Analysis and Evaluation of the Slope Stability of K49 + 800 Section of S207 Road in Shizong County

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Abstract. With the development of urban construction, slope engineering has become more and more important and difficult projects, and the hidden dangers of slope can not be ignored, which requires judgment and protection of the stability and safety of slope, so as to promote the economic development and construction of the city under the premise of ensuring the safety of people and property. Based on the analysis and study of engineering geological conditions and factors affecting slope stability of K49 + 800 section of S207 road in Shizong County, this paper analyzes and evaluates its stability and puts forward corresponding treatment measures.

Keywords: Highway Slope · Stability Evaluation · Treatment Measures

1 Overview of the Study Area

1.1 Project Overview

The research area is located at the south end of Gaolang Township government residence in Shizong County, on the left side of milepost No. K49 + 800 section of S207 Highway, which generally runs north-south. The inner part of the highway is an artificial steep ridge caused by the construction of the highway, with a height of about 25 m and good vegetation development on the upper part of the steep ridge. The slope of the road to be studied is located on the outside of the road. The slope is a soil slope, distributed under the road in an inverted U-shape, with a total length of about 38 m and a width of about 35 m. It is a small slope. The overall slope of the mountain is 32–36°, the slope direction is 67°, the foot of the slope is the Fengwei River, the rear wall of the slope is about 4.5 m high steep ridge, the slope height difference is about 20 m. The highway is sTable and open to traffic. The slope slope is about 34°, located on the bank of the mountain river, and vegetation is relatively developed around the slope body and on the slope body. When the sliding body slides, vegetation will slip synchronously with the sliding body. Bedrock exposure can be seen on both upper slopes (See Fig. 1).

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Fig. 1. Slope body

1.2 Meteorology and Hydrology

Shizong County is located in the middle of Yunnan-Guizhou Plateau, affected by the elevation of the terrain and the atmospheric circulation, belongs to the north subtropical monsoon climate area, which is characterized by mild climate all year round, no cold and dry winter, warm and dry spring, cool and humid autumn, dry and wet seasons, small annual temperature difference, large daily temperature difference, concentrated rainfall, sufficient light, there are four seasons like spring, rain into winter. The average annual temperature is 14.7 °C, the average temperature in the coldest January is 7 °C the average temperature in the hottest July is 20.1 °C and the annual frost-free period is 246 days. The average annual relative humidity is 74%, and the average annual rainfall is 976.5 mm. The seasonal distribution of rainfall is extremely uneven.

2 Engineering Geological Condition

2.1 Topography and Landform

It is intended to study that the bedrock near the slope is well exposed, and the bedrock occurrence is 146°∠31°. The slope is generally high in the west and low in the east, descending from west to east. Above the slope is a rocky scarp of silty mudstone with a height difference of about 25 m, a slope of about 75° and a scarp dip of 67°. There are shrubs above the steep ridge, and the vegetation is well developed. At present, there are no protective measures for the steep ridge, and the rubble falls under the action of running water in the rainy season, posing a threat to vehicles and pedestrians. To the west of the site is a river, named Fengwei River, Hanoi perennial flow, flow with seasonal changes, the bank is covered by the fourth system alluvial alluvial layer. On the other side of the river is farmland and a large number of houses. Along the highway, there are civil houses on both sides of the highway, and the civil houses are discontinuous and dislocated (See Fig. 2, Fig. 3, Fig. 4 for details).

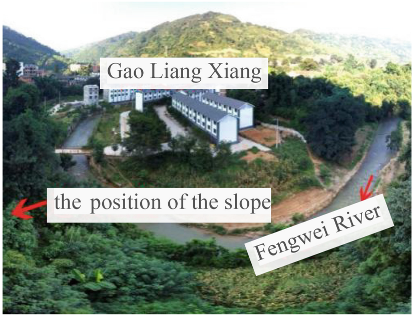

Fig. 2. Topography

Fig. 3. Inner rock slope of highway

Fig. 4. The status of both sides of the highway

2.2 Geological Structure

The study area is located in the Yangtze platform (I) and the eastern Yunnan platform wrinkle belt (I). The regional geological structure is dominated by folds, and the faults are not developed. The regional tectonic lines are distributed in the northeast direction, and are composed of four major structural systems: the northeast tectonic system, the North-South tectonic system, the northwest tectonic system and the joint peak arc tectonic system. In terms of a large area, the study area is located in the north of Luoping Shizong fold bundle in the southeast Yunnan fold belt of the South China fold system, and the structure is dominated by compression-shear faults extending to the north east, followed by near-east-west tensile faults and northeast-trending folds. The west of the study area is the Xiaojiang strong seismic fault, which runs through the middle of Yunnan Province from north to south along Huize, Dongchuan, Xundian and Tonghai. Xundian-xuanwei fault crosses Yiliang and Xiaojiang fault (east branch) through Xuanwei and Xundian fault; Qujing fault crosses Qujing, Luliang, Shilin and Maitrea-Shizong fault in Maitreya on the east side of the study area; the study area is located in Gaoliang Township, Shizong

County, far away from each fault zone, and no fault passes through the field, so it is a sTable block.

2.3 Formation Lithology

Through the investigation of the slope body [1], the borehole revealed that the formation is composed of quaternary mixed fill (Q_4^{ml}) and grey gravel silty clay (Q_4^{dl+el}) and the strong to medium weathering silty mudstone (T_2bc) of the first member of Banna Formation in the Middle Geold Formation of the Triassic. According to the characteristics of geotechnical layer in the field, in-situ testing and laboratory rock and soil test data, the geotechnical layer in the site is divided into four layers, which are as follows:

① Miscellaneous fill (Q_4^{ml}):

Variegated, light grey, mainly composed of crushed stone, containing a small amount of bricks and silt, smelly, surface containing a small amount of plant roots. Slightly wet, loosely structured. This layer is formed by the accumulation of fill for highway construction. The slope is a temporary dump, with a large amount of domestic garbage piled up in the upper part. In the center of the site there are north-south concrete and rubble retaining walls. The retaining wall slides down with the slope, and the structural integrity is not damaged. The layer is thicker in the center of the site. Due to the large changes in the layer, uneven distribution, containing concrete and other domestic construction waste. The thickness of the layer is 0.90–4.00 m, with an average thickness of 2.82 m.

② Pebbly silty clay (Q_4^{dl+el}):

Light gray, light grayish yellow, slightly wet, hard plastic, slightly dense structure, section is not smooth, rough fracture, high dry strength, medium toughness, local mudstone gravel. It is distributed in the site, the buried depth of the top layer is 0.9–4.0 m (816.50–831.77) meters, the thickness of the layer is 2.60–5.80 m, and the average thickness is 4.78 m.

③ Silty mudstone (Strong weatheringT_2bc):

Gray, light gray, silty, argillaceous clastic structure, strongly weathered like earth, containing about 25% gravel. It is distributed in the field, the layer thickness is 1.20–2.80 m, and the average thickness is 1.82 m.

④ Silty mudstone (moderate weatheringT_2bc):

Gray, dark gray, silty argillaceous structure, meso-like structure, is a soft rock, moderately weathered, joint fissure development, the gaps are mostly filled with mud, the core is broken, mostly fragmented, some short columnar, there are exposed silty mudstone on the upper and both sides of the slope in the site, the occurrence of exposed silty mudstone is $146°\angle 31°$. The saturated uniaxial compressive strength of the drilling rock is 17.65 MPa, the hardness grade of the rock is relatively soft rock, the quality of the rock mass is poor, the integrity degree of the rock mass is broken, the basic quality grade of the rock mass is IV, and the rock quality index RQD is about 50%. The survey did not expose this layer, and no karst cave was found within the range of drilling control depth. The maximum exposed thickness was 9.40 m, the exposed layer thickness was 6.20–9.40 m, the average thickness was 7.75 m, and the top buried depth of the exposed layer was 6.80–12.10 m.

3 Slope Stability Analysis and Evaluation

3.1 Analysis of Influencing Factors of Slope Stability

Soil condition and influence of rainfall. According to the investigation, no tension crack was found at the top of the slope, and the exploration drilling revealed the existence of weak surface between the soils, and the soil of the slope was in an unsTable state. With the coming of the rainy season, the surface water permeates, the shear strength of the soil decreases, and the stability of the slope becomes worse [2].

The impact of human engineering activities. The human engineering activities in the study area are mainly manifested as the building load on the top of the slope and cutting the slope to build the road.

With the construction of Gaoliang Township, limited by geographical conditions, houses had to be built on the top of steep slopes. The formerly fragile geological environment is worsening. At the same time, in order to meet the traffic needs, the provincial road is built on the top of the slope, which forms a lot of excavation and filling, and the rock mass of the slope is broken, which affects the stability of the slope even more (See Fig. 5).

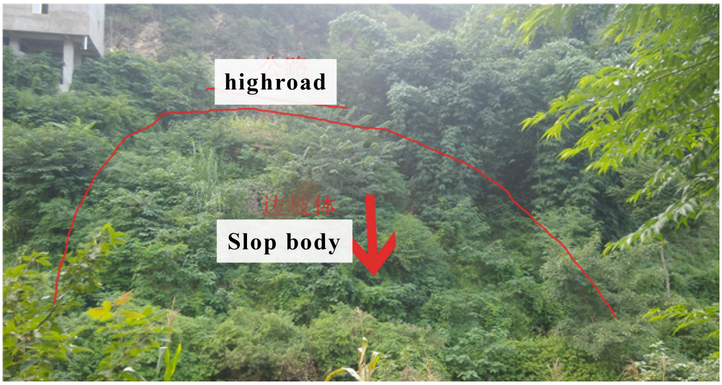

Fig. 5. Slope body

3.2 Evaluation of Slope Stability

Qualitative Evaluation. The slope area is a steep terrain with an average topographic slope of 34°. According to the survey data, the surface of the survey area is composed of quaternary mixed fill and residual slope deposits, and the rock and soil properties are mainly clay, gravel, broken strong to moderately weathered silty mudstone, with loose structure and poor physical and mechanical properties. In the rainy season, groundwater infiltration softenes the contact surface, which is easy to form a weak structural plane. Field investigation shows that the slope is in an unsTable state.

Quantitative Evaluation. The upper part of the slope is composed of quaternary mixed fill (Q_4^{ml}), grey gravel silty clay (Q_4^{dl+el}) and strong to medium weathering silty mudstone (T_2bc) of the first member of Banna Formation in the Middle Geold Formation of the Triassic. The sliding surface of the slope is in the quaternary loose soil. The sliding surface is regarded as a broken line, and the section parallel to the sliding direction is used to calculate the stability and thrust of the slope.

Calculation formula of slope stability. According to the analysis of the soft structural plane between rock and soil bodies of slope, the soft structural plane between rock and soil bodies is regarded as the sliding surface, and the sliding surface is approximately folded. According to the relevant requirements of the "Code for Exploration of Landslide Prevention and Control Engineering" [3], the transfer coefficient method is adopted, the sliding surface is regarded as the broken line, the unit width of landslide is taken as 1m, and the stability and thrust of landslide are simplified into a two-dimensional problem.

(1) Landslide stability calculation formula:

$$F_s = \frac{\sum_{i=1}^{n-1} (R_i \prod_{j=1}^{n-1} \psi_j) + R_n}{\sum_{i=1}^{n-1} (T_i \prod_{j=1}^{n-1} \psi_j) + T_n} \tag{1}$$

$$\psi j = \cos(\theta i - \theta i + 1) - \sin(\theta i - \theta i + 1)\tan\varphi i + 1 \tag{2}$$

$$\prod \psi j = \psi i \cdot \psi i + 1 \cdot \psi i + 2 \ldots\ldots . \psi n - 1 \tag{3}$$

$$\mathrm{Tj} = \mathrm{Wi}\ \sin\theta\mathrm{i}\ + \mathrm{PWi}\ \cos(\mathrm{ai} - \theta\mathrm{i}) \tag{4}$$

$$R_i = N_i \tan\varphi_i + c_i l_i \tag{5}$$

$$N_i = W_i \cos\theta_i + P_{Wi} \sin(\alpha_i - \theta_i) \tag{6}$$

$$W_i = V_{iu}\gamma + V_{id}\gamma' + F_i \tag{7}$$

$$P_{wi} = \gamma_w i V_{id} \tag{8}$$

$$i = \sin|\alpha_i| \tag{9}$$

$$\gamma' = \gamma_{sat} - \gamma_W \tag{10}$$

Calculation formula of hydrodynamic pressure:

$$P_{Wi} = \gamma_{Wi} V_{id} \qquad i = \sin|\alpha_i| \tag{11}$$

Of the form:

F_S—Coefficient of landslide stability;
Ψj—i calculates the transfer coefficient when the remaining sliding force of the bar is transferred to the i + 1 bar (j = i);
Ri—The anti-sliding force of the sliding body of the strip is calculated on the i(kN/m);
Ti—When the sliding component force (kN/m) on the sliding surface of the strip is applied to the i, and the sliding component force is opposite to the sliding direction, Ti should be negative;
Ni—i calculates the reaction force of the strip sliding body on the normal of the sliding surface (kN/m);
Ci—The standard value of the bond strength of the rock and soil mass on the sliding surface of the strip is calculated (kPa);
φi—i calculate the standard value of the internal friction Angle of strip sliding soil (°);
li—i Calculating strip sliding surface length (m);
αi—i calculate the average dip Angle of the strip groundwater flow line. In general, the average value (°) of the dip Angle of the infiltration line and the dip Angle of the slip surface is taken, and the negative value is taken when the dip is reversed;
Wi—i calculate the sum of strip weight and building and other ground loads (kN/m);
θi—i calculate the dip Angle (°) of the bottom surface of the strip, and take a negative value when reversing;
P_{Wi}—The i section calculates the osmotic pressure per unit width of the strip, and the inclination Angle of the action direction is αi (kN/m);
I—Seepage gradient of groundwater;
γ_W—The bulk density of water (kN/m^3);
Viu—Section i calculates the volume above the infiltration line of the rock mass per unit width of the strip (m^3/m);
Vid—Section i calculates the volume below the infiltration line of the rock mass per unit width of the strip (m^3/m);
γ—Natural bulk density of rock and soil (kN/m^3);
γ'—Floating bulk density of rock and soil mass (kN/m^3);
γ_{sat}—Saturated bulk density of rock and soil mass (kN/m^3);
Fi—Section i calculates the ground load on the strip (kN).

(2) Calculation formula of residual slide thrust of landslide

$$P_i = P_{i-1} \cdot \psi + F_{st} \cdot T_i - R_i \tag{12}$$

Of the form:

Pi, Pi-1—They are the residual sliding force of the sliding body of the i block and the I-1 block respectively (kN/m);
Fst—The safety factor of landslide thrust is calculated according to the harm degree of landslide;
Ti—Sliding component acting on the sliding surface of segment i (kN/m);
Ri—The skid resistance acting on the i of all segment (kN/m).

Notes:

(1) The groundwater is not revealed during the investigation of the slope area, and the groundwater pressure is not taken into account in the calculation;

(2) The seismic fortification intensity of the study area is 7°, the design earthquake is divided into the third group, and the basic design earthquake acceleration is 0.10 g. The comprehensive seismic influence coefficient is 0.20.

2. Calculate the load combination

There is no building load on the slope surface. The value of the trailing edge of the landslide is 0 kN/m.

Condition I: Sliding body soil natural weight load + Groundwater;
Condition II: Sliding body soil natural weight load + Groundwater + Heavy rain;
Condition III: Sliding body soil natural weight load + Groundwater + Earthquake [4];

3. Calculate the value of the parameter

The values of soil mass weight and shear strength (cohesion C, internal friction angle φ) of slope: according to the results of indoor geotechnical tests and combined with field observations, the average value and experience value of indoor soil test results are used for heavy soil mass, and the direct shear value and experience value are used for shear strength of soil mass. See Table 1 and Table 2 below.

Table 1. Table of weights

Soil layer number	Name of soil layer	Heavy (γ)
		KN/m^3
①	Fill	18.0*
②	Gravelly silty clay	18.9
③	Strongly weathered silty mudstone	21.3*
④	Medium weathered silty mudstone	26.7

Note: The above values are the average of the geotechnical test, with * for the empirical value

Table 2. Shear strength of slope soil

Soil layer number	Name of soil layer	Straight cut (q)	
		Cohesion (C)	Angle of internal friction (φ)
②	Gravelly silty clay	30.25	9.25
③	Strongly weathered silty mudstone	11.3*	20.8*
④	Medium weathered silty mudstone	18.9*	26.6*

Note: The above values are all the minor values in the geotechnical test, and the values with * are the empirical values

Safety factor of control engineering design: the grade of S207 slope regulation project in Gaoliang Township of Shizong County is II. According to the Technical Specifications for Design and Construction of Landslide Control Engineering (DZ/T0219-2006) [5], the following data is the anti-sliding safety factor of the slope under various working conditions:

ConditionsII: Ks = 1.02~1.15 Value 1.10;
ConditionsIII: Ks = 1.02~1.15 Value 1.05.

The infiltration depth of rainstorm is 3 m [6].

Evaluation of slope stability. According to the "Code for Exploration of Landslide Prevention and Control Engineering" (DZ/T0218-2006), the sTable state of slope should be determined according to the stability coefficient of slope according to Table 3. After calculation, the stability evaluation of S207 highway slope in Gaoliang Township is shown in Table 4.

Table 3. Slope stability Table

Stability FactorK_f	$K_f<1.00$	$1.00 \le K_f<1.05$	$1.05 \le K_f<1.15$	$K_f \ge 1.15$
Stability	UnsTable	Less sTable	Basically sTable	STable

Table 4. Table of evaluation results of slope stability

Section	Conditions					
	ConditionsI		ConditionsII		ConditionsIII	
	Stability Factor	Stability	Stability Factor	Stability	Stability Factor	Stability
1–1' Section	0.751	UnsTable	0.349	UnsTable	0.546	UnsTable
2–2' Section	0.636	UnsTable	0.320	UnsTable	0.583	UnsTable
3–3' Section	0.435	UnsTable	0.154	UnsTable	0.433	UnsTable

The calculation results show that the slope stability coefficient k = 0.435–0.751 under condition I, that is, the slope is unsTable under natural condition, and K = 0.154–0.349 under condition II, the stability coefficient k = 0.433–0.583 is less than the stability coefficient 1.00, and the slope is in the unsTable state.

4 Slope Hazard and Treatment

4.1 Slope Hazards

The slope has a large height and is a soil slope with weak structural planes between soils, low shear strength of soils, easy to form weak structural planes, and poor stability of the slope body. In external forces or heavy rainfall seasons, the slope body may lose stability and continue to slide, causing the slide body to slide into the river, which may cause a small range of river blockage.

4.2 Governance Suggestions

According to the geotechnical geological characteristics, distribution and regional experience in the site, the slope is high and the slope is large. After field investigation, the houses outside the nearby highway were built with pile foundation leveling, and there was no obvious strain deformation of the surrounding houses. The rock of the back wall of the slope is exposed, the geological condition of the site foundation is good, and the slope body has the risk of instability. In line with the economical and effective management measures, combined with the local building construction experience, it is recommended to adopt the following schemes for support [7]:

Gravity retaining wall. Gravity retaining wall is used for continuous support, and corresponding supporting facilities such as drainage are built on the upper part. The retaining wall has the advantages of simple structure, materials and convenient construction, large section size and heavy wall body, and the lateral earth pressure on the back of the wall is mainly balanced by the gravity of the wall body, so it occupies a lot of land, can not give full play to the strength performance of building materials, and is not easy to implement construction mechanization.

Cantilever retaining wall. The cantilever retaining wall is used for supporting, the wall section is small, and the stability of the wall is not or not completely maintained by its own gravity, so the structure is lighter, occupies less land, and increases the anti-overturning stability. Conducive to mechanized construction. However, the retaining wall is only suiTable for retaining walls less than 6 m high.

Buttress retaining wall. The use of arm-type retaining wall for supporting, the wall body section is small, the stability of the wall is not or not completely dependent on its own gravity to maintain, so the structure is lighter, occupies less land, and increases the anti-overturning stability, is conducive to mechanized construction. The retaining wall is suiTable for a wall height not higher than 15 m.

5 Conclusions and Recommendations

5.1 Conclusion

1. The seismic fortification intensity of Shizong County is the third group of 7°, and the designed basic seismic acceleration value is 0.10 g. The type of site soil is medium site soil, and the type of site is Class II building site, which is an unfavorable seismic area.
2. There is Fengwei River under the slope with low terrain, which has a great influence on the stability of the slope.
3. Unsaturated sand and silt within the proposed study site are not considered in the liquefaction of seismic sand (silt).
4. The slope body is affected by its own geotechnical geological characteristics, rainfall and human engineering activities, and there is a risk of sliding.

5.2 Suggestions

1. Remove the floating soil on the side slope to reduce the upper load of landslide;
2. The base of the slope is supported by gravity rubble or cantilever or armrest reinforced concrete retaining wall. The retaining layer of the retaining wall foundation can be the third layer of strongly weathered silty mudstone and the fourth layer of moderately weathered silty mudstone.
3. Make drainage measures such as truncation and drainage ditch for extension of the hilltop highway, and do a good job of drainage system to avoid rainwater scouring the slope and water softening the foundation; The foundation pit should be closed in time after excavation.
4. Landslide damage will have an impact on highway construction and social development, should be carried out in a timely manner before the landslide slide, it is suggested to improve the preliminary work in a timely manner, and pay close attention to the implementation of prevention and control projects.
5. Corresponding engineering measures should be taken according to the deformation mechanism of landslide and the special engineering geological conditions.
6. Before the landslide prevention and control project is completed, the monitoring, early warning and forecasting measures and publicity work of all landslides should be strengthened, and the disaster prevention awareness of site construction personnel and surrounding residents should be strengthened, especially during the rainy season, the relevant departments should do a good job of landslide emergency measures.
7. The proposed projects or engineering activities around the landslide should be supervised to prevent them from aggravating the deformation of the slope.

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