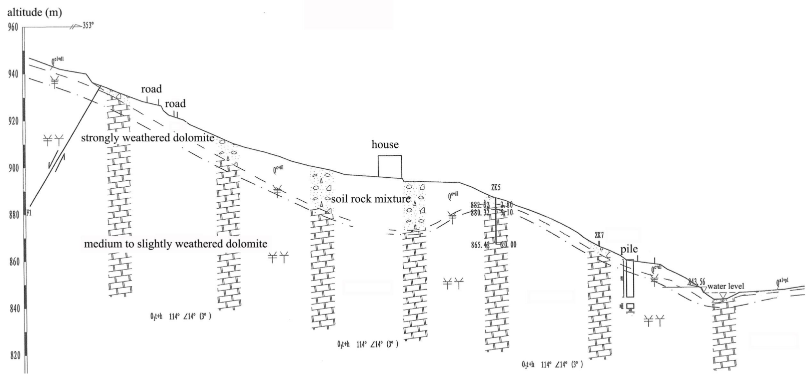
Figure 1: Kaili ring expressway.

Figure 2: Field condition.

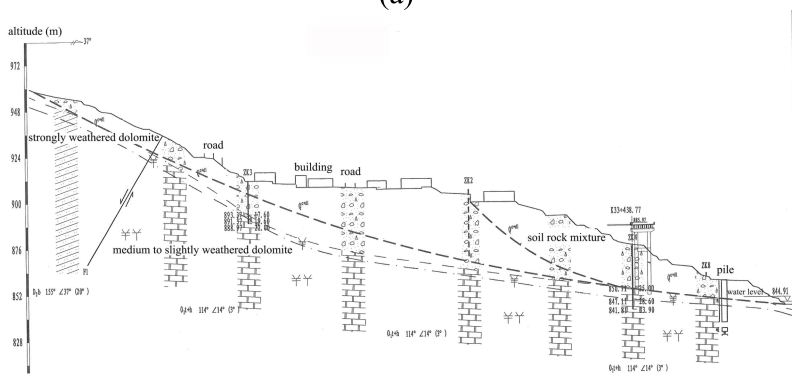
2.2. Engineering Geological Conditions

The project area is located at the foot of Miaoling mountain in the transition section from Yunnan Guizhou Plateau to central hills. The overall terrain is high in the northwest and low in the southeast. The landform of the site belongs to the dissolution erosion type of medium - low mountain landform. The surface is strongly eroded and fluctuated greatly. The accumulation body crossed by the project is located in Shaojiazhuang. There are a large area of farmland and households at the top platform of the accumulation body.

The accumulation body in the site area is about 403 m in length, 344 m in width and 83000 m2 in plane area. The overburden is a mixture of silty clay and block stone, and the bedrock is slightly to moderately weathered dolomite. There is about 3~4 m thick strongly weathered dolomite distributed at the interface of overburden and bedrock. The specific location information is shown in Figure 3.



(a)



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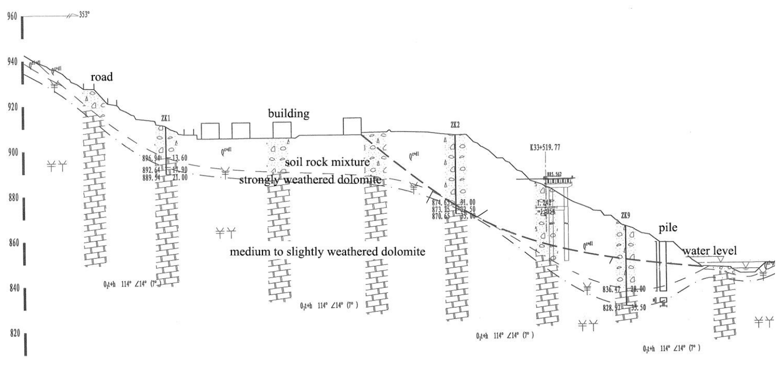


(c)

Figure 3: Geological sections.

2.3. Hydrogeological Conditions

The site belongs to subtropical warm and humid monsoon climate, with mild climate, abundant rainfall, long frost free period and hot rain in the same season. The annual average precipitation is 1249.3 mm , the annual maximum precipitation is 1458.5 mm and the daily maximum continuous precipitation is 184 mm. 70% of them are concentrated in April to August.

The project area belongs to the Yuanjiang River system of the Yangtze River Basin. The surface water system in the site area is developed, and there is a perennial river channel in the site area. The perennial flow is Q=20 L/s, the measured water level elevation is 842.29 m, the maximum flood level is 844.91 m, and the maximum flood flow is Q= 60 L/s.

The groundwater types are Quaternary loose pore water, bedrock fissure water and karst fissure water, and the loose pore water occurs in the form of upper stagnant water. Bedrock fissure water occurs in the joints and fissures of dolomite weathering layer, which is aquifer. Karst fissure water occurs in dolomite dissolution fissures and is also aquifer.

2.4. Evolution History of Ancient Landslide

It can be seen from Figure 4 that there is obvious drop in the red area above the accumulation body, and the shape is approximately oval. Through field investigation, it is found that there are many staggered zones with different scales in the area, so it can be judged that the landslide occurred at this location. According to the comprehensive analysis of geological conditions, this location should be the main fault wall of the landslide; On the other hand, through the analysis of river morphology, it is not difficult to find that the river distribution pattern is relatively gentle before point A and B, and there is obvious deflection when passing through point A and B, furthermore, the river distribution pattern between point A and point B is almost consistent with the slope toe shape of accumulation body. Therefore, it can be judged that the spatial form of the river is not only determined by erosion, but also by the external force caused by geological disasters such as landslides, etc., which makes the original river diversion. Furthermore, through the comprehensive analysis of the geological section in Fig. 3, it can be found that there is obvious concave erosion landform in the bedrock inside the anti slide pile in section 3-3, which is most likely the area where the ancient river once flowed. To sum up, this accumulation body is evolved from ancient landslide, so the main point of slope stability control in this area is to prevent the revival of ancient landslide.

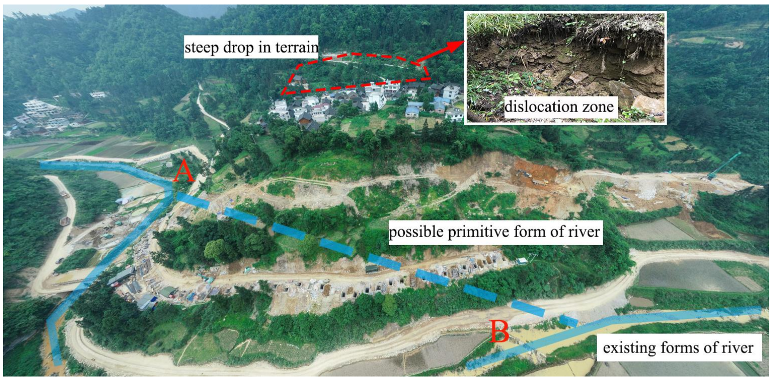


Figure 4: Geomorphological characteristics of ancient landslide.

3. Long Term Monitoring Analysis of Ancient Landslide

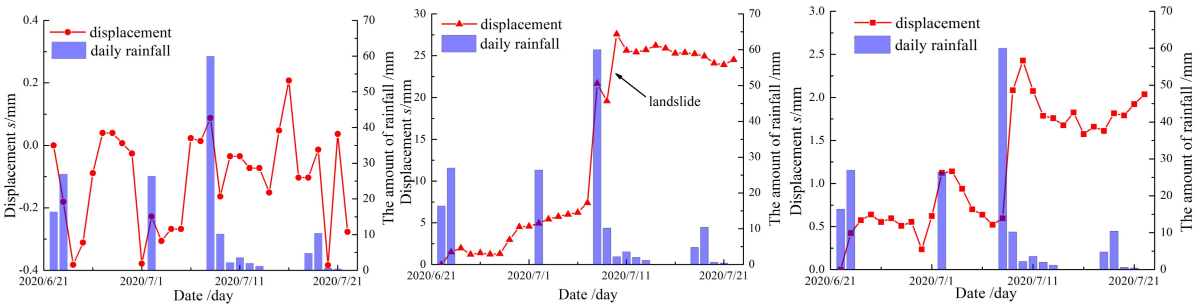
3.1. Layout of Measuring Points

In order to ensure the safety and stability of the accumulation during construction and operation, inclinometers were embedded on the top of the slope to dynamically monitor the surface and deep displacement of the slope for one month. The rainfall and groundwater activities during the construction period were collected by automatic groundwater level measurement and rainfall collection equipment. Engineering excavation of the slope was completed before the rainy season in June, and the test monitoring time was from June 22 to July 22. Collecting the deformation and stability changes of the slope after the excavation of the ancient landslide under the influence of rainfall is the main purpose of the work. CJK01, CJK02, CJK03 are the marks of measuring points. Meanwhile, the positions of rainfall and groundwater level monitoring are the same as CJK02. The slope displacement monitoring depth is 40 m. The specific plane layout information is shown in Figure 5.

Figure 5: Layout of measuring points.

3.2. Influence of Amount of Rainfall on Slope Deformation

Figure. 6 shows the curves of the displacement of the top of the slope with the change of the amount of rainfall (with the direction away from the slope displacement as positive). The height of excavation at CJK01 point is small, and the bedrock is the main part in the longitudinal depth. There have a shallow soil overburden on the bedrock which mainly exists in the bedrock erosion depression. During the monitoring period, the displacement fluctuates between 0.4 mm and -0.3 mm, and the change of the amount of rainfall has no obvious effect on the displacement of the top of slope; The excavation height of CJK02 and CJK03 measuring points is about 20.7 m, and its displacement on the top of the slope changes obviously with the amount of rainfall. The overall trend of the displacement of the two measuring points is as follows: when there is rainfall, the displacement increases with the emergence of rainfall, but the peak displacement lags behind the peak amount of rainfall, and the increase of displacement is positively correlated with the amount of rainfall. When the rainfall stops for 1-2 days, the displacement of the top of slope will drop greatly, and then the falling speed will be gradually gentle until it is finally stable. Especially for CJK02, a small-scale landslide occurred near the monitoring point, so the displacement fluctuation of this point is more significant than that of CJK03.



(a) CJK01 (b) CJK02 (c) CJK03

Figure 6: Relationship between the amount of rainfall and displacement.

Furthermore, the slope deformation response law under each rainfall event in the monitoring section is analyzed. Each continuous rainfall process is regarded as a rainfall event. The slope displacement changes during and after each rainfall event are listed in Table 1. It can be seen from the table that no matter CJK02 or CJK03, the the ratio of displacement increment to rebound during and after rain decreases with the increase of cycle times, and decreases with the increase of the amount of rainfall, which indicates that the deformation process of slope is mainly manifested as the accumulation of plastic deformation and soil fatigue damage in the process of repeated cycle rainfall. Meantime, according to the change of the ratio of displacement increase to rebound, when the slope stability is good, the s'/s ratio is high, and when the slope displacement rebound is small and the movement away from the slope body is more, that is, when the ratio is low, the slope stability decreases, especially in the process of rainfall event 3, a landslide occurred near CJK02, and its s'/s value decreased to 11.38%, while CJK03 was still in a stable state, and its s'/s value was 44.72%. Therefore, the ratio of the peak value of displacement increase to the peak value of rebound during the rainfall event can be used as a simple method to judge the change trend of slope stability. According to the field situation of this paper, it can be stipulated that when the ratio is less than 15%, the rainfall will have a great impact on the slope stability, and the dynamic change of slope should be paid close attention to. However, this method is not suitable for the case that the rainfall is less than 25 mm, such as rainfall event 4, because the rainfall has little impact on the whole slope and the slope is in a state of dynamic stability.

To sum up, the amount of rainfall has a significant impact on slope displacement. Higher rainfall is one of the main factors causing slope instability in rainfall events. In the process of cyclic rainfall, slope deformation is the result of plastic accumulation and damage. The stability change of slope in the process of cyclic rainfall can be judged by the ratio s'/s of displacement increase and rebound.

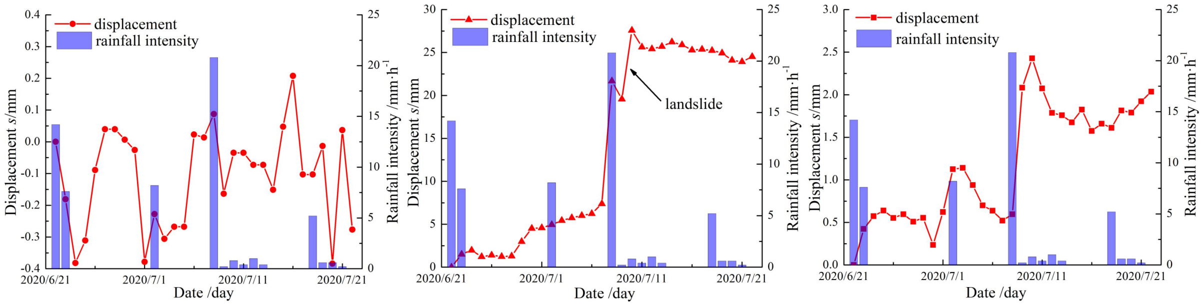
Table 1: Relationship between slope displacement and amount of rainfall.

Rainfall events	CJK02			CJK03			Amount of rainfall /mm
	Increase s/mm	Rebound s'/mm	s'/s(%)	Increase s/mm	Rebound s'/mm	s'/s(%)	
1	1.97	0.75	38.18	0.64	0.40	63.07	27
2	4.53	-1.63	-36.017	0.91	0.62	68.43	26.4
3	20.20	2.30	11.38	1.91	0.85	44.72	79.2
4	-1.19	-0.41	34.63	0.24	-0.22	-91.77	16.2

(The increase of displacement is positive in the direction away from the slope, and the rebound of displacement is positive in the direction towards the slope)

3.3. Influence of Short Time Rainfall Intensity on Slope Deformation

Figure 7 shows the relationship curve between the maximum short-term rainfall intensity and slope displacement. The maximum short-term rainfall intensity of rainfall event 3 is about 20.8 mm, followed by rainfall event 1, which is 14.2 mm. The maximum rainfall intensities of rainfall events 2 and 4 are 8.2 mm and 5.2 mm respectively. And there is no obvious correlation between CJK01 displacement fluctuation and rainfall intensity, while CJK02 and CJK03 have obvious increasing trend when higher short-term rainfall intensity occurs, but the correlation between the increase amplitude and rainfall intensity is weak. For example, the maximum short-term rainfall intensity of rainfall event 1 is about 68% of that of rainfall event 3, but in CJK02 and CJK03, the displacement increment caused by rainfall event 1 is only 10.1% and 28.2% of that caused by rainfall event 3. Therefore, short term high-intensity rainfall has a weak impact on slope stability, that is, short-term runoff is not the main factor affecting slope stability.



(a) CJK01 (b) CJK02 (c) CJK03

Figure 7: Relationship between short term rainfall intensity and displacement.

3.4. Numbers Influence of Groundwater on Slope Deformation

Figure 8 shows the relationship between the groundwater level and the displacement of the measuring point (the distance between the groundwater level in the figure is the distance from the bottom of the hole to the groundwater surface). Among the four rainfall events, the peak of the amount of rainfall occurred on June 23, July 2, July 8 and July 19 respectively, while the groundwater level reached the peak on June 26, July 4, July 11 and July 20 respectively. The change of groundwater level lags behind the rainfall, and the groundwater level generally reaches the peak within 1-3 days after the peak of amount of rainfall. The time when the peak value of groundwater level reaches is corresponding to the time when the displacement of each monitoring point rises slightly again after the rainfall or after the peak value of amount of rainfall. After the peak value of groundwater, the slope displacement will decrease with the decrease of groundwater level. The main reason is that the rise of groundwater level increases the internal saturation area of the slope, decreases the effective stress of soil and the suction of matrix, which makes the second significant displacement of the slope after rain, but its influence on the displacement of the slope is lower than that of the amount of rainfall.

To sum up, the influence of rainfall on slope stability is comprehensively reflected by the dynamic changes of the amount of rainfall, rainfall intensity and groundwater level. In the process of rainfall, the influence degree of each factor on slope stability is the amount of rainfall > groundwater level > short-term rainfall intensity. The amount of rainfall is the main factor affecting slope stability. Groundwater level can promote slope displacement to a certain extent. Short term rainfall intensity has a certain impact on slope displacement, but the impact is limited. Even under low rainfall intensity, continuous rainfall and rising groundwater level will still have a significant impact on slope stability. Therefore, the evaluation factors of rainfall on slope stability should focus on the joint change process of total rainfall and groundwater level in a concentrated rainfall process.

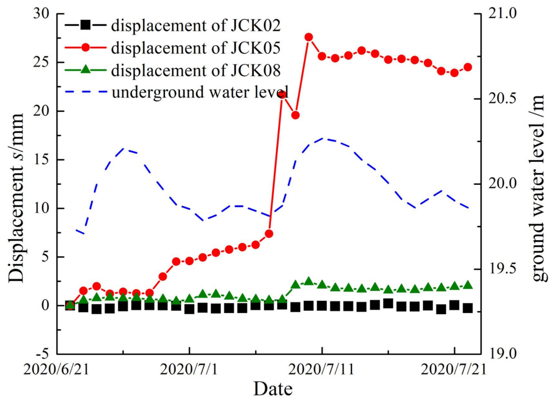
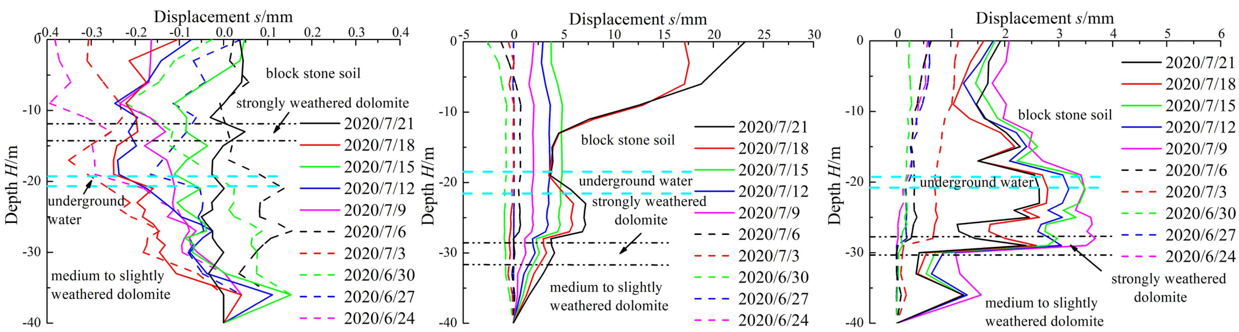


Figure 8: Relationship between groundwater level change and displacement.

3.5. Deep Displacement of Slope

Figure 9 shows the variation curve of the deep displacement of each measuring point during the monitoring period. The displacement of each measuring point increases in varying degrees with the increase of the number of cyclic rainfall, and the longitudinal variation amplitude of the displacement gradually decreases along the depth. Firstly, the displacement of CJK01 point has a certain degree of mutation in the strongly weathered zone and the groundwater level. The displacement of the soil at this position is significantly higher than that of the adjacent position, and the rebound of the soil is smaller in the period of no rain, which indicates that the fluctuation of the strongly weathered zone and the groundwater reduces the strength of the rock and soil, and the plastic deformation is greater after being disturbed by external factors. Therefore, deep sliding is more likely in the strong weathering zone and groundwater surface under the action of long-term rainfall; Secondly, the displacement of CJK02 is small at the initial stage of monitoring, and the displacement difference of each depth is small. With the increase of rainfall cycles and the effect of high rainfall, the shallow displacement of soil begins to increase significantly. The field performance is landslide damage near the measuring point, and the deep displacement also shows obvious increase between the groundwater level and the strongly weathered zone. After passing through the strongly weathered zone, the displacement decreases rapidly in the moderately to slightly weathered bedrock. Finally, the displacement of CJK03 point also increases with the increase of rainfall cycle times and the amount of rainfall, but the increment of shallow displacement with time is significantly less than the displacement of soil between groundwater level and strongly weathered zone.



(a) CJK01 (b) CJK02 (c) CJK03

Figure 9: Deep displacement of slope.

Further, by comparing the displacement of CJK02 and CJK03, it can be found that although there is a huge difference in the shallow displacement between the two points, the law of soil displacement between the groundwater level and the strongly weathered zone is basically the same. In this scope, the displacement of the soil is higher than that of the soil above the groundwater level and the middle to slightly weathered dolomite in the lower layer, and the maximum displacement of the two test points in this scope are 7.2 mm and 3.7 mm respectively, which can be considered to be in the similar displacement level compared with the shallow displacement. It indicates that the deformation and instability characteristics of ancient landslides under the action of rainfall are not limited to the shallow soil. The influence of rainfall on the stability of ancient landslides is more reflected in the deformation of deep position. The failure and deformation of rock and soil between the groundwater level and the strongly weathered layer or the interlayer of fracture zone under the action of rainfall is the key to the revival of ancient landslides. Therefore, the prevention and control of ancient landslide under the influence of rainfall should not only be limited to the treatment of shallow landslide, but also be combined with the relationship between the broken zone or strong weathering zone and groundwater to comprehensively evaluate the stability of the weak interlayer that may exist in the deep. The fundamental purpose of ancient landslide prevention and control is to prevent deep sliding.

4. Numerical Simulation

4.1. Establishment of Model

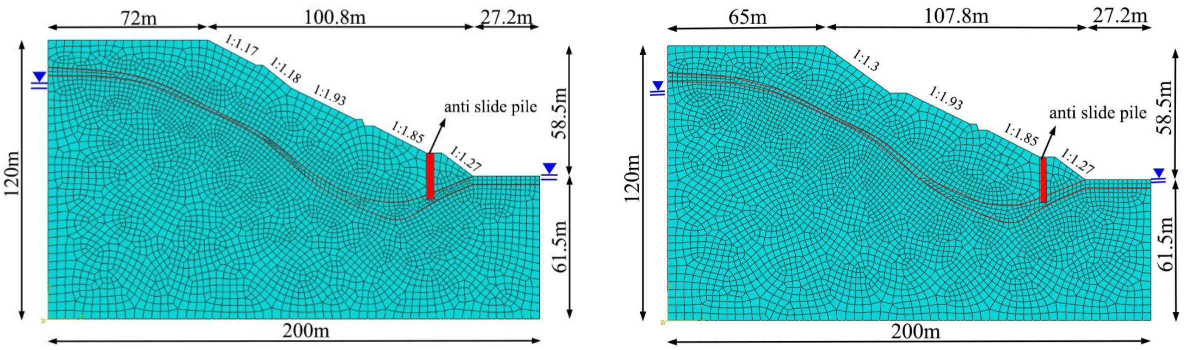
In order to further clarify the influence of cyclic rainfall and slope excavation on the stability of ancient landslide and analyze its reinforcement measures, this paper establishes a calculation model considering slope excavation and anti slide pile support under cyclic rainfall by ABAQUS software, and the specific calculation conditions are shown in Table 2.

Table 2: Numerical simulation conditions.

Conditions	Excavation	Anti slide pile
1	NO	NO
2	NO	YES
3	YES	NO
4	YES	YES

A reasonable selection of calculation section is an important premise to ensure the correctness of the analysis results. Specifically, the CJK01 slope excavation is small, and the overlying earth rock mass is less, so the slope is in a dynamic stable state during the monitoring period; The displacement of CJK02 changes obviously in the process of rainfall, and there is a local landslide, but the landslide volume is small and the scope is very limited, which may be due to the sudden change of rock and soil properties near the measuring point, and the strength is weaker than the average embedded strength of the field; But at measuring point CJK03, there is a strong correlation between the displacement change and the rainfall process, and the slope remains stable after the cyclic rainfall, which is in line with the general law of the site excavation section. Therefore, 3-3 section is selected as an example for analysis.

The two-dimensional model is adopted for calculation, with a width of 200 m and a height of 120 m, in which the slope height is 58.5 m and the plane size of anti slide pile is 20 m × 3 m. The left and right sides of the model constrain the X-direction displacement, the bottom of the model constrains the X-direction and Y-direction displacement, the rock and soil take Moore-Coulomb model, and the anti slide pile takes elastic model. Because the force between the anti slide pile and the slope is mainly thrust, the "binding" constraint is used to connect the anti slide pile and the slope interface. The groundwater surface is 20 m below the ground on the left side of the model, and another groundwater surface is on the ground surface of the right side of the model. The model adopts quadrilateral and triangle hybrid mesh, and the mesh types are CPE8P and CPE6MP. The specific model size and mesh division are shown in Figure 10.



(a) Before excavation (b) After excavation

Figure 10: Model size and mesh generation.

4.2. Parameter Setting

The rock and soil materials of the model can be divided into three types, which are soil rock mixture, strongly weathered dolomite and moderately to slightly weathered dolomite from top to bottom. The basic physical and mechanical parameters are obtained through geological exploration, while some parameters related to seepage can not fully reflect the relevant seepage characteristics of slope due to the large difference in spatial distribution. Therefore, in this paper, the relevant parameters of rock and soil are determined by back calculation method, and the calculation parameters of the model are shown in Table 3.

Table 3: Simulation parameters of model.

Name	Basic physical and mechanical parameters					Parameters obtained by back calculation	
	Density ρ/103kg·m-3	Young's modulus E/MPa	Cohesion c/kPa	Friction angle φ/(°)	Poisson's ratio μ	Void ratio e	Permeability coefficient k/m·h-1
Anti slide pile	2.45	3×104			0.15	0.2	1×10-20
Soil rock mixture	1.8	27	10	25	0.26	1.2	0.0324
Strongly weathered dolomite	2.4	36	21	32	0.22	0.6	0.042
Medium to slightly weathered dolomite	2.5	73	163	38	0.2	0.1	1×10-6

The relationship between water content of rock and soil mass and matrix suction is obtained from the research results of soil water characteristic curve in reference [15] shown in Figure. 11. Formula (1) V-G model was used to predict the relationship between water content and matrix suction. The rainfall is controlled by setting pore flow on the slope surface. The total time of simulation is 730 hours, which spends 10 hours at first on the simulation of the steady-state analysis of the slope and 720 hours later on the transient analysis of the cyclic rainfall during the monitoring period. The rainfall is measured in hourly rainfall and its curve during the monitoring period is shown in Figure 12.

$$\theta_w = \frac{\theta_s}{\left[1+(as)^{\frac{1}{1-m}}\right]^m} \tag{1}$$

Where, θs is the saturated water content, and θs=40.08, a, m are the parameters related to the soil water characteristic curve, and the values in literature [15] are a=0.067645, m=0.31396.

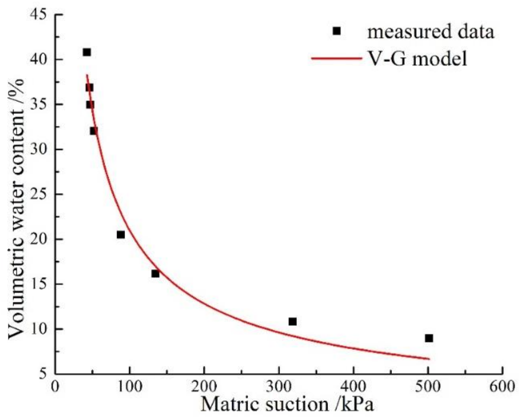


Figure 11: Relationship between matrix suction and water content in reference [15].

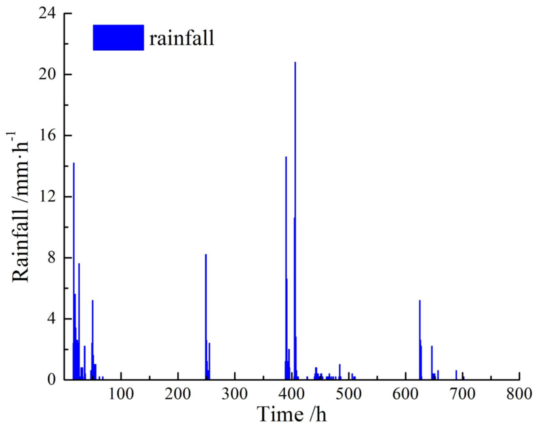


Figure 12: Rainfall amplitude.

4.3. Analysis of Result

4.3.1. Displacement of Slope

Figure 13 shows the displacement development curve of different simulated conditions and CJK03 monitoring displacement curve, in which condition 4 is consistent with the field condition. Through the comparison, it can be seen that the curve development of the numerical simulation and the actual monitoring is relatively consistent on the whole. The error between the numerical simulation and the actual monitoring in the displacement development process of each rainfall event is small, and the actual slope monitoring curve rebounds after the rainfall, but the numerical simulation results only have a small rebound after the first two rainfall events, and the rebound amount is very small, which has a certain difference with the field monitoring. This may be because the unloading rebound of soil in the numerical simulation is only related to the pore fluid load acting on the slope, while the rebound of real soil in the process of dry wet cycle of rainfall is much more complex, which is not only related to the fluid load, but also related to the temperature, field load and soil properties. But in general, the numerical simulation results obtained by this method still can reflect the deformation and stability of ancient landslide in the process of cyclic rainfall to a certain extent.

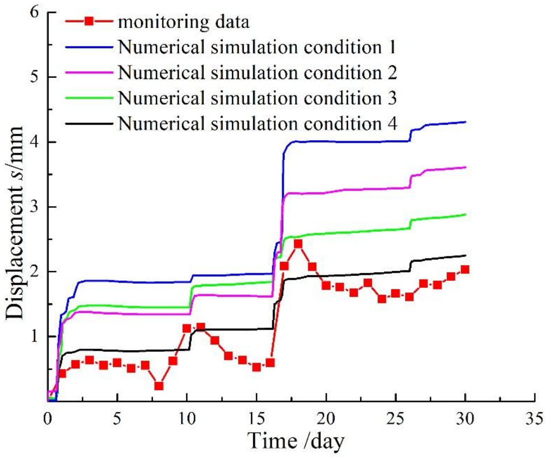


Figure 13: Displacement curves of the top of the slope.

According to the analysis of the change of displacement on the top of slope in Figure. 13, the displacement under different working conditions increases with the increase of rainfall cycle times, and the relationship of total displacement is as follows: no excavation + no anti slide pile > no excavation + anti slide pile > excavation + no anti slide pile > excavation + anti slide pile. The final displacement of condition 4 is 2.25 mm, and that of condition 1 is 4.31 mm. The displacement of top of slope is reduced by about 47.8%, which indicates that the excavation of top of slope and the setting of anti slide pile at slope toe can effectively improve the stability of ancient landslide under the effect of long-term cyclic rainfall and prevent the ancient landslide from reactivating.

In order to further explore the influence of excavation on the top of slope and anti slide pile on slope stability, the displacement increment of top of slope in four rainfall processes is calculated in Table 4. Through the comparison of working conditions 1 and 2, it can be seen that the control ability of anti slide pile on the deformation of top of slope is not very obvious for small rainfall, but when the rainfall is large, such as rainfall event 3, the anti slide pile has a significant control effect on the displacement of slope top; Compared with working conditions 2 and 3, it can be found that the control effect of the two conditions on the displacement of the slope top is basically the same when the rainfall is small, but in the case of large rainfall, the displacement of top of the slope can be better controlled through the excavation of the slope top. This is mainly because under the condition of this paper, the anti slide pile is far away from the top of the slope, and its control ability to the displacement of the top of the slope is weaker than that of cutting the slope at the top of the slope. Therefore, when the distance between the top of the slope and the foot of the slope is far away, the appropriate excavation load reduction can more effectively control the further development of the displacement of the top of the slope. If conditions permit, the anti slide pile at the foot of the slope can be added to achieve further optimization effect.

Table 4: Displacement increment at the top of the slope during the process of rainfall.

Rainfall events	Increment /mm			
	Condition 1	Condition 2	Condition 3	Condition 4
1	1.73	1.38	1.46	0.8
2	0.1	0.3	0.33	0.3
3	2.03	1.59	0.7	0.81
4	0.24	0.27	0.15	0.18

Figure 14 shows the change of slope displacement field under four conditions. It can be seen from the figure that no matter what kind of working condition, under the influence of cyclic rainfall, the soil on the upper part of the slope slides along the rock soil interface (strongly weathered layer), and the maximum displacement occurs not on the top of the slope, but on the sliding arc surface at a certain depth from the top of the slope. It shows that the instability characteristics of ancient landslide under cyclic rainfall are not the shallow sliding at the top of the slope, but the deep sliding at a certain depth of the slope.

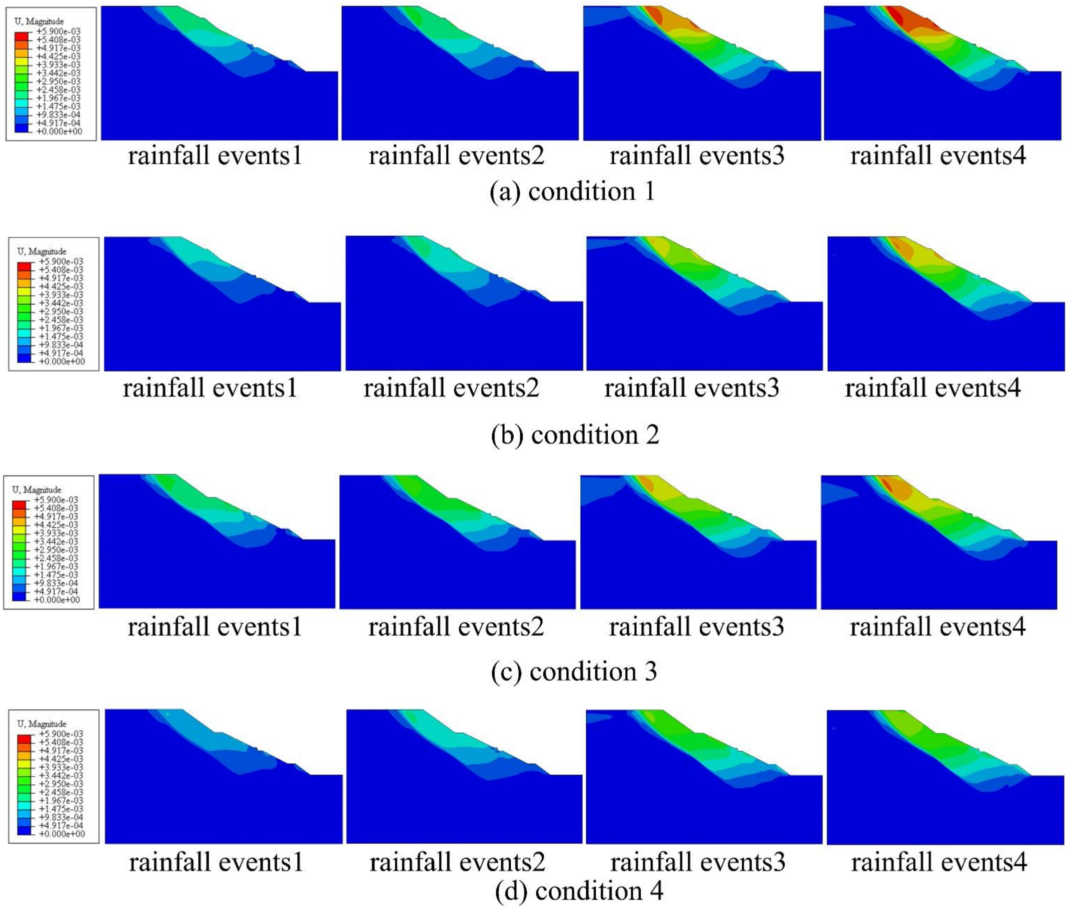


Figure 14: Contour map of slope displacement field.

Furthermore, the displacement characteristics of slope under different working conditions are analyzed. Under the same rainfall conditions, the relationship of displacement field of slope is as follows: no excavation + no anti slide pile > excavation + no anti slide pile > no excavation + anti slide pile > excavation + anti slide pile. By comparing condition 2 and condition 3, it is found that setting anti slide pile at the foot of slope can better restrain the development of deep displacement of slope. Therefore, although the setting of anti slide pile is not more effective than excavation in preventing shallow displacement at the top of slope, anti slide pile can effectively prevent the revival of ancient landslide, which plays an important role in improving the overall stability of ancient landslide and preventing the formation of large-scale landslide, through the excavation at the top of slope+ anti slide pile at the toe of slope comprehensive control measures can be more comprehensive to the slope of deep sliding and shallow landslide comprehensive treatment.

4.3.2. Stress Distribution

Figure 15 shows the change process of stress in slope under cyclic rainfall in different conditions. It can be seen from the figure that with the increase of the number of cyclic rainfall, the magnitude and scope of stress increment in the slope also gradually increase, and the stress increment is mainly concentrated in the middle and lower parts of the slope body. There are some differences in the development law of slope stress under different working conditions. In case 1~3, with the increase of the number of cyclic rainfall, the distribution of stress increment is no longer limited to the surface of the slope, but also appears in the interior of the slope and near the strongly weathered zone. The potential failure surface of the slope gradually shifts to the deep with the increase of the number of rainfall. Further comparison shows that in case 1, the stress in the inner part of the slope and the slope surface increases most obviously, while in case 3, when the top of the slope is excavated, the range of stress increment on the slope surface decreases to a certain extent, and the magnitude of stress increment inside the slope body also decreases, but the influence range is still large. In case 2, the magnitude and range of the internal stress increment are significantly reduced after the anti slide pile is set, while in case 4, the range of stress increment at the surface of the slope is significantly reduced and the internal stress increment is basically eliminated under the joint action of excavation and anti slide pile. The results show that the shallow damage of the ancient landslide is mainly concentrated in the middle and lower part of the slope, while the deep damage is mainly concentrated in the internal weak interlayer. The reinforcement of the slope toe is the key to prevent the ancient landslide from sliding again in a large range. The deep sliding caused by the failure of the internal weak interlayer can be effectively prevented by the excavation unloading at the top of the slope and the installation of anti sliding piles at the slope toe .

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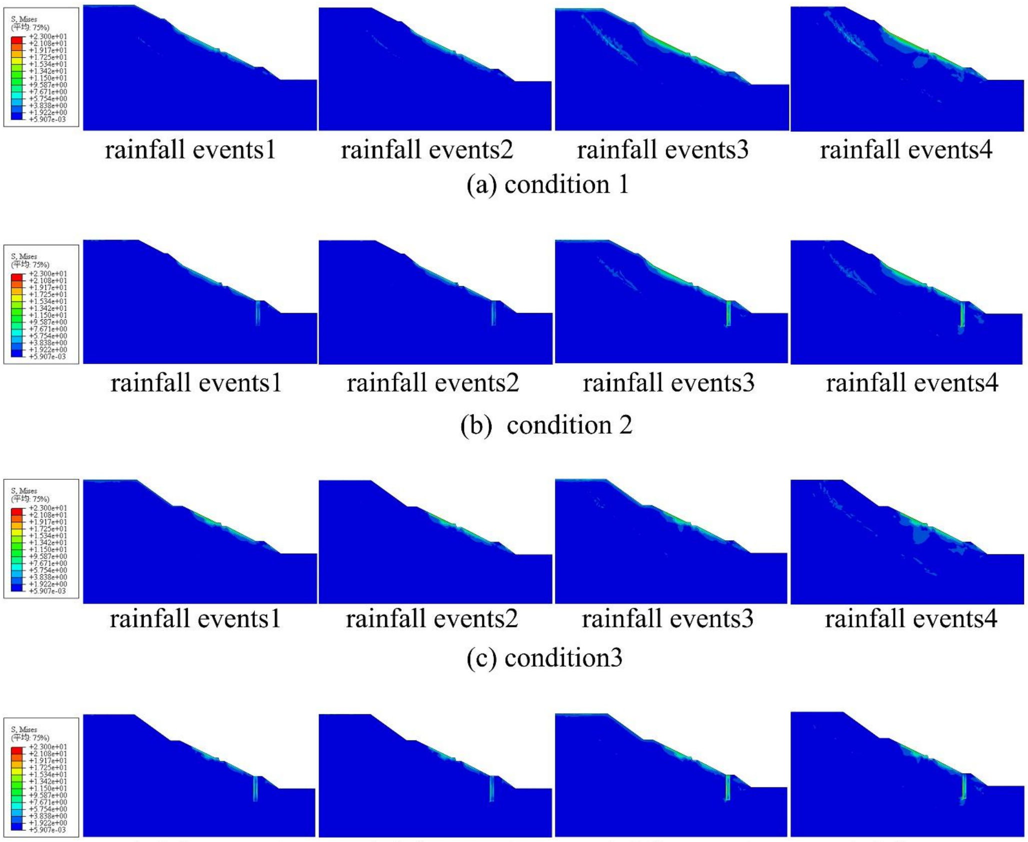

rainfall events1 rainfall events2 rainfall events3 rainfall events4

(a) condition 1

rainfall events1 rainfall events2 rainfall events3 rainfall events4

(b) condition 2

rainfall events1 rainfall events2 rainfall events3 rainfall events4

(c) condition3

rainfall events1 rainfall events2 rainfall events3 rainfall events4

(d) condition 4

Figure 15: Contour map of stress increment of slope.

5. Conclusions

(1) In the process of rainfall, the influence of various factors on slope stability is in the order of the amount of rainfall > groundwater level > short-term rainfall intensity. The evaluation factors of rainfall on slope stability should focus on the joint change process of total rainfall and groundwater level in a continuous rainfall process. The change of slope stability under cyclic rainfall can be judged by the ratio s'/s of displacement increase to rebound. When the ratio is less than 15%, landslide and other geological disasters are likely to occur near the measuring point. However, this method is not applicable when the total rainfall is less than 25 mm, because the slope is basically in a state of dynamic stability.

(2) The deep sliding of the ancient landslide mainly occurs between the groundwater level and the weak interlayer such as the strong weathering zone or the ancient sliding zone. The prevention and control of displacement of ancient landslide under the influence of rainfall should not only be limited to the treatment of shallow landslide, but also be combined with the relationship between the strong weathering zone or ancient sliding zone and groundwater to comprehensively evaluate the stability of the weak interlayer that may exist in the deep. Preventing deep sliding is the fundamental purpose of the prevention and control of ancient landslide.

(3) The related parameters of ancient landslide obtained by back analysis method can reflect the stability change characteristics of landslide under cyclic rainfall to a certain extent. The calculation results show that when the distance between the top and the toe of the slope is far, the excavation at the top of the slope can more effectively control the further development of the displacement at the top of the slope, and if conditions permit, the effect of further optimization can be achieved by adding anti slide piles at the toe of the slope.
(4) Under the action of rainfall, the shallow damage of the ancient landslide is mainly concentrated in the middle and lower part of the slope, while the deep damage is mainly concentrated near the internal weak interlayer. The setting of anti slide pile at the foot of slope can effectively prevent the deep sliding caused by the failure of weak interlayer inside the slope, which plays an important role in improving the overall stability of ancient landslide and preventing the formation of large-scale landslide. Through the comprehensive prevention and control measures of excavation at the top of the slope and anti slide pile at the foot of slope, the deep sliding and shallow landslide of slope can be comprehensively treated.

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