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Analysis of the Deformation Mechanism of the Top Slope at the Inlet of the Lijiaxia Hydropower Station Diversion Tunnel

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Abstract. After long-term operation of Lijiaxia Hydropower Station in Qinghai Province after reservoir storage, the surface part of the slope body at the top of the inlet of the diversion tunnel shows signs of deformation and tension cracking, which is a serious threat to the operation safety of the hydropower station. In order to study the deformation mechanism of the slope and its evolution process, analyse the causes of slope deformation and assess the safety and stability of the slope, this paper adopts comprehensive investigation means such as drilling, testing and inspection, and carries out a detailed investigation and research on the geological and environmental characteristics of the slope such as topography, stratigraphy and lithology, geological structure, signs of deformation, geostress and hydrogeological conditions. Combined with the monitoring data of 9 monitoring points to carry out three-dimensional modeling, numerical simulation evolution analysis, and the use of limit equilibrium theory, strength reduction theory method to analyze and calculate the stability of the slope, and at the same time calculated and predicted the height of the landslide surge, the results show that: the overall deformation of the slope deformer is in a critical state, the main deformation form of shallow surface collapse slip and the overall creep-slip deformation, the natural state occurs in the overall sliding The possibility of the whole slide in the natural state is small, and the possible landslide surge hazards can be controlled. After nearly 6 years of operation test, the deformation body of the slope basically maintains the status quo, which confirms the reliability of the previous deformation evolution cause analysis and assessment conclusions. The related ideas and methods can provide reference for the analysis and evaluation of similar reservoir slope deformations.

Keywords: Deformation mechanisms; Evolutionary processes; Numerical modelling; Slope stability; Landslide surges.

1. Introduction

In the past 40 years, in order to serve the rapid development of the national economy, China's hydropower engineering business, especially in the middle and upper reaches of the Yellow River, has flourished, injecting a steady stream of green power for the economic development of the western region. At the same time, the construction of hydropower stations in high mountain valley areas encountered various types of high and steep slope problems are complicated, especially under the external factors such as reservoir storage, rainfall, earthquake and other external factors, there are varying degrees of slope cracking and deformation, or even destabilisation and destruction of the phenomenon, which poses a serious threat to the operation of the hydropower station [1-4], thus, the study of hydropower station deformation and destruction of high slopes for the guidance of the management of the slopes and disaster prevention is of great significance. Therefore, the study of the deformation damage pattern of high slopes of hydropower stations is of great significance in guiding slope management and disaster prevention.

Lijiaxia Hydropower Station is located in Jianzha County, Qinghai Province, which is an important first-class large (I) type hydropower station in the upper reaches of the Yellow River. The normal storage level of the reservoir is 2180m, with a capacity of 1.65 billion m^3 and a normal dead water level of 2178m. The dam type is a triple-centred concrete double-curved arch dam, with a maximum height of 155m and a crest elevation of 2185m. The power plant is a back-of-the-dam double-row plant with a total installed capacity of 5×400 MW. During the initial construction phase

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of the Lijiaxia Hydropower Station, slope stability issues were particularly prominent. Specifically, the left bank of the reservoir developed a slope landslide (I), the right bank developed a slope landslide (II), and the high slope at the inlet of the diversion tunnel, among others. These unstable slopes underwent varying degrees of research and engineering treatment during the construction phase, ensuring the safe impoundment of the reservoir and the commissioning of the hydropower station. These unstable slopes have been studied and engineered to different degrees during the construction period, which ensured the reservoir storage and the commissioning of the hydropower station. However, the changes in the geological environment caused by the long term operation of the hydropower station after the storage of water have resulted in the occurrence of new cracking and deformation of the slopes that have not been completely and thoroughly dealt with in the original engineering treatment, and the slope at the inlet of the diversion tunnel is one of the prominent phenomena. Therefore, the study and analysis of its slope deformation and damage mechanism and stability has a strong reference significance for the prevention and control of similar slopes. And it is very important for ecological protection, protection of ecological environment and promotion of sustainable development.

2. Survey History and Geological Profile

2.1 History of the survey

The high side slope of the inlet of the diversion tunnel is located on the right bank of the river bend about 800m upstream of the dam. The total length of the diversion tunnel is 1146.5m, with a net section of $11\times15m^2$ after lining, which is a round-arched straight-wall type pressureless tunnel. The entrance slope of diversion tunnel is high and steep, the relative height difference reaches 350m. its pulling crack deformation problem has a long history, during the construction period, it was found that a rocky "deformation body" formed in the early period was developed between the elevation of 2135-2275 m, the volume was about $350,000m^3$. At that time, in order to ensure the construction safety of the diversion tunnel water crossing and the main project, a special study and evaluation were conducted on the stability of the high slope, especially the upper part of the 2130 m platform "deformation body" and its safety countermeasures, basically determining the deformation state and range of the upper part of the 2130 m platform loose rock, and in the early stage of construction, the concrete retaining wall and the concrete supporting beam with grid-connected slope were set up on the 2130 m platform, as well as the waterproof and drainage measures on the surface. In May 1990, the deformation monitoring facilities on the surface and in the cave were successively established..

In May 1993, on the basis of comprehensive analysis of geological survey, supplementary exploration and deformation monitoring data, further analysis and evaluation of the stability of the slope was made, and its results showed that: the high slope of the inlet of the diversion tunnel could remain generally stable during the construction of the dam, and there was no need to carry out a large-scale reinforcement, but the possibility of local instability still existed, and it was necessary to continue to do a good job of surface seepage control, drainage and monitoring and forecasting work. With the progress of engineering construction, its monitoring continued until 1999 when the hydropower station was put into operation and power generation, and then turned into conventional geological inspections. In July 2018, during the inspection of the hydropower station operators, it was found that the slope had a tendency to increase the tensile deformation. Therefore, the PowerChina Northwest Institute was entrusted to continue the survey and evaluation of the slope. This work adopted various survey methods such as measurement, drilling, geophysical exploration, test and monitoring, and further identified the collapse of the slope deformation body. The range of sliding and cracking and the deep deformation boundary have laid a solid foundation for the analysis of its deformation mechanism.

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2.2 Geological profile

2.2.1 Topography and geomorphology

The slope at the inlet of the diversion tunnel is high and steep, the height of manual excavation slope is 85 m., and there is a bridleway at the elevation of 2130 m, and the overall trend of the slope is NE50° . The slope is gentle and steep at the bottom, the upper part (elevation above 2200m) is natural slope with slope angle of 35-40° , the lower part (elevation 2200-2080m) is artificial slope with slope angle of 55-60° ; it is cut by several shallow gullies, and the slope is uneven in the transverse direction. As shown in Fig.1.

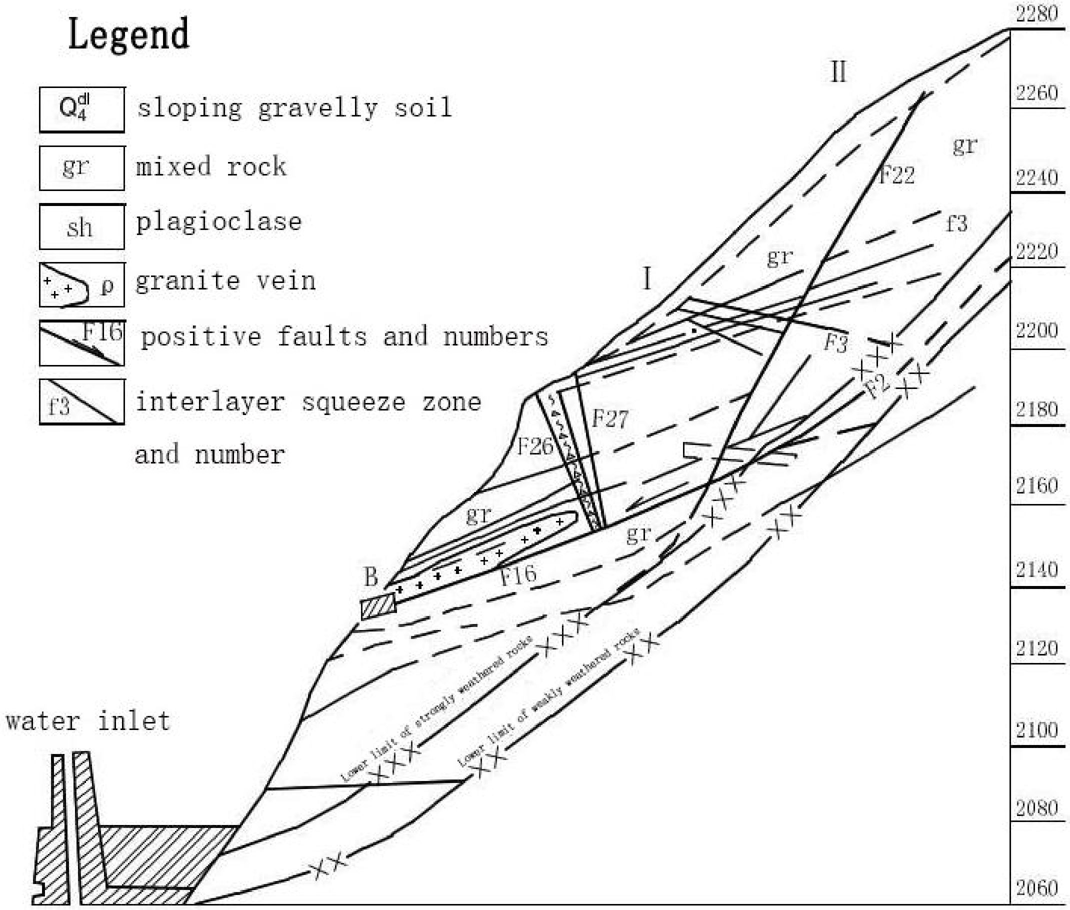

Fig.1 Typical geological longitudinal sections

2.2.2 Stratigraphic lithology

The surface layer of the slope is covered by Quaternary slope debris and sandy loam, with a maximum thickness of 3-7m. It is mainly distributed above 2180m elevation, and is in unconformable contact with the underlying bedrock. The slope consists of pre-Aurignan metamorphic banded mixed rock (gr) and oblique long schist (sh), with a few granitic pegmatite veins (ρ) of the Huarixi period interspersed. The mixed rock layer is 6-20 cm thick, hard and strong, with developed schist and hidden fissures, and brittle. The schist layer varies from several centimetres thick, and the rock quality is softer. Granite pegmatite is hard, brittle and resistant to weathering, and is mainly distributed in the Luanshi ditch and its downstream area within the slope of the diversion tunnel, in a strip-like distribution.

2.2.3 Geological formation

The regional tectonic traces in this area are mainly monoclinic tectonics, and the stratigraphy is NW300-325°/SW∠50-70°, the inclination of the rock strata is nearly orthogonal to the slope

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direction (NW320°), and the overall inclination is offshore and upstream. There is no large fault in the slope area, mainly developing II and III structural surfaces, with NW interlayer extrusion zone as the main structural surface, followed by NE～NEE steeply dipping structural surface, both of which account for about 80%～90% of the total number of structural surface statistics. In addition, a small number of gently dipping structural surfaces of NW340～NE25°/SW(NW)∠10～27° are also developed, which often constitute the bottom sliding surface of the local rock body instability, and their continuation characteristics have a controlling effect on the stability of slopes.

2.2.4 Geological stress environment

The slope of the inlet of the diversion tunnel is located in the upstream of the right bank of the dam site area, and the mountain is strong, in addition to the self-gravitational stress, generally there is still a remnant of low-quantity tectonic stress field. Considering the characteristics of high and steep slopes in this area, serious weathering and unloading of the rock body, and general development of landslides and deformations, there is a certain release of tectonic stress, therefore, it can be considered according to the self-gravitational stress field during the calculation of the stability of the slopes.

2.2.5 Hydrogeological condition

Lijiaxia area is a plateau arid ~ semi-arid, alpine continental climate, with drought and low rainfall, large temperature difference as the characteristics of the average precipitation for many years is only 350mm, the average evaporation for many years is 1700mm; the project area surface water drainage conditions are good, infiltration into the underground part of the limited, so bedrock fissure water is not abundant to be endowed with the influence of faults in the zone or fissure dense zone of the bedrock fissure water as the main feature. And the groundwater depth before storage is much lower than the front of the deformation body, the deformation body is not affected by groundwater, only in the rainy season and rainfall infiltration.

3. Analysis of Slope Deformation and Damage Mechanism

3.1 Morphological Characteristics and Scale of Deformation Body

3.1.1 Scale of the deformation body

Based on the results of this geological mapping, the extent of the current deformation body has increased upstream, downstream and at the top compared to the pre-2000 period, but the top elevation does not exceed the range of deformation predicted in 2000.

Currently, the deformation body is narrow at the top and wide at the bottom, the width along the river is 94m and 178m at the top and bottom respectively, the maximum elevation of the back edge of the deformation body is about 2300m, and the shear outlet of the front edge has been completely submerged, and the elevation of the body is about 2135m. the overall length of the deformation body along the sliding direction is 205m, and the planar area has been increased from 13006m^2 before 2000 to the current 26660m^2 . According to the thickness of the deformation body revealed by drilling, the maximum thickness of the deformation body is nearly 61m, and the thickness of the deformation body is larger on the upstream side than on the downstream side in the direction along the river. The comprehensive estimation of the volume of the deformation body has increased from 350,000m^3 to 642,000m^3 at present, as shown in Fig.2. Under the influence of water storage in Lijiaxia Reservoir, the lower 50m range of the deformation body has been completely submerged, and its underwater volume is about 217,500m^3, and 424,500m^3 above the water.

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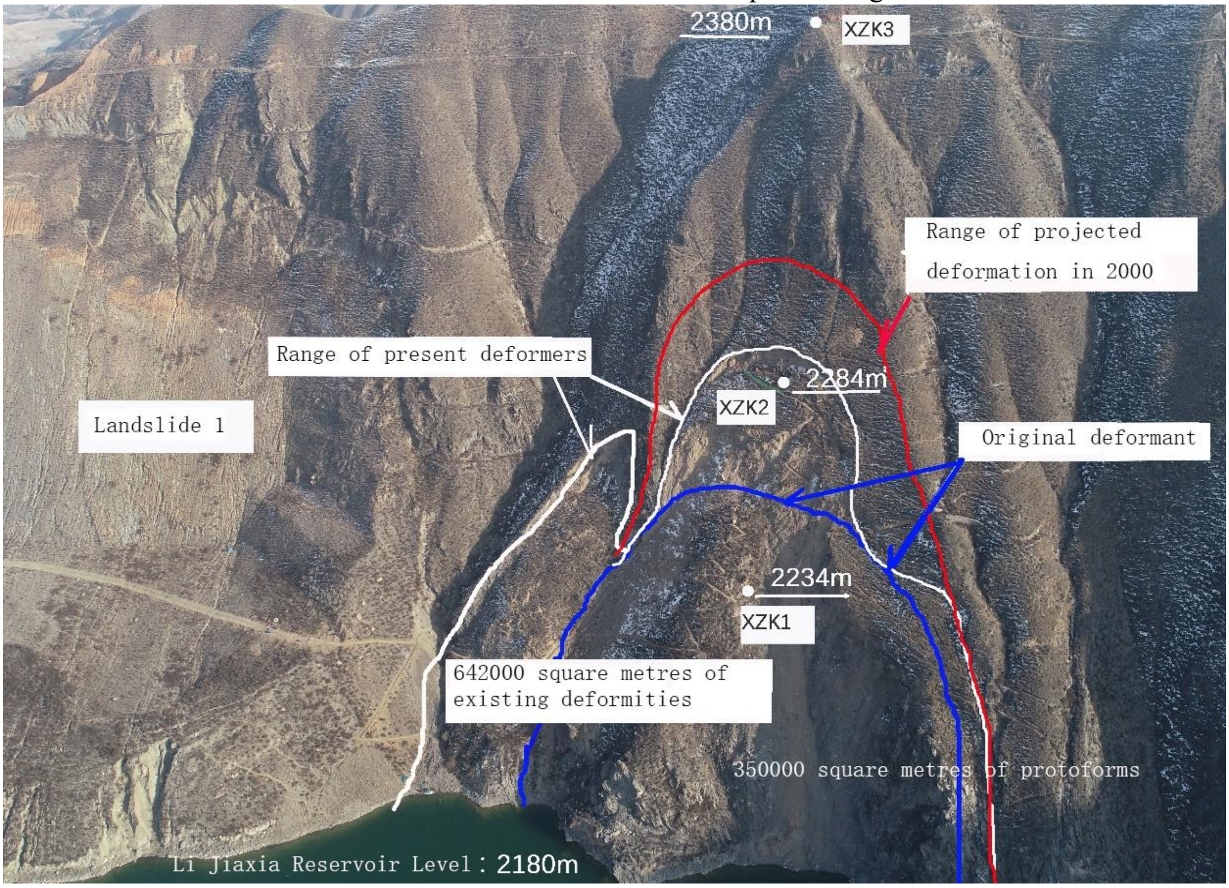

Fig.2 Range of deformation body

3.1.2 Morphological characteristics of deformation body

The tensile fracture range of the deformation body of the slope is larger than that before 2000. The extension of the tensile fracture of the deformation body is lengthened and widened, and new deformation cracks are generated on the downstream side. The collapse of the local scarp is obvious, mainly as follows :

(1) Above the reservoir water level, the scope of the deformation body expands, and the surface collapses seriously.

On the basis of the original deformation body in 2000, the present deformation body extends downstream by nearly 60 m; at the elevation below 2248m, it has expanded upstream by about 10m (Fig.2). At the same time, the stability of the surface of the deformation body is relatively poor, and there are many traces of avalanche-slip accumulation on the surface. The drainage ditch set up during the previous construction period is completely cracked and damaged, and only two points, DC12 and DC16, remain intact at the geodetic monitoring points.

(2) Below the reservoir water level, the potential shear outlet elevation of the original deformation body is between 2130m ~ 2135m, Due to years of water storage, the shallow surface of the deformation body collapses and enters the reservoir, and obvious accumulation occurs underwater. The front edge of the accumulation is between 2085 m and 2100 m, which is basically flat with the top of the concrete retaining wall of the intake tower. According to the underwater topographic map, there is no obvious accumulation on the side of the retaining wall near the riverbed. Compared with the 2130 m elevation of the potential shear outlet of the original deformation body, the accumulation height is 30 m ~ 45 m. The horizontal accumulation thickness reaches 10m ~ 20m at the elevation of 2130m, generally 20m ~ 25m at the elevation of 2100m, and the maximum horizontal accumulation thickness reaches 62m. (see Fig. 3).

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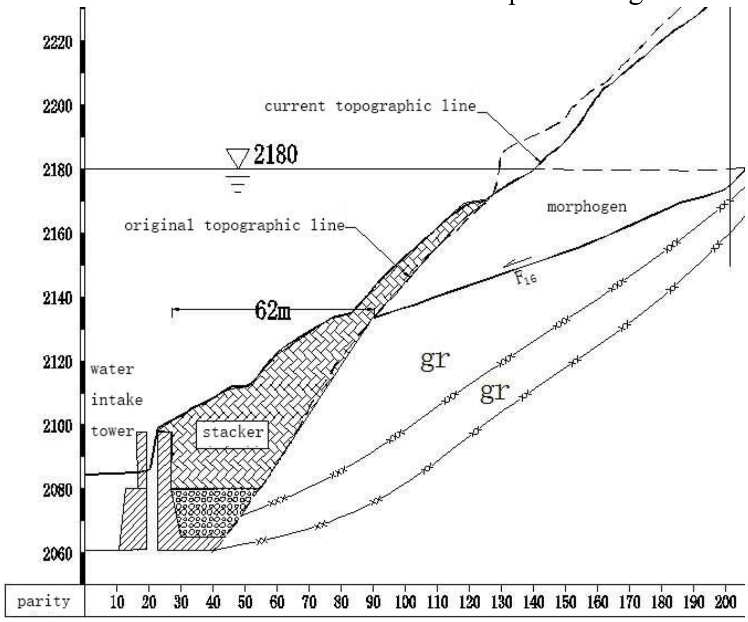

Fig.3 The present situation of accumulation body under water

3.1.3 Distribution of tensile cracks in deformation body

This investigation found that the tensile crack I & II found in the previous geological investigation have been unable to identify their tensile characteristics , due to the continuous deformation, tensile fracture and collapse of the deformation body for many years. I At the trailing edge of the deformed body (elevation between 2275m ~ 2300m), new tensile cracks appear, there are new pulling deformation, mainly increased III, IV, V, V-1 tensile cracks . Among them, the deformation and cracking of tensile crack III is the most obvious, and the vertical dislocation distance is 8 ~ 10 m ; the tension crack IV is the trailing edge boundary of the current deformation body, and the vertical staggered distance is about 0.7 ~ 1.0 m.Its overall scale is smaller than that of tensile crack III, and its formation time is later than that of tensile crack III. As shown in Fig. 4 and Fig. 5.

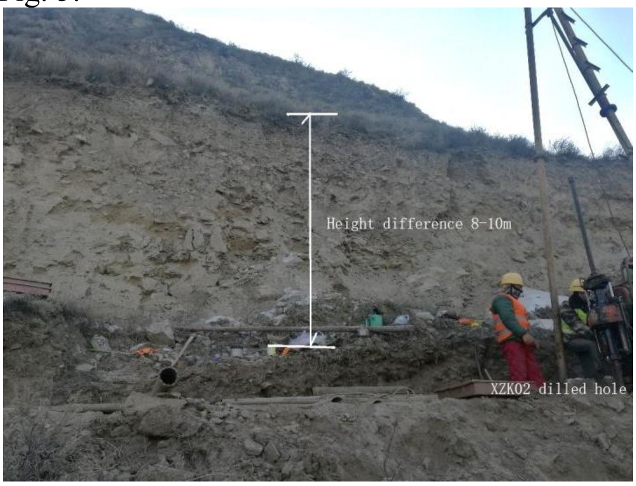

Fig.4 Photograph of the current condition of tensile crack III

Fig.5 Photographs of the current condition of tension crack IV

3.1.4 Monitoring and analysis of deformation body

The main task of this monitoring is to review the three existing monitoring benchmarks near the slope, and to observe the deformation of the six original monitoring points on the slope. Among them, DC12 and DC14 are located at the front edge of the deformation body, DC19 is located near

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the upstream side edge of the deformation body, DC20, DC21 and DC22 are located on the stable bedrock outside the deformation body. During the survey, the existing monitoring points were monitored for a total of 3 times, and the monitoring frequency was once every 10 days. Combining the results of the deformation monitoring before the previous storage, the results are shown in Fig. 6 to Fig. 7.

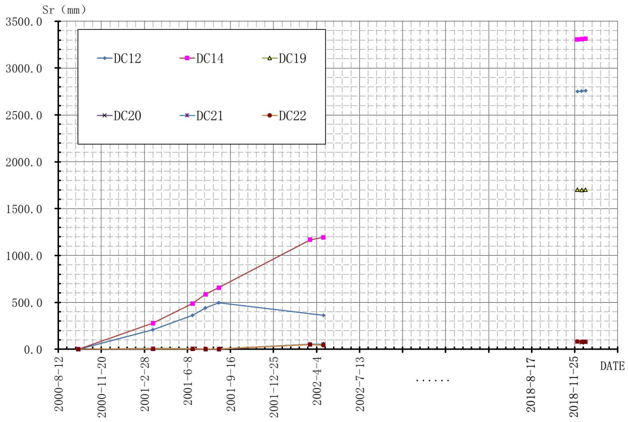

Fig.6 Synthetic Displacement Curve for Each Monitoring Point

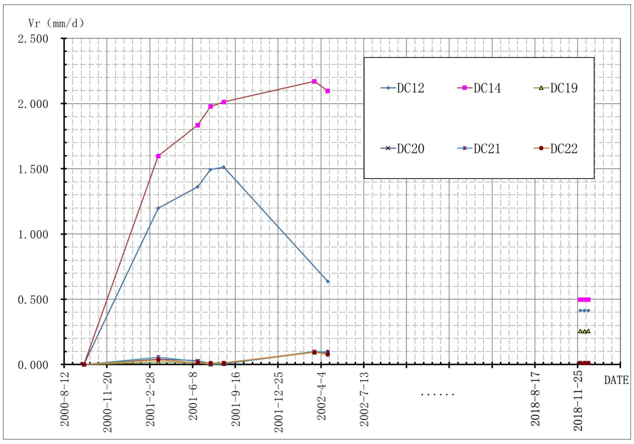

Fig.7 Synthetic Rate Curve for Each Monitoring Point

As can be seen from the figure, the deformation of the deformation body mainly occurs in the early stage of water storage, and the slope deformation body has been in continuous creep-slip deformation during the past 19 years from September 2000 to December 2018, and the cumulative deformation of the monitoring points is as high as 2.75-3.3 m, and the deformation rate is in the range of 0.41-0.50 mm/d. The observation points located on the stable bedrock outside of the deformation body of the slope (DC20, DC21.) are considered to be in a stable state, with little combined deformation, DC22) are located on the stable bedrock outside the deformation body, and the combined deformation amount is very small, which can be considered to be in a stable state. This deformation state is consistent with the results of geological investigation.

3.2 Causes and Evolution Process of Deformation Body

3.2.1 Geological background to the genesis of deformation body

The geological background for the genesis of the current deformation has not changed significantly from the previous period in terms of valley topographic conditions, geostress environment, and controlling structural surfaces, except for water storage conditions.

At the present stage, the slopes showed obvious tension deformation compared with the previous period, which was mainly caused by the continuous deformation under the action of soaking and gravity of steep slope after the elevation of reservoir water level [5]. Under the boundary condition of high and steep slope and its own stress, the shallow part of the slope first produces unloading and tension, which gives precipitation infiltration provides a good condition, surface runoff along the fracture surface infiltration, transport, enrichment, its pore water effect not only makes the rock slope increase the downward force, coupled with the reservoir water immersion, softens the controlling weak surface, reduces the shear strength, and deteriorates the stability conditions of the slope. Therefore, the pore water effect formed by the surface water flow scouring and seepage along the fracture surface and the reservoir water immersion are the main factors for the further development of the deformation body.

3.2.2 Analysis of the evolutionary process of deformation body

(1) Accelerated shear creep stage: since the formation of this slope deformation body, before water storage has experienced the tensile crack dumping and shear creep stage, after water storage, with the rise of the reservoir level, the slope deformation body enters into the accelerated shear

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creep stage, the surface of the deformation body appeared number of tensile cracks, the appearance of these tensile cracks is a result of the joint action of the slope tectonic stress concentration and gravitational creep and slip.

(2) Continuous creep-slip damage stage: after 2001, Lijiaxia Reservoir reaches the normal storage level of 2180m, the gently inclined structural surface (F16) near the elevation of 2130m is completely located below the reservoir level, and so far it has experienced nearly 20 years of long-term soaking and softening, which further reduces its shear strength, and worsens the stability conditions of slopes, and furthermore, affected by the infiltration of rainfall, the trailing edge of the tensile cracks further development and expansion, local pore water pressure may be formed, further reducing the shear strength of its accumulation body and its potential sliding surface. As a result, a larger penetrating boundary is formed in the upper part of the deformed body, the deformation of the body below the boundary by the action of the self-gravity continues to creep and slide deformation damage, the deformation damage manifested itself in two ways: one for the shallow surface layer of the loose body of the slope body of the collapse of the slide, deformation is larger; and the second is along the existing control of the weak surface to produce Deformation of the whole body creep slip, deformation is relatively small. This continuous creep-slip damage can be regarded as the result of the joint action of stress concentration, gravity creep-slip, reservoir water immersion and rainfall infiltration.

In addition, the accumulation at the foot of the slope formed by the collapse and sliding of the shallow surface layer has played a good role in loading and resisting the sliding of the slope. Since the impoundment, the deformation rate of the deformation body has experienced continuous acceleration and deceleration alternately with the multiple rise and stability process of the reservoir water level since the impoundment. This creep deformation makes the deformation body gradually break up and disintegrate, which greatly reduces the possibility of its overall damage and rapid landslide.

3.3 Parameter Values of Deformation Body and Structural Surfaces of Slopes

3.3.1 Values of fault strength parameters

The recommended values of strength parameters of each fault are shown in Table 1.

Table 1 Suggested Values for Fault Strength Parameters

Faults subgroups	Compendial fault (geology)	porosity ratio	proportion	General climatic conditions		Continuous heavy or torrential rain		underwater	
		e		f	c kPa	f	c kPa	f	c kPa
NE-steeply dipping fault	F22	0.456	2.77	0.38	40	0.365	30	0.366	30
NE-gently dipping fault	F16	0.417	2.78	0.48	50	0.460	40	0.43	35

3.3.2 Strength parameters of rock and deformation body

The main components of the deformation body are loose rock, sand and soil, etc. The parameter values can be referred to the following Table 2.

Table 2 Suggested values of deformation body parameters

Parametric / Materials	Natural Heavy kN/m^3	Angle of internal friction °	Cohesive force kPa	Saturation Heavy kN/m^3	Note
Deformation body (Above water level)	24.0	26.01	45	25.5	The shear parameter is the effective stress
Deformation body (Below water level)	25.5	23.75	35	25.5	
Intact rock mass	26.0	70.0	400	26.1	

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3.4 Numerical Simulation of Deformation Evolution of Slope Deformation Body

The model is established based on the results of field investigation and combined with the results of 3D geological modelling. In order to ensure the relevance of the stability analysis and the feasibility of the modelling and calculation analysis, the calculation model of the slope deformer at the top of the Lijiaxia diversion tunnel is appropriately simplified. According to the actual situation of the geological environment in which the slope is located, this analysis imposes full constraints on the bottom surface of the model to make it completely fixed, normal constraints are imposed on the boundaries around the model, and the top surface is free. However, on the waterfront side, hydrostatic pressure load constraints are imposed according to the actual height of the reservoir water level and groundwater infiltration surfaces are set up to start the calculation and analysis in accordance with the actual groundwater line disclosed by the survey, and the partial results of the calculations are shown in Fig. 8 and Fig. 9.

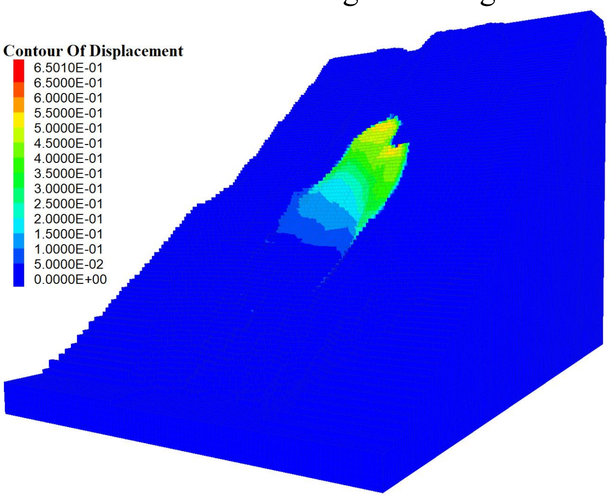

Fig.8 Contour of displacement

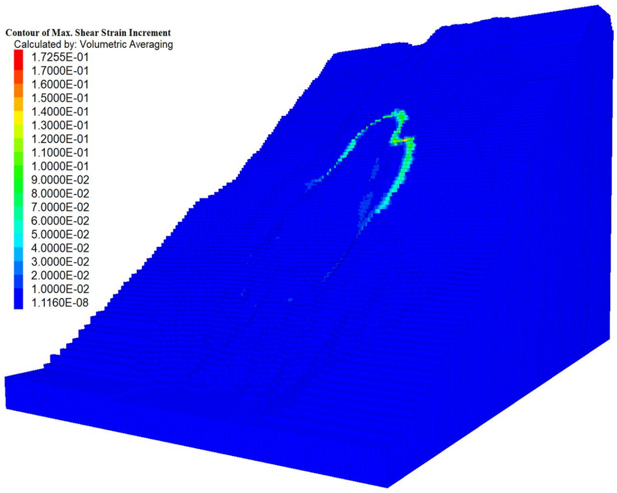

Fig.9 Contour of maximum shear strain increment

Fig.8 shows the displacement distribution of the slope, from the figure can be seen, the current topographic conditions, hydrological conditions and geological conditions of the slope, the deformation of the deformation body is still basically concentrated in the back edge of the deformation body, the calculation of the maximum displacement of 0.65 m. The deformation of the underwater part is small due to the hydrostatic pressure and the uplift of the reservoir water. Therefore, it can be inferred that the deformation of the deformation body in the future may still be the loose deformation and expansion of the upper deformation body, and gradually slide into the water, forming the pressure foot on the bottom of the slope, and finally reach the equilibrium state.

Fig.9 shows the maximum shear strain increment distribution of the slope body, from which it can be seen that the maximum shear strain distribution of the slope body is mainly concentrated in the trailing edge of the deformation body, which basically corresponds to the location of the cracks in the deformation body as mapped by the current geological survey. This shows that the current deformation of the slope body has not stabilised, and there is a possibility that the deformation body will continue to develop and expand with cracks in the coming period of time.

4. Calculation and Evaluation of Slope Stability and Surging Waves

4.1 Calculation and Evaluation of Slope Stability

According to the level of buildings affected by the high slope at the entrance of the diversion tunnel and the degree of damage caused by the slope failure, the stability evaluation criteria are considered at level 3 [6,7]. In this calculation, the longitudinal section II is selected as the representative section for calculation.

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4.1.1 Stability Analysis Based on Limit Equilibrium Theory

(1) The working condition for stability calculation

The working conditions for stability analysis are determined as follows:

Condition 1 : Natural. The c, φ and γ values of rock and soil under natural conditions are selected as the stability calculation parameters.

Condition 2 : Rainstorm. The c, φ and γ values of rock and soil in saturated state are selected as the stability calculation parameters.

Condition 3 : Earthquake. The c, φ and γ values of rock and soil under natural conditions are selected for calculation, and the earthquake action is considered.

(2) Stability calculation results

1) Stability calculation according to the sliding surface determined by the survey results

The calculation model is shown in Fig. 10 and Fig. 11 (In the figure, ① and ④ are intact rock masses, ② is deformation body above water level ③ is deformation body below water level).

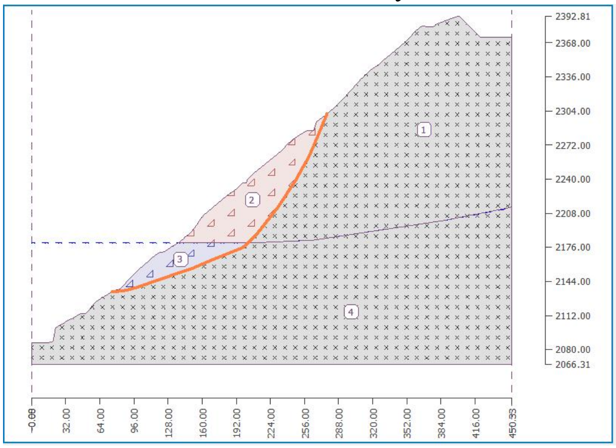

Fig.10 Stability calculation of folded linear sliding surface obtained by geological survey

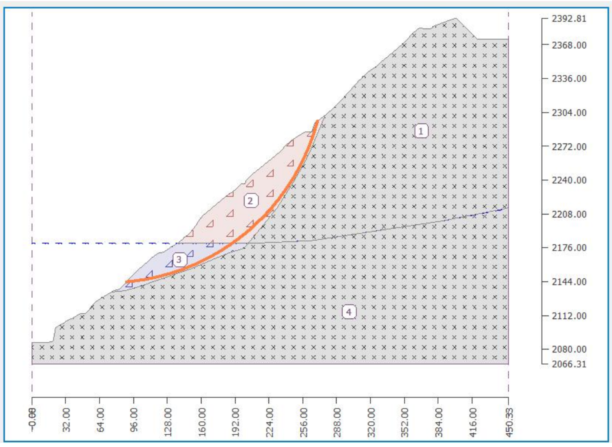

Fig.11 Stability calculation of the circular arc sliding surface obtained by automatic search

2) Calculation results of automatic search for the most dangerous sliding surface

If the unbalanced thrust method (implicit) is used to automatically search the sliding surface of the deformation body section, the location of the sliding surface obtained from the search under the natural working condition is shown in Fig. 11.

The stability coefficients of the deformation body obtained from the unbalanced thrust method for the two types of sliding surfaces under different working conditions are shown in Table 3 below.

Table 3 Stability coefficient obtained by unbalanced thrust method

Working condition / calculation method	Natural	Rainstorm	Earthquake
Folded linear sliding surface	1.03	1.00	1.01
Circular arc sliding surface	0.93	0.86	0.90

4.2.2 Stability Analysis Based on Strength Reduction Theory

The longitudinal II section is also selected as a typical section for calculation, because the strength reduction calculation tool is not available in the seismic dynamic calculation in the numerical software. Only natural working conditions and rainstorm conditions are considered in this calculation. Through the modelling analysis of geological longitudinal section II, the stability coefficients obtained using the strength discount method are shown in Table 4.

Table 4 Stability coefficients obtained by strength reduction method

Working condition	Natural	Rainstorm

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Calculation method		
strength discounting	0.83	0.73

The corresponding maximum shear strain increment distribution is further extracted as shown in Fig. 12 and Fig. 13. As can be seen from the figures, the distribution of the maximum shear strain increment corresponding to the safety factor calculated by the strength reduction method is in the form of strips, and basically through the entire slope, from which it can be judged that the current slope is in an unstable state. The stability coefficient calculated by this method is relatively low.

Fig.12 Contour of maximum shear strain increment for natural condition

Fig.13 Contour of maximum shear strain increment for rainstorm condition

4.3.3 Stability evaluation of slope deformation body

The stability coefficient of the deformation body calculated by the folded linear sliding surface obtained by the geological survey is obviously higher than that of the sliding surface obtained by the automatic search.

According to geological mapping and drilling data, there is no obvious deformation in the deep part of the deformation body. Referring to the calculation results, it is considered that the potential sliding surface in the deep part of the deformation body is basically stable ~ unstable, and the possibility of overall sliding under natural conditions is not large.

In fact, the shallow surface of the deformation body has undergone obvious collapse deformation. According to the stability calculation results obtained by the automatic search, the stability coefficient is between 0.73 and 0.98, which is also consistent with the tensile deformation and monitoring results of the shallow surface of the deformation body in the field. It can be considered that the shallow surface of the deformation body is in an unstable state under natural conditions.

4.2 Prediction and Evaluation of Landslide Surge

At present, there are many methods for calculating the slip velocity of landslide accretion or slope destabilisation, among which the more widely used methods are Pan Jiazheng method, energy method and so on. The energy method is a calculation method based on the energy conservation theorem. The calculation formula is :

$$V_s = \sqrt{1 - \frac{f}{tga} - \frac{cl}{W * \sin a}} * \sqrt{2gh}$$

Where: a : Sliding surface inclination (along the sliding direction);

W : The weight of single width of the sliding body;

f, c : Shear strength parameter of the sliding surface;

h : The height difference of the centroid of the sliding block;

l : The length of contact between the slider and the sliding surface (along the sliding direction);

This calculation uses energy to calculate, and the calculation parameters are determined according to the recommended values of the parameters in Table 2. The distance between the high slope at the entrance of the diversion tunnel and the opposite bank is about 450 m, and the nearest

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distance from the dam is about 650 m, as shown in Fig.14. According to the field investigation and calculation, the maximum volume of one-time instability sliding is determined to be 424,500 m^3 (above the water level).

Fig.14 Relative position map of slope and dam

Calculation of the height of the surge is based on the empirical formulae of the China Institute of Water Resources, the sliding speed of the reservoir landslide and the volume of the sliding body are the main factors affecting the height of the surge, and their relationship is:

$$\eta_{\max} = K \frac{V^{1.85}}{2g} U^{0.5}$$

Where: $\eta_{\max}$:Maximum surge height (m);

K: Integrated impact coefficient, to the opposite bank takes the value of 0.2, to the dam takes the value of 0.15;

V: Landslide speed (m/s);

U: Volume of sliding body ($10^4 m^3$); calculated by a one-time instability sliding of 424,500 m^3;

g: gravity acceleration (m/s^2).

The surge height calculated according to the above formula is shown in Table 5

Table 5 Calculation results of surge height

Landslide distance（m）	134
Landslide velocity（m/s）	12.7
Surge height to the opposite bank（m）	7.3
Surge height to dam（m）	1.4

According to the above calculation results, under the influence of rainstorm, earthquake, etc., according to the most unfavorable conditions of the largest one-time instability sliding of 424,500 m^3, the height of the surge generated on the opposite bank is 7.3m, and the height of the surge generated in the dam is 1.4m, which is significantly smaller than the height of the dam 's crown wall (6.2m), and does not produce overtopping phenomenon.

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5. Conclusions and Recommendations

5.1 Conclusion

(1) The scope and volume of the deformation body of the slope at the top of the diversion tunnel is compared with that before 2000, the overall scope of the deformation body has been extended downstream, the extension distance is nearly 60m; the plane area of the deformation body has also increased significantly, up to 26660m^2, and its volume has increased from 350,000m^3 to 642,000m^3 at present.

(2) At present, the main deformation forms of the deformation body are shallow surface collapse and overall creep deformation. The comprehensive deformation of the observation points located on the stable bedrock on the upper part of the slope deformation body is very small, and the monitoring points are completely preserved. The monitoring period is up to 23 years, which can be considered to be in a stable state. This is also a strong evidence for the stability of slope rock mass above 2300 m elevation outside the deformation range.

(3) The deep potential sliding surface of the current deformation body is basically stable to unstable, and there is little possibility of overall sliding under natural conditions. The shallow surface of the deformation body is in an unstable state under natural conditions.

(4) According to the most unfavorable working conditions, the overall one-time instability slip occurs, and the generated surge height to the opposite bank is 7.3 m, and the surge height to the dam is 1.4 m, which is lower than the height of the dam 's crown wall, and the surge hazard is small.

(5) After the completion of the work described in this paper to the completion of this paper nearly 6 years, the author has visited the slope near the inspection many times, the overall operation of the slope is smooth, basically maintaining the status quo, confirming the reliability of the assessment conclusions described in this paper.

5.2 Recommendations

Based on the above conclusions, further work on this slope is recommended as follows:

(1) At present, the deformation of the deformation body of the slope is still continuing, in order to grasp the deformation dynamics in time, it is recommended to set up a number of monitoring points on the surface and periphery of the deformation body, and implement monitoring and early warning. Before and after the rainy season or the reservoir water level variation is larger time to be encrypted monitoring, and the slope to strengthen the patrol.

(2) The deformation of the deformation body of the slope is closely related to the infiltration of rainfall, but at present, the intercepting and draining ditch at the surface part of the slope has basically been completely destroyed, and it can be considered to rebuild the intercepting and draining ditch on the stabilised slope body at the back edge of the slope, so as to reduce the adverse effect of infiltration of rainfall on the slope.

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