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Dynamic Assessment of Geological Hazard Risk of Double-Track High-Risk Slope of Chongqing-Hunan Expressway

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Abstract

This study focuses on the dynamic assessment of geological hazard risk of the Hetaoping landslide on the left side of Beacon K51+960--K52+060 of Bapeng Road 3 in the Banan-Pengshui section. Through a variety of means such as Utilizing various methods, including field geological mapping, in-situ testing, and indoor geotechnical tests, we conducted a comprehensive investigation of the slope's topography, stratum lithology, geological structure, and hydrogeological conditions. Based on the monitoring data, we dynamically analyzed the slope's stability under different working conditions using both the limit equilibrium method and numerical simulation techniques. We evaluated the likelihood and impact range of geological disasters, such as landslides and collapses. The results indicate that the slope is generally stable under natural conditions; however, under extreme circumstances, such as heavy rainfall and earthquakes, the local stability coefficient of the slope decreases, posing a risk of instability that could lead to small-scale landslides and collapses. This dynamic assessment provides a crucial foundation for the scientific prevention and engineering decision-making regarding the slope, aiding in the reduction of geological disaster risks and ensuring the safety of surrounding residents and the smooth progression of construction projects.

Keywords

Hetaoping landslide, dynamic analysis, dynamic assessment, data monitoring.

1. INTRODUCTION

As a prevalent and significant geological disaster, landslides frequently occur worldwide, posing a major threat to human life, property, infrastructure, and the ecological environment. This paper comprehensively examines the formation mechanisms of landslides, revealing that they result from the complex interplay of various factors, including topography, rock and soil properties, geological structure, precipitation, earthquakes, and human engineering activities. In terms of research methods, this study encompasses geological surveys, remote sensing monitoring, geographic information system (GIS) technology, and numerical simulations, among others. These approaches facilitate the research and prediction of landslides from various perspectives. This paper provides a detailed discussion of landslide prediction methods, including empirical statistical models, physical and mechanical models, and artificial intelligence models. Additionally, in response to landslide disasters, a comprehensive prevention and control strategy is proposed, centered on avoidance, engineering management, and monitoring and early warning systems. Engineering treatment methods, such as anti-slide piles, retaining walls, and drainage systems, are also examined for their effectiveness in reducing landslide risk in practical applications. Through an in-depth exploration of landslides

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from multiple angles, this paper aims to offer a theoretical foundation and practical guidance for the scientific prevention and control of landslide disasters, enhance society's capacity to respond to such events, and minimize disaster-related losses.

Chongqing Xiang Expressway double line Banan to Pengshui section of Bapeng Road 3 mark K51 + 960 - K52 + 060 left side of the Hetaoping landslide, located in Shizhuang Village, Shixi Town, Nanchuan District, Chongqing City, small place name Waltaoping, coordinates: 107°4'29.48", 29°19'15.34", Shizhuang Village to the slope area has a rural road through, convenient traffic conditions.

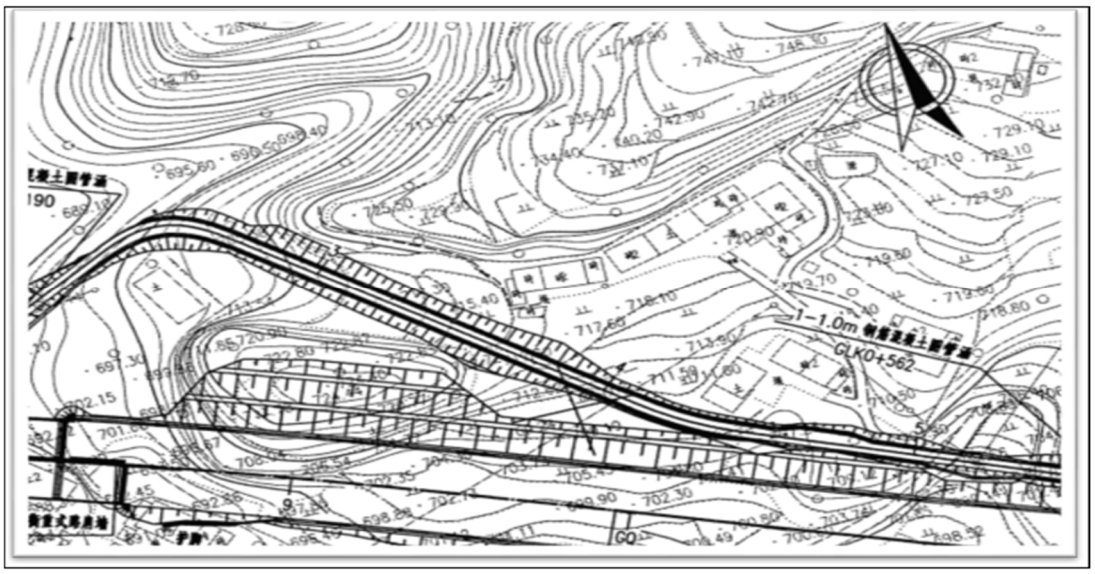

Figure 1. Location map of the work site

2. PROJECT OVERVIEW

2.1. Engineering background

The original design height of the slope is 5~13m, a total of 2 levels of slope, the original design is to grade according to 1:1, the preliminary slope prevention and control plan proposed the installation of a cutting retaining wall along the rock and soil boundary at the original slope. Additionally, the slope surface is to be protected by applying a double net and spraying an organic substrate for grass planting. In May 2021, the construction unit commenced work on this section and excavated to the second-level slope stage. During this process, the slope experienced significant deformation, with localized collapses and damage. Additionally, multiple tensile cracks developed along the trailing edge of the slope, measuring approximately 19 to 50 meters in length, with a splay of 5-20 cm and a visible depth of about 5-30 cm. On October 14, 2021, continuous rainfall caused subsidence at the surface of the trailing edge of the excavated slope. Following a survey and consultation, the four households located in the area of significant deformation were evacuated and temporarily resettled. Subsequent assessments by survey, design, and construction teams confirmed that this location posed a hidden risk for a landslide geological disaster. The front edge of the landslide is defined by the slope of the highway excavation section, while the rear edge is bounded by the residential area, creating a landslide zone approximately 70 m in length, 120 m in width, and covering an area of about 8,400 m2. Eight houses were affected. Based on the deformation state of the slope at that time, it was determined that the slope was in an unstable to nearly stable condition. Given the excavation of the slope according to the original design and the impact of rainfall, the slope

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material could potentially experience localized slip failure or a complete slip failure along the weak surfaces or foundation interfaces of the soil.

In November 2021, China Railway Yangtze River Transportation Design Group Co., Ltd. completed the "Yuxiang Expressway double-line Banan to Pengshui section K51 + 960 - K52 + 060 left side of the Waltaoping landslide disposal change design document", the report for the scale and stability of the Waltaoping landslide to develop a prevention and control plan, the plan is: set up D = 2m circular anti-slide pile support on the back side of the primary slope, pile center spacing 5m layout, pile body using C30 reinforced concrete, pile after the pile set up a water interception ditch, Through the slope rapids groove into the roadbed ditch, the soil between the pile and the slope retaining wall is appropriately leveled and brushed after the gentle slope planting and greening protection.

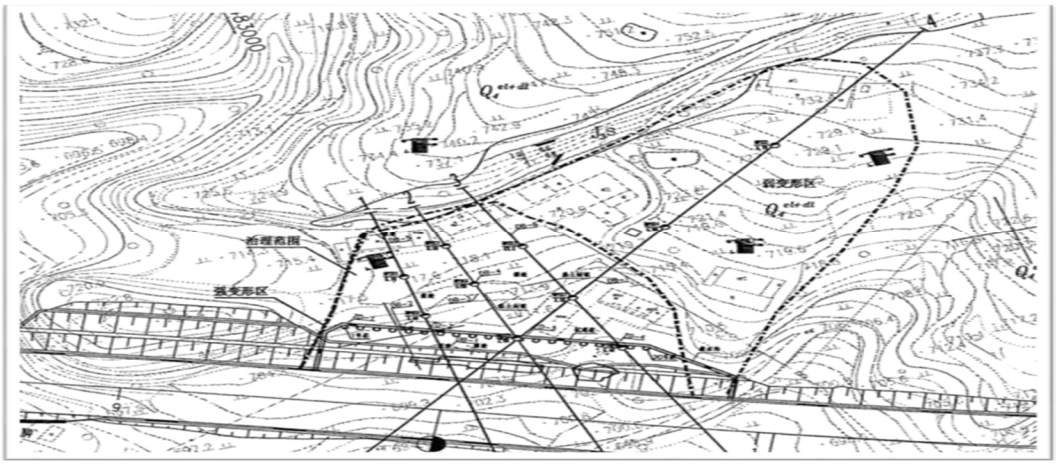

Figure 2. Distribution map of landslide control project

2.2. Construction status

During the pre-flood dynamic assessment and investigation of the high-risk slope, the construction of anti-slide piles was completed, with a total of two circular anti-slide piles (D=2m) installed. Following the post-flood survey, the slope and drainage works associated with the landslide control project for the anti-slide pile construction were largely finished; however, grass planting and greening protection had not yet been implemented. An on-site investigation revealed that after the landslide treatment, the original cracks in the slope had not worsened, and there were no indications of new deformation.

Figure 3. Photographs of slope construction during the pre-flood survey

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Figure 4. Photographs of slope construction during the post-flood survey

2.3. Slope geological environment

2.3.1 Topography

The road section traverses a sloped landform characteristic of the middle and low mountain regions shaped by tectonic denudation. The route follows the slope's strike at approximately 294°. The longitudinal topography along this path remains relatively consistent, with a slope ranging from 3° to 5°. In contrast, the transverse terrain exhibits a steeper gradient, generally between 7° and 28°, with some areas featuring steep slopes predominantly consisting of cultivated land. The ground elevation varies from 691.3 to 741.3 m, resulting in a maximum relative elevation difference of about 40 m.

2.3.2 Stratigraphic lithology

According to the site investigation report, the distribution of strata in the road section area primarily consists of a Quaternary Holocene residual slope silty clay layer, as well as sandstone and mudstone from the Suining Formation of the Upper Jurassic period.

2.3.3 Geological structure and earthquakes

The cutting section is located in the east flank of the north slope of the Shixi Fort subfield, the rock layer is monoclinic output, the rock formation is 270°∠10°, and two groups of fractures are mainly developed: (1) 169°∠66°, the crack surface is straight, the width is 1-2.1 mm, the spacing is 0.5-1.6 m, the extension is 2-2.7 m, the degree of bonding is very poor, and it is a weak structural plane; (2) 310°∠68°, the crack surface is straight, the width is 1-2.2 mm, the spacing is 0.8-1.4 m, and the extension is 1.5-2.2m, the degree of bonding is very poor, and it is a weak structural plane.

The rock formation on the eastern side of the line (Pengshuiduan) is 345°∠20°. Two groups of fractures have developed within the rock mass: (1) 134°∠79°, the crack surfaces are straight, the width is 1~3mm, the spacing is 1~5m, and the extension is 3~5m; (2) 229°∠81°, the crack surface is straight, the width is 1-3 mm, the spacing is 3-5 m, and the extension is 1-5 m, which is a hard structural plane with poor bonding.

According to the "Zoning Map of Ground Motion Parameters in China" (GB18306-2015), the peak ground motion acceleration in the area is 0.05g, the characteristic period of the ground motion response spectrum is 0.35 s, and the corresponding basic seismic intensity is classified as VI. The site is located in the middle of a steep slope, which is covered with loose slope deposits, making it an overall unfavorable seismic zone.

2.3.4 Hydrogeological conditions

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According to the stratigraphic composition and groundwater occurrence conditions in the area, the groundwater types in the excavation site can be classified into Quaternary loose soil pore water and bedrock karst fracture water.

(1) Quaternary loose soil pore water

The pore water within the Quaternary loose soil layer is primarily located in the Quaternary overburden of the slope. The thickness of the surface soil layer in the engineering area ranges from 2.2 to 8.5 m and is predominantly found in the middle and lower sections of the slope. This layer is mainly recharged by atmospheric precipitation. The Quaternary soil is primarily composed of silty clay, which exhibits poor permeability and water retention properties, classifying it as an aquifer.

(2) Bedrock fissure water

The bedrock fissure water primarily exists in shallow weathered fractures. The groundwater in the rock layer is influenced by fold tectonic stress, leading to the development of tectonic fissures and joints in the sandstone. This process generates interlayer fissure water. However, the presence of longitudinal gullies and transverse valleys facilitates the drainage of groundwater, resulting in a limited amount of bedrock fissure water and an average water distribution.

2.3.5 Undesirable geological phenomena

The Hetaoping landslide in the survey area is situated within a tectonic denudation low-mountain landform region, with its orientation extending in a north-south direction. Due to the impact of rainfall, the slope's surface has experienced subsidence and cracking. The topographic fissures in the cultivated land are pronounced, and the damage to residents' homes is significant, jeopardizing the safety of residential areas. Currently, measures have been implemented to prevent and control the landslide, in accordance with the "Design Document for the Disposal and Change of the Left Waltaoping Landslide of the Banan to Pengshui Section of the Double Line of Chongqing-Hunan Expressway", completed by China Railway Yangtze River Transportation Design Group Co., Ltd. Following these preventive measures, the slope has stabilized, with no new or exacerbated deformations observed.

2.3.6 The relationship between the permeable structural plane and the slope

The penetrating structural planes in the field area primarily consist of geotechnical interfaces. Following the excavation of the slope, there is a significant risk that the overlying soil layer will slide along the rock-soil interface, potentially inducing landslides. In May 2021, this phenomenon resulted in local deformation, posing a safety threat to the properties of eight households and causing damage to a portion of the farmland. To address this issue, the design scheme was modified, and anti-slide piles were implemented as the primary treatment for the Hetaoping landslide. The current treatment project is nearly complete, and no new or aggravated deformation has been observed since the intervention. Consequently, the likelihood of instability due to continued deformation from the landslide is minimal.

2.3.7 Human engineering activities

The investigation of human engineering activities primarily revealed that road excavation altered the original slope topography, created a high-cut slope, and triggered landslide geological disasters. These activities significantly affected the geological stability of the site.

2.4. Slope geological environment problems

The left Waltaoping landslide on the left side of the 3rd mark of Bapeng Road K51+960--K52+060 is the geological hazard dynamic assessment survey point provided by Party A, after two investigations before and after the flood, and combined with the design and construction

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data, K51+960--K52+060 The main geological environment problems of the left Waltaoping landslide are as follows:

1. Slope problem. This site belongs to the excavation slope section, the original design height of the slope is 5~13m, the original design is 1:1 grading, a total of 2 slopes, and the slope prevention and control scheme is that the slope is protected by hanging double net spraying organic substrate grass planting, and the cutting retaining wall is set up at the original slope along the geotechnical boundary position. During slope excavation, the slope is deformed.

2. Geological hazards. During the excavation process and after the excavation, the slope behind the slope is deformed as a whole. After the pre-flood investigation, the anti-slip ability of the slope section of the slope is reduced after the excavation of the front edge of the slope, which induces the slope to slide along the rock-soil interface, resulting in the deformation of the slope and the geological disaster of the landslide.

3. HAZARD ASSESSMENT

3.1. Risk assessment of geological hazards on pre-flood slopes

On October 14, 2021, the excavation of the left slope of the 3rd mark of Bapeng Road K51+960--K52+060 induced the deformation of the slope, and the continuous intensification of the deformation led to the avoidance and transitional temporary resettlement of 4 residents in the serious deformation area of the slope, and in November 2021, China Railway Yangtze River Transportation Design Group Co., Ltd. completed the "Design Document for the Disposal and Change of the Left Walziping Landslide of the Banan to Pengshui Section of the Double Line of Chongqing-Hunan Expressway K51+960--K52+060". In the report, the scale and stability of the Walnut Ping landslide were formulated, that is, the D = 2m circular anti-slide pile support was set on the outside of the route slope, the pile center spacing was 5m arranged, the pile body was made of C30 reinforced concrete, and a water interception ditch was set up behind the pile, which was merged into the roadbed ditch through the slope rapids groove, and the soil between the pile and the slope retaining wall was appropriately leveled and brushed after the gentle slope was planted and protected by grass planting. During the pre-flood dynamic assessment and investigation of high-risk slopes, the slope area has been constructed in accordance with the landslide treatment plan of the "K51+960-K52+060 left Waltaoping landslide disposal change design document of the double-line Banan to Pengshui section of the Yuxiang Expressway", and 20 D=2m circular anti-slide piles (20 design schemes) have been completed, the main anti-slide project has been basically completed, the slope and grass planting and greening protection projects have not been moved, and the slope deformation has been effectively alleviated under the support of the anti-slide pile. The possibility of instability caused by the continuous intensification of landslide deformation is medium, and the personnel in the danger area have been temporarily resettled, with little loss and little danger.

3.2. Risk assessment of geological disasters on post-flood slopes

3.2.1 Assessment of the current situation

During the post-flood dynamic assessment and investigation of the high-risk slope, the current landslide area has been addressed in accordance with the new prevention and control plan. Most of the treatment projects have been completed, including the installation of anti-slide piles and slope stabilization measures. The only remaining tasks are the grass planting and greening protection projects. Following the post-flood investigation, it was observed that the original deformation cracks in the slope did not worsen, and there were no indications of new deformation. The effectiveness of the treatment measures is evident. Given the current interventions, the likelihood of landslide instability is minimal, and the potential for loss is low.

3.2.2 Predictive Evaluation

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According to the new treatment scheme, the landslide and the slope will be provided with a trench retaining wall support at the original slope along the geotechnical boundary position, a circular anti-slide pile support of D=2m will be set on the outside of the route slope, a water interception ditch will be set behind the pile, and a three-dimensional net grass planting protection will be adopted between the anti-slide pile and the slope line of the roadbed slope. After the completion of the construction of the treatment project, the landslide will be comprehensively prevented and controlled, and the possibility of geological disasters in the landslide is small and the danger is small.

3.3. Comprehensive assessment of slope geological hazard risk

According to the new treatment scheme, a trench retaining wall will be constructed to support the landslide and slope along the original geotechnical boundary. Additionally, a circular anti-slide pile with a diameter of 2 meters will be installed on the outer side of the slope. A water interception ditch will be placed behind the pile, and a three-dimensional grass planting protection net will be implemented between the anti-slide pile and the slope line of the roadbed. Upon completion of the treatment project, comprehensive measures will be in place to prevent and control the landslide, significantly reducing the likelihood of geological disasters and associated risks. As shown in Table 1.

Table 1. Slope pre flood and post flood assessment

slope	Comprehensive assessment	
	Pre-flood	Post-flood
Bag Peng Road 3 mark K51 + 960 - K52 + 060 left side of the Walnut Ping landslide	The slope cutting retaining wall and the anti-slide pile project of the main body of landslide control are basically completed, and the possibility of geological disasters is medium, the loss is small, and the danger is small	Assessment of the current situation: the slope cutting retaining wall, the anti-slide pile and the slope grading project of the main body of landslide treatment are basically completed, and the possibility of the current situation is small and the danger is small. Prediction and evaluation: After the construction of the prevention and control project, the possibility of landslide instability on the slope is small and the danger is small.
	Comprehensive assessment: the possibility of geological disasters on the slope is small, and the danger is small	

4. CONCLUSION

4.1. Suggestions on geological disaster prevention and control measures

Combined with the engineering design scheme and the results of pre-flood and post-flood surveys, the following prevention and control measures are recommended to mitigate the risk of geological disasters, considering the current condition of the slope and the potential geological hazards.

1. Strengthen the stability monitoring of the bevel edge during construction.

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2. During the construction period, ensure effective dredging and drainage of both surface water and groundwater to minimize their impact on slope stability. Additionally, enhance functional monitoring and conduct timely dredging of the drainage system.

3. Strengthen the management of progress for prevention and control projects, and enhance the grass planting and greening protection initiatives aimed at mitigating landslide geological disasters in a timely manner.

4. Ensure effective organization and arrangement in the construction process to minimize disturbances and prevent damage to the landslide prevention and control project during the construction period.

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REFERENCES

[1] K.Z. Qian, T.Z. Su, H. Qu, et al. Disaster prevention and control of high-risk slopes in typical limestone areas in western Beijing, The 12th National Slope Engineering Technology Conference (Guiyang, China) (2020).

[2] Z.H. uang, D. Shi, X. Chen, etc. Safety risk assessment method and its application for cutting slope of expressway. Guangdong Highway Traffic, 2024, 50(4): 48-54. DOI: 10.19776/j.gdgljt.2024-04-0048-07.

[3] T. Zhou. Western Exploration Engineering. Vol. 35 (2023) No. 09, pp.12-14.

[4] Y.L. Xu. Risk assessment and prevention measures of engineering geological disasters of a highway in Gansu Province, Western Resources. (2021) No. 04, pp. 59-61.

[5] Z.Y. Lin. Geological hazard risk assessment of Jianhe-Rongjiang Expressway in Guizhou, Western Resources (2017) No. 06, pp. 100-101.

[6] Y. Qiu, C.P. Zhu, X.M. Yi. Application of geological hazard risk assessment in highway engineering, Journal of Wuhan Institute of Technology. Vol.36 (2014) No. 08, pp. 38-45.

[7] F.L. Shao, S.Q. Li Research on the risk assessment of geological disasters and its prevention and control countermeasures of expressway: A case study of the Nanyang-Xiping section of Shangwu Expressway, Henan Science and Technology. (2014) No. 14, pp. 154-155.

[8] W. Huang. Research on risk assessment method of engineering geological hazard of highway slope. Chongqing Jiaotong University. (2012).

[9] E. Bear, S. Yuan. How to do a good job in highway engineering geological disaster risk assessment Shanxi Construction, 2009,35(04), pp.113-115.

[10] X. Qi, A. Wang. Risk assessment of geological hazards in expressways. Highway, 2000, (09): 61-63