Stability Analysis and Treatment of a Landslide

Zeng Yuping
Sichuan College of Architectural Technology, Deyang, Sichuan, China

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. Project Overview

The area where the project is located is located in Lushan County, Ya'an City, in the west of Sichuan Basin, in Qingren Township, northwest of Lushan County, with good geographical location, accessible by organic lane, and convenient transportation.

Lushan County is located in Sichuan Province, located on the east side of Erlang Mountain and Jiajin Mountain, and is frequently the center of heavy rain due to mountain ranges. the average annual rainfall in Lushan County is 1313.1mm, the maximum rainfall is 1717.3mm in 1978, and the minimum rainfall is 916.7mm in 1974, a difference of 1.87 times. the evaporation is not large in the area, only 950.9mm. the annual rainfall is concentrated from May to October, reaching 1196.5mm, accounting for 91% of the annual rainfall, especially from July to August, the rainfall is prominent, reaching 604.2mm, accounting for 46% of the annual rainfall. Rainfall greater than 50mm or more averaged 3.5 times a year. the maximum daily rainfall in the area is 188mm, the maximum hourly rainfall is 86mm, and the maximum 10-minute rainfall is 30.1mm. In addition, due to the low topography in the south and high in the north, the spatial distribution of rainfall in the region shows a downward trend from south to north due to the influence of topography. Geological disasters are obviously controlled by rainfall, and the frequency of geological disasters is the highest from July to August.

At present, through the observation of Lushan County Meteorological Station for many years, the 50-year rainstorm is 215mm/day, the 20-year rainstorm is 188mm/day, and the 10-year rainstorm is 146mm/day.

The landform type in the exploration area is eroded low mountain landform, the slope slope is relatively gentle, the underlying bedrock is dominated by the middle-thick sandstone and mudstone of the Tertiary Lushan Formation, the joints and fractures of the rock mass are relatively developed, and the surface rock mass is broken. the thickness of the superficial weathering zone is about 4~6m. the slope strikes about 35°, and the whole is a downward slope structure with a bedrock dipping down the slope and slightly upstream.

The landslide section is on the right side of the slope of the survey area. the overall shape of the slope is ridge-like protrusion, and the trailing edge is bounded by Qingsi weir. the slope is longitudinally straight, the slope of the top of the slope is relatively gentle, the front edge is relatively steep, and the terraced terrain is developed, and the overall slope is about 22°. the front edge of the landslide in this area is mainly farmland and villager gathering points, the rear section is cultivated land, and the central part is forest land and cemetery. the landslide section has a plane area of 7133m2, a longitudinal length of 150m, and a maximum width of 65m. the total volume of the landslide is about 35, 000 m^3.

The landslide on Nanjie is below the residential area of Luxi Village, and the landslide has obvious deformation aggravation phenomenon in the local area after the 5.12 earthquake, and more tensile cracks have developed in the middle and rear edges.

The groundwater in the area is mainly recharged by atmospheric precipitation, and the groundwater in the site is mainly Quaternary pore water, bedrock fissure water and local upper stagnant water. the water quality type is generally calcium bicarbonate or calcium bicarbonate magnesium water, with low salinity, generally less than 0.3mg/m3.

Affected by the season, the flow rate of springs and wells in the dry season is generally reduced by 1~4 times.

The impact of human engineering activities on the geological environment of the landslide on South Street is manifested in slope tillage, planting cover and local small-scale slope cutting. the activities of human engineering are only limited to the superficial layer of the earth, and the deformation and damage of the superficial rock and soil mass are not enough to cause the destruction of the large-scale deep geological environment.

2. Hazard Situation

The plane shape of the slope where the landslide sliding area on Nanjie Street is located is tongue-shaped, with a longitudinal length of 160m and a lateral width of about 40-70m, covering an area of about 35, 000 m2. On the landslide profile, the ground shape is mainly stepped, with a height difference of about 40m between the front and rear edges and an average longitudinal slope angle of 12. According to the analysis of the survey data, the depth of the landslide generally varies from 3 to 6 m, which belongs to small-scale soil landslide. the landslide on the south street is mainly critical to the safety of life and property of more than 45 people in 15 households under the landslide and the safety of the water diversion project at the back edge of Qingshiyan. According to the classification of hazard degree in Technical Specification for Design and Construction of Landslide Prevention Engineering (DZ/T0219-2006), the hazard degree of this project is determined to be Grade III. the landslide on Nanjie Street was deformed before the "5.12" earthquake, but it did not cause obvious losses. After the "5.12" earthquake, the landslide on Nanjieshang has undergone obvious deformation and destruction, and its stability has been further reduced. the surface cracks of the landslide have developed, and the sliding body has become looser under the earthquake vibration. With the passage of time and the rain, the cracks have further developed and the sliding surface has been further penetrated, which may lead to further or even overall deformation, which will cause great danger to 15 households in Luxi Village under the slope.

3 Basic characteristics of landslides

The overall plane shape of the landslide area is quadrilateral, as shown in **Figure 1**. the longitudinal length of the landslide is about 160m, and the transverse width is about 250m m. the overall slope is straight and slightly arc-shaped. Outside the right boundary, the slope direction turns into a circle, the middle part protrudes into a ridge, and the overall slope direction is 150. the slope has a gentle slope at the rear edge and a relatively steep front edge, and a gentle platform and a steep front edge are developed, with an overall slope of about 22°.

Figure 1. Overall View of Landslide

3. Deformation Characteristics of Landslide Body

The deformation and failure of the landslide body have different deformation characteristics in each section, specifically the following obvious characteristics:

(1) Ground cracking deformation and overall creep deformation at the trailing edge of the landslide section

The on-site investigation found that the landslide section developed multi-level platform terrain, in which the trailing edge platform has different degrees of deformation and cracking in the rainy season in the second half of each year, and it is more obvious after the earthquake, and the longitudinal and transverse network cracks are developed, and the crack trend is mainly 150~170° in the slope direction and 60~70° in the cross-cutting slope direction, in which the longitudinal extension is longer, the boundary cracks at the trailing edge of the sliding body are arc-shaped, and the opening and staggering of the trailing edge cracks are very obvious. the width of the unfolding can be more than 10cm, and the depth can be more than 30cm. However, none of the fractures extended to the bedrock slope section on the outside of Qingsi Weir.

There is a first-class platform in the middle section of the landslide section, and the soil on the left side of the platform is extruded and deformed, and the ground is swollen and deformed. the ground in the middle and early sections of the landslide section is obviously deformed, which is manifested as the skewed trees, the cracking and destruction of the mounds, the undulating ground, and the overall creep down the slope.

The signs of deformation of the leading edge of the landslide section are also obvious, and the shear soil bulges out, destroying the original path. According to the analysis of the degree of deformation and the signs of failure, the signs of deformation gradually weakened from the trailing edge to the leading edge of the landslide, that is, the deformation of the trailing edge was the strongest, and the deformation of the leading edge was relatively weak. the topography of the sliding body in the leading-edge section is bundle-shaped, so the shear shear characteristics of the sliding body in the middle and front sections, which are slightly extruded to the left, and the ground uplift characteristics are obvious, showing the characteristics that the deformation is constrained by the landform.

The above deformation phenomenon shows that under the control of surface water convergence landform and slope landform, the terraced landform of the trailing edge is developed, the front edge of the platform at all levels has good air conditions, and the overall sliding occurs under the action of continuous heavy rain, the topography of the leading edge slows down, the leading edge belongs to the anti-slip section, and the overall stability of the slope gradually recovers. In case of unfavorable conditions such as heavy rain, instability will be initiated, resulting in overall sliding or creeping damage.

The overall sliding direction of the landslide section is 146°.

(2) Surface collapse and ground cracks in the middle of the deformation zone

There are multiple shallow landslide bodies in the middle of the landslide deformation area, which are closely related to the nearby local topography and rock and soil structure, sliding along the free direction of the front edge of the local cultivated land platform, and the cultivated land steps are as high as 1.5m.

4. Characteristics of Landslide Material Structure

According to drilling and mountain engineering, the landslide material is mainly silty clay containing crushed stone, and the gravel composition is mainly strongly weathered sandstone, argillaceous sandstone or coarse sandstone containing conglomerate, which is block and angular, and the common block diameter is 10-30mm, gray and dark gray, and it is in a hard plastic-plastic state. the content of broken stone is 20%-40%, and in the vertical direction, the area with large particle size of broken stone is found in the exploration wells and exploration grooves in the middle and rear sections of the landslide, and there is a layer of broken stone interlayer at 2m, and the particle size is 40-50cm.

The surface investigation drilling and trenching data reveal that the material structure of the landslide belongs to the relatively dense soil at the interface between the shallow layer of strongly weathered mudstone and the lower sandstone of the slope body. the sliding material is mainly composed of Quaternary residual slope accumulation (Q_4^{edl}) and strongly weathered mudstone layers, the sliding surface is silty clay, and the sliding bed is the sandstone of the middle member of the Tertiary Lushan Formation.

According to the borehole, the landslide body is a Quaternary landslide accumulation layer (Q_4^{del}), which can be divided into surface cultivated soil and landslide accumulation layer from top to bottom, and the material structure belongs to plastic-hard plastic rocky soil.

According to the exploration results, the sliding surface of the landslide is the base overburden and its fully weathered mudstone section; the sliding surface near the shear outlet of the leading-edge cuts through the soil layer, which is the weak layer in the middle of the soil. the thickness of the deformation zone is small, the sliding surface passes through the soil layer, and the exploration data show that the deformed body controlled sliding surface is the base overlay rather than the weak layer in the soil.

According to the comprehensive analysis of exploration data, the characteristics of the slip zone soil are: the material composition is mainly silty clay containing breccia small gravel, the content of breccia gravel is

generally 10-20%, local pure silty clay, the breccia component is mainly calcareous sandstone, and there are polishing traces on the surface; the silty clay is gray or light black, which is quite different from the color of the upper and lower soils, and the humidity is relatively large due to the existence of crack water in some borehole soils, and it can be molded to a soft plastic state; the viscosity is generally high and often has a slippery feeling.

There is no obvious difference in the thickness of the slip zone, which is generally between 0.2-0.5m.

From the exploration data, the thickness of the sliding body is 6.5m in the trailing edge of the slope borehole ZK01, the burial depth of the sliding surface in the middle of the landslide is 5.6m, and the burial depth of the leading-edge sliding body is 2.2m according to the excavation depth of the sliding surface in borehole ZK03.

5. Stability Analysis of Landslides

The stability calculation of each profile was carried out using the transfer coefficient method, and the calculated results are shown in **Table 1**.

The calculation results show that the landslide mass in the sliding zone maintains a stable state under natural conditions, with a stability coefficient between 1.42 and 1.56; the stability of the landslide mass decreases under rainstorm conditions, and it is in an unstable-to-unstable state, with the stability coefficient between 1.01 and 0.91; Under earthquake conditions, it is in a stable state.

The overall stability analysis of the slope in the shallow deformation zone shows that it is in a stable state under various working conditions.

In general, the residual sliding thrust of the landslide mass is small, and the maximum residual thrust occurs under rainstorm conditions. Therefore, according to the design principle of the most unfavorable load, the maximum value of landslide thrust is taken as the control condition for design.

Table 1. Statistical Table of Stability Calculation of Each Section of Landslide

Section number	Calculate profile	natural		rainstorm		earthquake	
		Stability coefficient	stable state	Stability coefficient	stable state	Stability coefficient	stable state
Main sliding surface 1-1 in landslide area	①-①Profile	1.43	stability	0.92	Instability	1.18	stability
	②-②Profile	1.56	stability	1.01	Lack of stability	1.27	stability
	③-③Profile	1.42	stability	0.91	Instability	1.15	stability
Main sliding surface 2-2 in landslide area	2-2’Profile	1.53	stability	1.02	Lack of stability	1.33	stability
Shallow deformable body	4-4’ Profile	2.69	stability	1.91	stability	2.09	stability

6. Governance Engineering Design

(1) Design of gravity based anti-skid retaining wall

Install a gravity retaining wall near the shear outlet at the leading edge of the sliding body.

The anti sliding gravity retaining wall adopts a rubble concrete structure with a concrete strength of C20 and a rubble strength of MU30. The retaining wall has a height of 3.5m, a burial depth of 1.5m to 2m, a total length of 39.5m, a top width of 1.3m, a bottom width of 3.2m, a surface slope ratio of 1:0.2, a back slope ratio of 1:0.1, and a foundation bottom slope ratio of 1:0.1. the wall teeth are 0.5m high and 0.5m wide; Gravity retaining walls are equipped with settlement joints, with one joint set every 10 meters, for a total of 2 joints. Two rows of PVC pipe material drainage holes with a diameter of 75mm and a spacing of 2m are installed on the wall, with a spacing of 0.8m between the upper and lower rows, arranged in a zigzag pattern.

(2) Intercepting and drainage ditch

A drainage ditch is designed at the corner of the retaining wall slope, divided into sections AB and BC, using M7.5 mortar block stone structure with a design length of 43.5m. the drainage ditch has a trapezoidal interface with dimensions of 0.5m × 0.3m, a wall thickness and bottom thickness of 0.2m, a slope ratio of 1:0.2 on the side slope, and a surface coating thickness of 30mm. the BC section of the drainage ditch is connected to the original surface ditch and can discharge surface water behind the wall.

References

[1] Tian Dongfang. the three gorges reservoir area yangjiaping middle landslide stability

analysis and control research [J]. Journal of subgrade engineering, 2011(3):4. DOI: 10.3969/j. i SSN. 1003-8825.2011.03.065.

[2] Jia Zhuping. Large open slope landslide stability analysis and treatment solutions [J]. Journal of metal mine, 2014, 43(5):27-31. DOI: 10.3969/j. i SSN. 1001-1250.2014.05.007.

[3] Hu Wei, Fang Ming. Stability analysis and treatment of landslide in section k117+ 380-450 of Shaohuai Expressway [J]. Highway engineering, 2007(5):129-132. the DOI: 10.3969/j. i SSN. 1674-0610.2007.05.028.

[4] Wang Yi, Xie Guangying, Liu Yahui. Stability analysis and treatment method of slope engineering landslide under complex geological conditions [J]. Urban Construction Theory Research (Electronic Edition), 2024(18):135-137.

[5] ZHANG Xiaomin, Wang Yobin. Stability analysis and treatment of road landslide in mountainous area [J]. Gansu Water Resources and Hydropower Technology, 2024, 60(2):57-60. (in Chinese)

[6] Yang Xiaohua, Wang Dongqing, Yuan Shuai, et al. Based on the homogenization theory and limit analysis of expansive soil landslide stability analysis [J]. Hydrogeology engineering geology, 2024, 51(2):172. DOI: 10.16030/j. carol carroll nki. Issn 1000-3665.202302050.

[7] Nie Bingqi, Jia Xiangxin, MAO Yuchao, et al. Stability analysis and evaluation of a landslide based on transfer coefficient method [J]. Journal of Geotechnical Foundations, 2024, 38(3):369-372.

