Construction Risk Evaluation and Prevention Countermeasures for a Deep Excavation Slope in Chongqing Wuling Mountain Area

Hao Yu *, Yuanyuan Deng, Yan Ma, Zhiyan Tang

Chongqing Yuxiang Double Line Expressway Co., Ltd, Chongqing 400067, China

* Corresponding Author: Hao Yu (Email: 769258269@qq.com)

Abstract. Chongqing Wuling Mountain area has steep mountains and dense forests, and complex geological conditions, which bring more difficulties to the construction of highways along the route, especially the excavation of deep excavation slopes, which faces many risks and challenges. This paper evaluates the construction safety risk of deep excavated rocky slope on the right side of a highway K4+530-K4+916 in Chongqing as an example. On the basis of fully investigating the construction risk impact indexes, the risk evaluation indexes are ranked in order of importance, the index system method is used to determine the weight of each index, and the quantitative value of each index is taken according to the investigation and design data and the on-site field survey. Using the risk evaluation theory, the risk level of the slope is rank Ⅱ (medium risk), combined with the evaluation results, the proposed risk prevention and control of prevention and control countermeasures, which can provide a certain reference for the evaluation of the risk level and the development of prevention and control countermeasures for similar projects.

Keywords: Chongqing Wuling Mountain Area; Deep Excavation Slope; Risk Evaluation; Prevention and Control Measures.

1. Introduction

Wuling mountainous area refers to a series of rolling peaks in western Hunan, western Hubei, eastern Chongqing and eastern Qiandong, the site is a deep excavation slope of a highway in Chongqing, the geological conditions along the project are complex, the terrain is steep, the river valley is deeply cut, the rainfall is rich and concentrated, and the geological disasters along the line are frequent, which brings serious threats to the safety construction of the highway along the line. During the construction of high and steep slopes, due to the unloading effect of excavation, the rock and soil mass is disturbed to a certain extent, and the slope is prone to collapse, which brings great difficulty to the construction excavation, and is affected by the construction conditions, construction technology, management and other factors, the construction safety of the high and steep slope in Wuling Mountain is full of uncertainty. The accurate assessment of the construction risk of high and steep slope is a prerequisite for ensuring the safety of the project, and on the basis of the assessment results, the corresponding prevention and control measures are formulated to fully ensure the safety of the slope.

In terms of slope construction risk assessment, scholars and engineering technicians at home and abroad have done a lot of research, involving the selection of influencing factors, the quantification of evaluation indicators, the determination of index weights, and the establishment of risk evaluation systems. However, the project is unique, and is affected by factors such as geology, topography, climate and hydrology, and construction conditions in the region, and the influencing factors in the evaluation system are not the same, and the degree of influence is also different. In this paper, taking a deep-excavated slope site in Wuling Mountain, Chongqing as an example, this paper analyzes the influencing factors of construction risk and constructs a risk evaluation system based on the "Guidelines for Construction Safety Risk Assessment of Highway Cutting High Slope Engineering" (hereinafter referred to as the "Guide"), combines the actual situation of the slope, quantifies the index factors, obtains the overall risk value of a slope, and uses the risk assessment theory to obtain the risk level, which provides a theoretical reference for the prevention and control measures.

2. Project Overview

An expressway in Chongqing is located in the Wuling mountainous area, which is a two-way four-lane expressway in the mountainous and hilly area, with a design speed of 80Km/h, a roadbed width of 25.5m, and a load grade of highway-I. The right slope of K4+530-K4+916 is a deep-excavated rock slope, and the maximum excavation height is 55.3m. The course strikes 93° and is 386m long.

(1) Topography

It belongs to the tectonic denudation hilly landform area, which is a natural slope, the slope is generally low in the north and west and high in the south and east, the line passes along the middle and upper part of the slope, the longitudinal terrain changes along the line are small, the slope is 5°-31°, the transverse terrain slope is larger, the local is steep, the surface is mostly woodland, the vegetation is dense, the ground elevation is 298.6-365.7m, and the relative elevation difference is about 67.1m.

(2) Stratigraphic lithology

The surface overburden is mainly residual slope (Q4 el+dl), with a thickness of about 0.5-0.8m, and the underlying bedrock lithology is Upper Jurassic (J3s) Middle Jurassic (J2s) mudstone, and the rock formation occurs 330°∠9°. The thickness of the strong regolith layer is about 2.5-4.6m, the rock mass is relatively broken, the rock quality is soft, and the engineering mechanical properties are poor. The weathered rock mass is complete, the rock quality is soft, and the engineering mechanical properties are good.

(3) Geological structure

There are two groups of tectonic fractures in the rock mass: 1) 149°∠75°and 2) 232°∠86°, the structural plane combination is general, the rock mass is relatively broken, and the rock mass structure type is blocking structure. There are two groups of fractures on the slope, and the slope direction of the slope intersects with the rock layer and the fractures at a large angle, which is a tangential slope. The slope aspect of the slope intersects with the composite structural plane at a large angle, and there is no unfavorable camber structural plane, and the stability of the slope is controlled by the strength of the rock mass itself. The geology of the region is stable, and there are no adverse geological phenomena such as landslides, debris flows, collapses, and special rock and soil.

(4) Meteorological and hydrological conditions

The average annual rainfall in this section is 1104.5mm, but the rainfall is unevenly distributed in time, generally concentrated in May - September, the rainfall accounts for about 2/3 of the year, and there are many heavy rains and torrential rains, and the maximum daily rainfall is 363.8mm. According to the borehole in the road section, there is no groundwater in the hole, and the groundwater in the project area is generally poor.

(5) Engineering measures

According to the topography and geological conditions, combined with the experience of similar projects in Chongqing, the slope grading height is determined to be 10m level, the slope slope slope ratio is 1:1, the platform width is 2m, and the slope surface is protected by anchor frame beam + hanging net grass planting.

3. Evaluation Indicators and System Construction

The risk assessment of slope construction adopts the index system method in the "Guide", and divides the construction risk of high cutting slope into five factors: construction scale, geological conditions, inducing factors, construction environment, and data integrity, and each category is subdivided into multiple influencing factors, forming a total of 11 influencing factors. In order to distinguish the different importance of each evaluation index in the safety risk of engineering construction, the evaluation indicators should be ranked in order of importance from high to low according to the specific situation of each project and combined with expert experience, and the index weight should be calculated by using the method of "determining the weight value according to the importance of the evaluation index" recommended in the guide, it is calculated as follows:

$$\gamma = \frac{2n-2m+1}{n^2} \tag{1}$$

where , γ ——weight coefficient

n——number of metric items

m——ranking of importance, m≤n

According to the evaluation index and weight, the construction risk assessment index system is established, and the index weights taken by the slope are shown in Table 1.

Table 1. Indicator weights

Ranking of importance	Evaluate metrics	weight
1	Stratigraphic lithology	0.17
2	Slope structure	0.16
3	Slope height	0.14
4	Slope grade	0.12
5	The type of engineering action	0.11
6	Surroundings	0.09
7	Construction season	0.07
8	groundwater	0.06
9	Geological data	0.04
10	Design files	0.03
11	The impact of natural disasters	0.01

The Guidelines divide the sections of each assessment index into 4 levels according to the risk from small to large, and the corresponding scores are 0-24, 25-49, 50-74, and 75-100 respectively. According to the specific situation of each evaluation index corresponding to the slope, the corresponding quantitative score was selected according to the qualitative description of the guide. The product of the corresponding score and the weight of the indicator is the formula for calculating risk F, which is as follows:

$$\begin{gathered} F = \sum X_{ij} \\ X_{ij} = R_{ij} \cdot \gamma_{ij} \end{gathered} \tag{2}$$

Where Xij is the score of the assessment indicator and γij is the weighting coefficient of the assessment indicator.

After calculating the risk value F, the overall risk level of construction safety of the high cutting slope is determined according to Table 2.

Table 2. Corresponding risk levels

Risk level	risk value F
Level IV. (Very High Risk)	F>60
Level III (High Risk)	45<F≤60
Level II. (Medium Risk)	30<F≤45
Level I. (Low Risk)	F≤30

4. Risk Assessment and Prevention and Control Measures

In accordance with the index system method in the "Guide", the above index weights are used to evaluate the construction safety risk of the right slope of a highway K4+530-K4+916 in Wuling Mountain, Chongqing, and assign values to each evaluation index according to the geological survey data, design data, on-site survey, etc., and the evaluation table is shown in Table 3.

Table 3. Slope risk assessment table

Classify	Evaluate metrics	Separate into different kinds	Base score: Score range	Base score: Valid values	Weight factor	Evaluate the score	Remark
Scale of construction	Slope height	Soil slopes H≥40m, Rocky slopes H≥60m	75-100	68.4	0.14	9.58	The maximum height of the stony slope is 55.3m
		Soil slopes 30m≤H<40m, Rocky slopes 40m≤H<60m	50-74				
		Soil slopes 20m≤H<30m, Rocky slopes 30m≤H<40m	25-49				
		Soil slopesH<20m, Rocky slopes H<30m	0-24				
	Slope grade	The cutting slope exceeds the comparable slope value of the natural slope where it is located Δα≥15°	75-100	50	0.12	6	The stable slope is 30° and the cut grade is 45°, with interpolated values
		10°≤Δα<15°	50-74				
		5°≤Δα<10°	25-49				
		Δα<5°	0-24				
Geological conditions	Stratigraphic lithology	Slippery and weak formations	75-100	37	0.17	6.29	The thickness of the residual slope is about 0.5-0 .8m, the underlying bedrock is mudstone, and the thickness of the strong regolith layer is about 2.5-4.6m
		Whole regolith bedrock	50-74				
		Strongly regolithic bedrock	25-49				
		Weakly regolithic bedrock	0-24				
	Slope structure	The presence of weak structural surfaces or assemblages in slopes that are gently inclined in the slope direction: Through	75-100	12	0.16	1.92	No unfavorable outward sloping structural surfaces, other structural surfaces not penetrating, not developed, median value
		The presence of weak structural surfaces or assemblages in slopes that are gently inclined in the slope direction: not coherent	50-74				
		The presence of hard structural surfaces or assemblages in the slope that are gently inclined in the direction of the slope: Through					
		The presence of hard structural surfaces or assemblages in the slope that are gently inclined in the direction of the slope: not coherent	25-49				
		The presence of structural surfaces in other directions in the slope with penetration and development of the					
		Presence of structural surfaces in other directions in the slope, not coherent and not developed	0-24				
	underground water	Groundwater outcrops within 0.25H of the lower portion of the slope with no drainage measures	75-100	5	0.06	0.3	If there is no groundwater and drainage measures are considered in the slope protection facilities, a low value of 5 points will be taken.
		Groundwater is present in the lower and middle (0.25-0.5)H portions of the slope and no drainage is available	50-74				
		Groundwater is present in the upper-middle (0.5-0.75)H portion of the slope and no drainage is available	25-49				
		Groundwater is present within the upper (0.75-1.0)H of the slope and there is no drainage	0-24				
predisposing factor	construction season	Construction during the rainy season, with heavy rainfall occurring during the construction cycle; or the average annual rainfall in the construction area exceeding 800mm in the past 5 years.	75-100	100	0.07	7	Average rainfall of 1100-1200mm per year
		Construction during the rainy season, with heavy rainfall during the construction cycle; or the average annual rainfall in the construction area	50-74				

		exceeds 600-800mm in the past 5 years.					
		Construction in rainy season with moderate rainfall during the construction cycle; or the average annual rainfall in the construction area exceeds 300-600mm in the past 5 years.	25–49				
		Construction during the rainy season, when there is little or no rainfall during the construction cycle; or when the average annual rainfall in the construction area does not exceed 300mm in the past 5 years.	0–24				
	Impact of natural disasters	Frequent natural disasters	75–100	12	0.01	0.12	No adverse geologic phenomena were observed, taking the median value
		High incidence of natural disasters	50–74				
		Occasional natural disasters	25–49				
		Few natural disasters	0–24				
construction environment	Type of engineering measure	Skid pile	75–100	50	0.11	5.5	Anchor frame beam + wire mesh hanging inside the frame spraying substrate grassing
		Anchor engineering	50–74				
		Grouting type of work	25–49				
		Retaining wall engineering	0–24				
	Surroundings	Surface buildings, buried objects, high voltage towers, water facilities within 0.5H beyond the excavation line at the top of the slope and 1.0H below the roadbed.	75–100	10	0.09	0.9	No surface buildings, buried objects, high voltage towers, or water facilities beyond the excavation line at the top of the slope, worth 10 points.
		Surface buildings, buried objects, high voltage towers, and water facilities within 1.0H beyond the excavation line at the top of the slope and 1.5H below the roadbed.	50–74				
		Surface buildings, buried objects, high voltage towers, water facilities within 1.5H beyond the excavation line at the top of the slope and 2.0H below the roadbed	25–49				
		Facility is located outside of the above	0–24				
Data integrity	Geological information	One or no survey sections per high slope work site, and only 1 or no exploration points per section (drilling, excavation, physical exploration)	75–100	37	0.04	1.48	There is a survey section with 2 exploration points per section, taking the median value
		At least one survey section per high slope work site and 2 exploration points per section (drilling, excavation, physical exploration)	50–74				
		At least one survey section per high slope work site, with 3 exploration points per section (drilling, excavation, and physical exploration)	25–49				
		At least one survey section per high slope work site and at least 3 exploration points per section (drilling, excavation, physical exploration)	0–24				
	Design Documents	One slope, one map, one description of incomplete maps	75–100	50	0.03	1.5	One slope, one map, one description of the map is more complete, take the lower value
		One slope, one map, one description of the map is more complete	50–74				
		A slope, a map and a description of the complete map, with calculation parameters, the size of the slope damage (such as landslide thrust), and the location of the rupture surface.	25–49				
		A slope, a map and a description of the map is very complete, there are calculation parameters, the size of the destructive force of the slope (such as	0–24				

		landslide thrust), the location of the rupture surface, the resistance to sliding force of engineering measures (such as anti-slip piles of the anti-sliding force), the proposed construction of safe working conditions, the construction process of special projects and precautions, construction risk analysis and control measures					
Subtotal risk assessment indicator score (F)						40.6	

From equation 2 and table 2, the calculated risk value F=40.6, and the risk level is class II (medium risk). The risk acceptance criterion is acceptable, but it is necessary to take risk prevention and control measures, strict daily safety production management, and strengthen site inspection to prevent its risk from expanding. In addition, from the column of assessment scores in Table 3, it can be seen that the slope height, slope shape and slope rate, stratum lithology, and construction season account for a high proportion. Attention should be paid to the sequence of multi-stage slope excavation and protection, adopting reasonable excavation depth and width, adopting economic and effective temporary support to ensure safety during construction, constructing in strict accordance with the design documents, excavating one level of protection, and paying attention to the safe use of scaffolding. Affected by the regional meteorological influence, annual rainfall is large, should be reasonable and scientific development of construction organization plan, to avoid the construction of the rainy season, do a good job of optimizing the construction progress, arrange scientific and efficient flow construction, to ensure that the rainy season before the arrival of the slope related construction processes. Strengthen the temporary protection and drainage during the construction period to avoid the deterioration of the physical and mechanical properties of the slope caused by water. Strengthen the monitoring and early warning during the construction period, real-time access to monitor the slope deformation, stress, water level and other data, the establishment of the slope construction early warning system, real-time alarms on the monitoring of abnormalities, and then take appropriate emergency measures to minimize the loss of accidents.

5. Conclusion

In this paper, for a deep excavation slope site in Wuling Mountain area of Chongqing, through sufficient research and site investigation, we select 11 index factors for the construction risk of deep excavation slopes from five factors, namely, construction scale, geological conditions, triggering factors, construction environment, and completeness of information, and use risk theory to derive the construction risk level. The main conclusions are as follows:

(1) This paper adopts the recommended method and risk evaluation index system of the Guide to evaluate the risk equivalence of a deep excavation slope in Wuling Mountain Area of Chongqing, and the evaluation result is class II (medium risk), which is in good agreement with the actual situation on the site, and proves that the adopted index system and risk grading method are accurate and reliable.

(2) Influenced by the engineering geology and climate and hydrology of Wuling Mountain area in Chongqing, the index factors of stratum lithology, slope structure, slope height, slope shape and slope rate have a greater impact on the construction risk of deep excavation slope, and the total weight accounts for more than 50%.

(3) Influenced by the slope height of this deep excavation, regional climate and other characteristics of the slope itself, the height of the slope, slope form slope rate, stratum lithology, construction season indicator factors accounted for a large proportion of the total risk assessment score, should be scientifically developed construction excavation process, take temporary engineering protection and temporary drainage measures water. Reasonable development of construction organization plan, avoiding construction in the rainy season.

(4) Strengthening construction management and monitoring and early warning is a favorable initiative for risk control of deep excavation slopes, through real-time monitoring of slope

deformation, stress, water level and other data, and timely warning of abnormalities to maximize the reduction of safety risks in slop construction and reduce the loss of manpower and material resources.

Acknowledgments

This research work was sponsored by the Chongqing Transportation Technology Project of China [Project No. CQJT2022ZC19].

References

[1] ZHANG Runzhi, ZHONG Guoqiang, WANG Chao, et al. Overall risk assessment of highway marl high slope excavation construction [J]. Value Engineering, 2023, 42 (25): 39-41.

[2] LIU Ruiqi. Safety risk assessment of highway slope based on FAHP and its engineering application[D]. Huazhong University of Science and Technology, 2021.

[3] Xia Yifeng, Yin Guohua, Lin Rui, et al. Slope geological hazard risk assessment method and engineering application based on fuzzy comprehensive evaluation [J]. Science & Industry, 2022, 22 (10): 378-382.

[4] ZOU Zongmin. Application of analytic hierarchy process in construction risk assessment of highway slope [J]. Journal of Highway and Transportation Research and Development (Applied Technology Edition), 2018, 14 (10): 5-8.

[5] Du Y, Sheng Q, Fu X, et al.Risk evaluation of colluvial cutting slope based on fuzzy analytic hierarchy process and multilevel fuzzy comprehensive evaluation. [J]. Journal of Intelligent and Fuzzy Systems, 2019, 37(3):4245-4271.

[6] TIAN Qingyan, ZHANG Qingqing, YIN Quanchun, et al. Research on Risk Assessment Model of Operational Highway Slope Based on Unstable Index Method[J]. Zhongwai Highway,2022,42(5):30-37.

[7] Wang Helin, Xie Wangxiang, Hu Qingguo. Determination of the risk level of the impact of high slope construction on operation safety of reconstruction and expansion expressway[J].Zhongwai Highway, 2014, 34(6):4.

[8] LIU Huaixiang, ZENG Sheng, ZHU Gang. Optimal Selection of Slope Treatment Scheme Based on Analytic Hierarchy Process[J]. Zhongwai Highway,2007,27(5):27-31.

[9] YE Xian, CHEN Huabin, WU Zhu, et al. Discussion on the overall risk assessment technology of construction safety of high cutting slope engineering of highway in mountainous areas[J]. Highway, 2018, 63 (3):42-47.