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Stability Analysis and Treatment Method of a Landslide

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Abstract: In this paper, the characteristics of the landslide are described in detail, the stability of the landslide is analyzed, the stability safety factor under different working conditions is calculated, and finally the treatment measures are proposed.

Keywords: Landslide Deformation Characteristics; Stability Analysis; Governance measures

1. Basic Characteristics of the Landslide

The landslide, located in Qingchuan County, Sichuan Province, is a mid-high mountain slope landform with a strip-like shape on the plane (see **Fig. 1**), and the terrain is high in the south and low in the north, and is inclined.

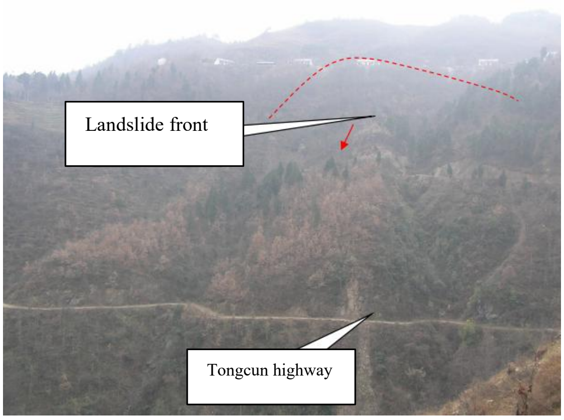

Figure 1. Overall View of the Landslide

The slope elevation where the landslide is located is 918.85~1023.80m, the relative height difference is 104.95m, the slope angle is generally 25~42°, the slope angle of the trailing edge is generally 30~45°, and the vegetation is relatively developed. the elevation of the leading edge of the landslide is 988.45~996.21m, the elevation of the trailing edge is 1001.27~1002.62m, and the relative elevation difference is 5.06~14.17m. There is a gully on the east and west sides of the landslide body, which is a typical mountain river, and the water level change has the dynamic characteristics of steep rise and fall, and is recharged by atmospheric precipitation and slope surface flow.

The plane shape of the landslide body is strip-shaped, the north-south longitudinal length of the landslide is 20~32m, the east-west width is 202~256m, the average thickness of the landslide is about 8m, and the volume of the landslide is about 4.7×104m3. According to the on-site investigation, due to the influence of topography, there are two main sliding directions of Wenjialiang landslide, which are 4° and 9°, the height of the front edge of the free surface is about 8~13m, and the slope is 30~42°.

The landslide material is composed of crushed stone and silty clay that were abandoned during the construction of the national highway. the front edge forms a steep slope of about 8-13m in height, with a gradient of 30-42 °, and no support measures have been taken for support. the local soil mass at the front edge of the landslide has collapsed. Three sets of tensile cracks have appeared at the rear edge of the landslide, on the north side of National Highway 212, and around nearby residential buildings, with a spacing of 0.30-0.50m. the crack width is generally 10-20mm, and the crack extension length is about 100-190m. the visible length is about 12-27m, and the extension direction is about 20-100 °. According to villagers, after the 5.12 earthquake, the width of the crack along the back edge of the landslide was relatively large, about 50-80mm wide, and the extension length almost penetrated the entire landslide, locally extending to the middle line of National Highway 212. the main sliding direction was displaced by 0.20-0.30m and vertically shifted by 0.20-0.50m.

2. Composition of Landslide Material

According to the mapping and exploration data, the entire slope is composed of artificial fill and residual slope layer block stone soil from top to bottom, and the bedrock is the Precambrian Bikou Group to Central Asia Group (*Pz_1bk*) phyllite.

(1) Quaternary Holocene artificial

accumulation layer (Q^{ml}): mainly composed of plain fill, consisting of gravel and silty clay. There are many construction and household waste such as broken bricks visible at the edge of the slope, with mixed composition, poor uniformity, and loose structure. This floor is mainly distributed in the housing construction area and on the north side of the road, and was built from the abandoned pile of National Highway 212.

(2) Quaternary Holocene residual slope layer (Q^{el+dl}): mainly composed of silty clay, composed of gravel and cohesive soil, with many block stones distributed on the slope surface. the main components of the parent rock of fragmented and block stones are tuff and phyllite, with a particle size of generally 200-300mm, poor roundness, strong to moderately weathered state, angular shape, and a small amount of cohesive soil filling; the particle size of the crushed stone is generally 10-20mm, and it is in a strongly weathered state. This layer is mainly distributed in the gentle slope zone and under the landslide body.

(3) the Bikou Group to Central Asia Group (Pz_1bk) of the Precambrian Sinian System are mainly composed of phyllite, distributed under residual slope deposits, and serve as base rocks.

3. Hydrogeological Conditions of Landslides

3.1 Aquifer (Aquitard) Group

According to factors such as the composition of the aquifer, the degree of development of pores and fissures, water bearing capacity, and the distribution of spring water, the aquifer (aquitard) group is divided. the Quaternary system is a permeable layer group, and most of the pores in this layer group are developed. On the one hand, it is in contact with the underlying bedrock fissure aquifer group, and on the other hand, its water content is greatly affected by terrain. the upper part of the bedrock is weathered, with developed structural fissures and shallow fissure water content. the underlying bedrock rock mass tends to be intact and exhibits water-resistant characteristics.

No groundwater level was measured during the survey period.

3.2 Characteristics of Groundwater Recharge, Runoff, and Discharge

The overlying Quaternary loose accumulation layer in the work area is a moderately permeable layer, while the strongly weathered zone of the underlying phyllite is a weakly permeable layer, and the weakly weathered layer is a slightly permeable layer. According to the type of storage medium of groundwater, it is divided into two categories: pore water and bedrock fissure water.

(1) Groundwater recharge

Loose rock pore water is mainly supplied by atmospheric precipitation. the upper soil and strongly weathered rock layers in the survey area have a large thickness, loose structure, high porosity, and good permeability. Atmospheric precipitation can quickly infiltrate downwards, directly replenishing the pore water of loose rocks. Based on the amount of water discharged from the loose rock voids during the normal and wet periods into the valleys on both sides, it can be inferred that atmospheric precipitation has a significant impact on groundwater recharge.

Loose rock voids infiltrate and recharge bedrock fissure water.

(2) Groundwater runoff

Loose rock pore water: When pore water flows, its direction of movement is from high water level to low water level in a planar manner.

Bedrock fissure water: Due to the development of weathered joints, the permeability of bedrock fissure water is average, and the water level difference is large. It infiltrates along the tensile fissures to the weathered or rock interface, flowing from high to low.

(3) Groundwater discharge

The main discharge methods of groundwater are vertical discharge and horizontal discharge.

Vertical discharge: the loose rock voids in the upper part of the slope are submerged, and the water volume is mostly seasonal, appearing during the rainy season and disappearing 1-4 days after rain. Supplying bedrock fissure water through evaporation, excretion, or infiltration.

Horizontal discharge: Groundwater flows from high water level to low water level along a certain hydraulic gradient under the action of gravity, and some fissure water flows along fissures or weak layers and sliding surfaces.

(4) Groundwater quality

According to the relevant requirements of the "Code for Investigation of Geotechnical Engineering" regarding the evaluation of water quality corrosiveness, the site environment category is Class II, and the groundwater type in the area is HCO_3^- $SO4^{2-}$ Ca^{2+} Mg^{2+} freshwater. It has no corrosiveness to concrete structures and steel bars in concrete structures, but water has weak corrosiveness to steel structures.

In summary, the aquifer group in the landslide area is relatively simple, but there are significant differences in composition, thickness, porosity, and crack development. the groundwater source is relatively single, and the reserves vary greatly with seasons and precipitation dynamics. the water quality is good, and the hydrogeological conditions are relatively simple.

4. Deformation Characteristics of Landslides

Affected by the 5.12 earthquake, the landslide has undergone deformation, with local tensile cracks appearing on the surface. the landslide has also experienced deformation and collapse on the north side of National Highway 212 and the leading edge of Tongcun Road. Through this engineering geological survey and mapping, the main deformation and failure modes in the area are ground cracking and collapse deformation. the specific description is as follows:

(1) Ground cracking

On the plane, it is mainly distributed at the rear edge of the landslide, the north side of National Highway 212, and the surrounding residential buildings. According to statistics, there are a total of three groups of cracks, all of which are tension cracks. the crack width is generally 10-20mm, and the crack extension length is about 100-190m. the visible length is about 12-27m, and the extension direction is about 20-100 °. According to villagers, after the 5.12 earthquake, the width of the crack along the back edge of the landslide was relatively large, about 50-80mm wide, and the extension length almost penetrated the entire landslide, partially extending to the middle line of National Highway 212. the main sliding direction was displaced 0.20-0.30m and vertically shifted 0.20-0.50m. It had been sealed and filled by local villagers before the survey.

(2) Collapse and deformation

The steep slopes located on the inner side of Tongcun Road and the outer side of National Highway 212 have experienced deformation and collapse (sliding), with a soil and rock volume ranging from approximately 5.0 to 16.0 cubic meters.

3. Calculation of landslide thrust and stability coefficient

(1) Landslide thrust calculation

According to the assumed landslide damage calculation model, working conditions, calculation methods, and parameters, the calculation results of each exploration profile under different safety factor conditions are listed in **Table 1**.

Table 1. Calculation Table of Landslide Thrust

Computational profile	Working condition	safety margin	Residual glide thrust (KN/m)	remarks
2—2′	Natural state	1.20	0	The sliding zone is formed along the weak surface of the contact surface (zone) between artificial fill and gravel containing silty clay, resulting in a zigzag sliding mode.
	Saturated	1.10	0	
	Natural+Earthquake	1.05	0	
3—3′	Natural state	1.20	72.87	
	Saturated	1.10	184.59	
	Natural+Earthquake	1.05	107.09	
4—4′	Natural state	1.20	65.03	
	Saturated	1.10	186.29	
	Natural+Earthquake	1.05	88.29	

(2) Stability coefficient calculation

Based on the failure calculation model, working conditions, calculation methods, and parameters determined by the landslide, the stability calculation results of each exploration section are listed in **Table 2** after calculation.

Table 2. Calculation Table of Landslide Stability

Calculate profile	Working conditions	Stability coefficient	remarks
2—2′	Natural state	2.003	The sliding zone is formed along the weak surface of the interface (zone) between artificial fill and silty clay containing gravel, resulting in a
	Saturated	1.703	
	Natural+Earthquake	1.638	
3—3′	Natural state	1.151	

	Saturated	0.983	broken-line sliding mode.
	Natural+Earthquake	0.984	
4—4′	Natural state	1.161	
	Saturated	0.995	
	Natural+Earthquake	1.001	

5. Landslide Stability Analysis

According to the calculation results of landslide thrust and stability coefficient, whether under natural conditions, saturation conditions and natural+ seismic conditions, the landslide body above the potential weak surface of the 2-2′ profile is stable, and the remaining sliding thrust calculated according to the corresponding safety factor is 0. the landslides above the potential weak surface of the 3-3' and 4-4' profiles are stable in the natural state, and the remaining sliding thrust calculated according to the corresponding safety factors is 72.87 kN/m and 65.03 kN/m. the remaining sliding thrust calculated according to the corresponding safety factor is 184.59 kN/m, 186.29 kN/m and 107.09 kN/m~88.29 kN/m, respectively, while it is unstable under saturation and natural+ seismic conditions.

It can be seen that the potential weak sliding surface and the slip of the landslide body along the 2-2′ profile do not exist, that is to say, the stability coefficient is greater than 1.15 under natural working conditions, saturation or natural+seismic conditions, and the landslide body will not be unstable in a stable state, but the local soil near it will collapse, and the potential weak sliding surface along the 3-3′ and 4-4′ profiles exists, and under the natural working conditions, the stability coefficient of the 3-3′ profile is less than 1.00 and is in an unstable state under the saturation condition and natural+seismic condition, and the stability coefficient of the 4-4′ profile is less than 1.05 and is in an unstable state, so the hypothetical conditions of the above-mentioned landslide exist and are consistent with the reality. Once the landslide is unstable, it will cause great harm to the safety of local residents, the road through the village and its passing vehicles and pedestrians, and will seriously affect the safe operation of National Highway 212 and the traffic and economic development of the surrounding villages, so it should be controlled.

6. Governance Measures

The landslide treatment scheme adopts the treatment measures of "leading edge retaining wall+slope section, drainage engineering+slurry block stone lattice structure+sealing cracks".

1) Construct an anti-slip retaining wall at the shear outlet of the leading edge of the landslide to prevent the landslide and improve the overall stability of the landslide;

2) Slope structure lattice engineering, slope protection, prevention and control of slope local instability;

3) the part of the interception ditch between National Highway 212 and the landslide body is not built, so that the surface water collected by the slope at the trailing edge of the landslide body is discharged from the natural ditch on both sides of the landslide body.

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