Deformation Analysis and Treatment of a Landslide

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Abstract: The article provides a detailed description of the characteristics of landslides, analyzes landslide stability, calculates stability safety factors under different working conditions, and finally proposes control measures.

Keywords: Landslide Deformation Characteristics; Stability analysis; Governance Measures

1. Project Overview

(1) Sanlong Township, located in the middle and upper reaches of the Minjiang River, is situated in the Minshan Mountains of the Qionglai Mountains. the Minshan Mountains generally extend in a northerly direction, with an elevation of 1250.00~1600.00m at the front edge. the terrain is higher in the northwest and lower in the east and middle. the landslide area belongs to the erosion and erosion of Zhongshan landform, with deep cutting, large height difference, and steep terrain slope. Generally, steep cliffs are formed at the exposed bedrock of 35-45 ° in some areas. the elevation of the rear edge of the landslide is between 3720 and 3740m, and the elevation of the front edge is between 3420 and 3470m, with a relative height difference of 270 to 300m; the slope surface is generally in a zigzag shape, with some areas being platforms (dry land). the overall terrain slope of the slope is 25-35 °, with the road at the rear edge of the residential area as the boundary. the terrain slope at the rear edge of the landslide is relatively steep, about 25-40 °; At the front edge of the landslide, the terrain in the residential area has a gentle slope of 10-20 °. Gullies are developed on both sides of the landslide, with a cutting depth of generally 3-6m.

(2) the lithology of the strata is exposed in some areas on the right side of the landslide, and is buried under the loose soil layer of residual slopes and accumulated fragments in the landslide area, with varying burial depths. It belongs to the Devonian Weiguan Group (Dwg), and its lithology is dark gray to black gray carbonaceous phyllite. the surface rock layers are strongly weathered and structurally strong, with a large thickness of strong weathering, generally ranging from 7.0 to 8.0 meters.

According to the different types of causes, it can be divided into two major types: residual slope soil and landslide accumulated soil. Due to differences in the formation environment, various types of soil have significant differences in their physical and mechanical properties. Now it is described as follows:

1) Residual slope layer

(1) Gravel containing silty clay (Q_4^{el+dl}): mainly distributed in the surface layer of the lower part of the landslide body, mainly composed of silty clay, containing 30-40% of fragmented stones, and the parent rock is mainly composed of phyllite. the content of fragmented stones is about 30-40%, and the particle size is generally 100-400mm, with a maximum of 80cm or more. It is filled with clay particles and has a loose structure. the thickness of this layer is about 12m, and the content of crushed stones increases correspondingly with depth.

(2) Gravel soil (Q_4^{el+dl}l): It is distributed throughout the landslide body, with a thickness greater than 30 meters. the depth of this layer was not revealed during this drilling, and it is mainly composed of gravel soil, with a small amount of block stones. the parent rock is mainly composed of phyllite, with a content of about 65-85% of block gravel and a particle size of 100-400mm, with a maximum of over 1.5 meters. It is filled with clay and powder particles, with a dense structure and a semi cemented state (see figure 1), and has good mechanical properties.

2)Landslide accumulation layer:

(1) Gravel containing silty clay (Q_4^{el+dl}): mainly distributed in the surface layer of the lower part of the landslide body, mainly composed of silty clay, containing 30-40% of

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fragmented stones, and the parent rock is mainly composed of phyllite. the content of fragmented stones is about 30-40%, and the particle size is generally 100-400mm, with a maximum of 80cm or more. It is filled with clay particles and has a loose structure. the thickness of this layer is about 16m, and the content of crushed stones increases correspondingly with depth.

Within the landslide area, the bedrock is buried at a relatively deep depth, and no bedrock was exposed during this drilling. Based on the exposed bedrock near the landslide, the main rock type in the working area is the Devonian Weiguan Group (D_{wg}), which is mainly composed of dark gray to black gray carbonaceous phyllite. the bedrock attitude is 238 °∠ 64 °, with developed joints and fissures, and a thick strongly weathered layer with significant thickness variations.

2. Basic Characteristics of Landslides

The landslide is located in the northwest of Sichuan Province and belongs to the eroded and eroded Zhongshan landform. According to the on-site survey, the elevation of the landslide's rear edge is between 3720 and 3740m, and the elevation of the front edge is between 3420 and 3470m, with a relative height difference of 270 to 300m. the landslide appears as an irregular strip on the plane, with gullies as the boundary on both sides, steep and gentle slopes at the rear edge, and steep slopes at the front edge of residential areas. the main sliding direction of the landslide is 169 °. the average width of the landslide is about 250m, the inclined length is about 800m, and the sliding area is about 200.0 × 103m2. the sliding body is composed of silty clay containing gravel, with an average thickness of about 12m. It is a mid-level landslide with a volume of about 240 × 104m3. According to the "Code for Investigation of Landslide Prevention and Control Engineering" (DZ/T0218-2006), the scale grade of this landslide belongs to a large-scale landslide, as shown in **Figure 1**.

3. Deformation Characteristics of Landslide Body

1) Landslide deformation characteristics

Through the engineering geological investigation of the landslide, the deformation of the landslide in the area has the following two characteristics.

(1) It has the characteristics of small deformation in the front part of the landslide and large deformation in the middle and rear parts. According to the investigation and visits, the main deformations of the landslide are: tensile cracks appeared at the trailing edge of the landslide before the earthquake, there was a local landslide in the middle and rear of the landslide, behind the residential gathering area, and a descending spring appeared at the landslide; the 5.12 earthquake reduced the stability of the landslide, which not only increased the deformation of the tension crack at the trailing edge, but also produced new tension cracks in the front part of the landslide. In the middle of the left side of the landslide, the houses were cracked due to the deformation of the slope surface due to the deformation of the surface of the house, which had a great impact on the life and safety of the residents.

(2) It has the characteristics of great harm: once the landslide is unstable, it will endanger the life and property safety of 144 villagers from 34 households in the Dazhai sub-group of Zhuowuzhai Village, the landslide body, causing an economic loss of about 2.88 million yuan.

Figure 1 Overall View of Landslide

2) Landslide deformation and failure mode

The landslide was an old site before the earthquake, which had been deformed before the earthquake, and after the 5.12 earthquake due to the influence of earthquake and rainfall, a new deformation appeared, and the characteristics of each crack are shown in **Table 1**.

Deformation before earthquake: the deformation before earthquake mainly includes tension cracks appearing at the rear edge of the landslide, with a width of about 30-40cm, a strike of 81 °, and an extension length of about 15m.

Before the earthquake, there was a local sliding on the left side of the landslide, behind the residential gathering point, on the inner

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side of the rural road. In 2006, there was a local sliding with a volume of about 3000m3, which did not cause any casualties. the trees here are crooked, and a descending spring is exposed. the spring has water flowing out all the year round, with a maximum flow of 0.2L/s. the spring water appears turbid after rainstorm.

Table 1. Fracture Features

features / Crack number	trend	Extended length(m)	Time of appearance	Causes of formation
L1	81°	15	Before the earthquake	The front edge of the platform is exposed to the air.
L2	80°	21	After the earthquake	It is caused by the loosening of rock and soil under the action of seismic forces and the influence of heavy rain.
L3	77	30	After the earthquake	It is caused by the loosening of rock and soil under the action of seismic forces and the influence of heavy rain.
L4	75°	15	After the earthquake	The front edge of the house is exposed to the air, and the impact of earthquake force causes the house to crack.

4. Characteristics of Landslide Material Structure

The landslide body is composed of crushed stone and silty clay: mainly distributed in the surface layer of the middle and lower parts of the landslide body, mostly composed of silty clay, containing 30-40% of fragmented stones. the parent rock is mainly composed of phyllite, with a content of about 30-40% of fragmented stones and a particle size of generally 100-400mm, up to 80cm or more. It is filled with clay particles and has a loose structure. the thickness of this layer is about 16m, and the content of crushed stones increases correspondingly with depth.

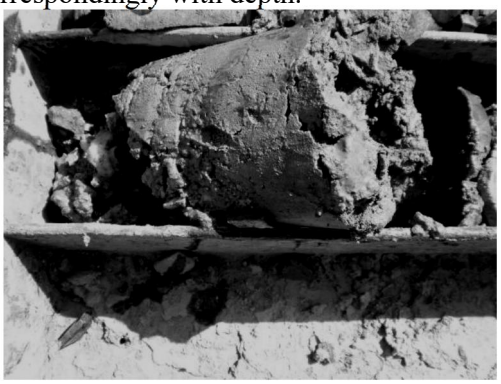

Figure 2. Soil Near The Slip Surface Slip Zone

According to the drilling data during the exploration phase, the sliding zone soil is revealed: some boreholes are located near the contact between gravel containing silty clay and gravel soil, mainly composed of silty clay, with less gravel content and smaller particle size than the upper gravel. the gravel has a certain arrangement pattern and is relatively soft in strength. the rock core is in the form of debris, damp, with a particle size of generally 2-15mm and a layer thickness of about 0.2-0.3m. This is mainly due to the sliding and sliding of the soil in this layer. Through analysis and judgment, this layer is the sliding surface of this landslide, as shown in **Figure 2**.

4.1 Analysis of Landslide Deformation Formation Mechanism

Through this survey, the formation mechanism of landslide deformation is analyzed as follows:

(1) Analysis of intrinsic factors of landslide deformation

Terrain factor: It is significantly controlled by the terrain, with a steep slope of 50-60 ° at the front edge of the shear outlet. the terrain slope is steep and the air conditions are good, providing favorable terrain conditions for the formation of landslides;

Material factors: the slope material and landslide material are loose structured silty clay containing gravel, with a large variation in thickness, averaging about 12.0m, and high self weight stress of the soil.

Structural factors: the landslide area is located in the eroded Zhongshan region, 1km north of the reverse syncline of the Shidaguan arc-shaped structure. the terrain is strongly cut, the rock mass is fragmented, the lithology and geological structure of the strata are complex, the folds are strong, and the faults are developed, accelerating the weathering of the rock mass and the formation of soft weak zones. the new tectonic activity in the landslide area is strong and obvious, and the active new tectonic movement provides the original kinetic energy for the landslide movement.

(2) Analysis of External Factors of Landslide Deformation

Precipitation impact: After atmospheric rainfall,

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the infiltration and erosion of surface water not only increase the soil weight, but also reduce the shear strength index of the soil. A large amount of surface water infiltrates along the structural planes. Due to the residual slope silty clay mixed with fragmented stone and soil, the structure of the landslide is loose. Under long-term gravity and weathering, with the development of deformation, the weak surface gradually expands to the deeper part, and a surface that connects with the outside world appears. the slope structure loosens with the development of deformation. When certain external forces suddenly intensify, causing the slope body to suddenly suffer damage without obvious signs of movement, forming a landslide.

Earthquake impact: Under the action of seismic force, the originally loose slope rock and soil mass slides towards the free direction.

In combination with the deformation characteristics of the landslide ground and the deformation characteristics of residential houses, it is judged from the macro perspective that the Dazhaizi landslide is currently in a basically stable stage as a whole and partially unstable. Under the continuous adverse load, earthquake, rainstorm and other adverse working conditions, with the development and intensification of deformation, its stability may be reduced, and sliding instability may occur.

4.2 Recent Development Stages of Landslides

The landslide was formed before the May 12th Wenchuan earthquake and was an old site before the earthquake. It was officially designated in 2007. Through on-site investigation and interviews, it was found that the landslide had tension cracks at the edges before and after the earthquake. In the middle and rear of the landslide, there was a partial collapse behind the residential area, but no casualties were caused. A descending spring appeared at the collapse site; the occurrence of the 5.12 Wenchuan earthquake caused an increase in the deformation of the tension cracks at the rear edge, and new tension cracks appeared in the front part of the landslide. Multiple cracks appeared in residential houses, and the water volume at the spring point increased. During the rainy season, the spring water became turbid. There are no signs of overall sliding, and it is currently in a generally stable state, with some areas being unstable.

5. Analysis, Calculation, and Evaluation of Landslide Stability

5.1 Macroscopic Assessment of Landslide Stability

Based on the above analysis of the formation mechanism and failure mode of landslide deformation, combined with the emergency survey data, it is determined that the landslide is basically stable in natural state, under stable~basically stable under the influence of adverse geological processes such as earthquake and rainstorm, and partially unstable. Due to the tension cracks appearing on the landslide body, it is conducive to the infiltration of surface water, which can further soften the original sliding surface. Under the continuous action of other unfavorable loads, the deformation will be further intensified, which may reduce the overall stability of the landslide.

5.2 Calculation and Evaluation of Landslide Stability

The stability calculation and analysis of sliding surfaces a and b of 1-1 ', 2-2' and 3-3 'profiles show that: for 1-1' profile, through comparative analysis, sliding surface a is stable under natural conditions, with a stability coefficient of 1.161, and is basically stable under rainstorm and earthquake conditions, with a stability coefficient of 1.056~1.059; the slip surface b is in a stable state under three operating conditions, with a stability coefficient of 1.19-1.317.

2-2 'profile, through comparative analysis, it can be seen that slip plane a is stable under natural conditions, with a stability coefficient of 1.167, and basically stable under rainstorm and earthquake conditions, with a stability coefficient of 1.06~1.064; the slip surface b is in a stable state under three operating conditions, with a stability coefficient of 1.27-1.412.

The 3-3 'profile is in a stable state under three operating conditions, with a stability coefficient of 1.461-1.653.

Therefore, the landslide is generally stable under natural, earthquake and rainstorm conditions, and there will be no overall instability or secondary shearing. However, most of the residential houses are built on the

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berm, with the front edge facing the sky, which will lead to the cracking of houses under the effect of continuous rainstorm and aftershocks in the future. Therefore, there is no need to carry out large-scale treatment of landslides. Instead, they should be turned into emergency response points and certain engineering measures should be taken at the steep slopes in front of residential houses.

6. Prevention and Control Measures

Based on the stability analysis of the landslide and the terrain conditions on site, the following preventive measures are taken:

(1) Fully fill and compact the cracks on the landslide body, reduce the infiltration of surface runoff or rain and snow, and improve the stability of the landslide body.

(2) On the left side of the landslide, because the residential houses were built on the berm with the front edge facing the sky, cracks appeared around the houses during the earthquake. According to the stability analysis, the stability of the slope is insufficient, which will lead to further cracking of the houses under the effect of continuous rainstorm, aftershocks, etc. in the future. Therefore, retaining walls are used to support residential houses with strong deformation in the middle of the left side of the landslide.

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