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Research on Safety Risk Assessment of Long-span Suspension Bridge Construction in Deep Valley in Mountainous Area Based on Cloud Model

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Abstract: *Based on the fuzziness and randomness of cloud model, it is applied to the construction safety risk assessment of long-span suspension bridge in deep valley in mountainous area. According to the situation of Jiangdi River Bridge project, the cloud model evaluation method is adopted to add two indexes of wind load condition and import and export construction condition to the index system. The index weight is calculated by the maximum deviation weighting method, the comprehensive determination degree is calculated and the construction safety risk level is determined. By comparing the standard evaluation results of construction Safety Risk Assessment Guide for Highway Bridges and Tunnels (Trial) and the cloud model evaluation results, it is shown that the evaluation index system is constituted by adding corresponding special risk factors to the actual project and cloud model calculation is more reasonable and accurate than the traditional risk evaluation results.*

Keywords: *Cloud model; Mountain valleys; Large span suspension bridge; The risk assessment*

1. Preface

Highway Bridges in mountainous areas with high pier and long span are difficult to build. Their construction and operation are risky due to the complexity and uncertainty of external environment, the complexity of the project itself and the limitation of people's forecasting ability. At present, a complete disciplinary system of risk science has not been formed, and the research in this field still relies on the communication among scholars to promote gradually. Highway Bridge and Tunnel Engineering Construction Safety Risk Assessment Guide (Trial) (hereinafter referred to as the Guide), which is used to guide the safety risk assessment of bridge construction, is only aimed at general Bridges, and the evaluation indexes do not meet the requirements of some special Bridges. Therefore, it is valuable and promising to systematically study the theory and method of mountain bridge risk assessment.

Domestic and foreign scholars have done a lot of research on this. CHEN Changsong[1]used the fuzzy comprehensive evaluation method to evaluate the construction safety risk of cable-stayed bridge; HONG Liu[2]established the WBS-RBS coupling matrix to evaluate the construction safety risk of bridge; LU Xinxin[3]established the Kent index method evaluation model for analysis.

The cloud model is a mathematical model proposed by LI Deyi, which aims to realize the uncertainty transformation between qualitative concepts and quantitative values, improve the traditional membership function which only considers fuzziness, and unify the randomness and fuzziness between the linguistic value of uncertainty and the exact value[4]At present, it has been widely used in slope stability assessment, surrounding rock stability classification, dam risk assessment and other fields.

In this paper, a new construction safety risk assessment model of long-span suspension bridge in mountainous and deep valleys is established based on cloud model. Considering the influence of risk factors such as special topography and wind load on the safety of bridge construction, the cloud model is characterized by fuzziness and randomness to accurately evaluate the risk value of each evaluation index of Jiangdi River Bridge. By comparing the calculated results with those obtained according to the Guidelines, the risk assessment results are more accurate and reliable.

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2. Overview of Jiangdi River Bridge Project

Jiangdi River Bridge is located at K28+612 ~ K30+280 of Yongda (Yongren County - Dayao County) expressway. It is a control project of Yongda Expressway, with a total length of 1.668km, including the main bridge, approach bridge, abutment and Dayao bank approach road foundation.

The Guide selects six evaluation indexes, including construction scale, geological conditions, climatic environmental conditions, topographic and geomorphic conditions, bridge location characteristics and construction technology, quantifies each index into 2-4 risk levels, and establishes a risk assessment index system[5].According to the survey report, construction design drawing of Jiangdi River Bridge and site survey, the risk assessment indicators are described as follows.

2.1 Construction scale

The main span of Jiangdi River Bridge is (255+920+255) m, and the approach bridge of Yongren an is 2× (50+65+50) m.

Continuous box girder composite bridge; Dayao Bank approach bridge is (60+70+60) m continuous steel box composite structure beam bridge with a deck width of 25.5m. The project includes the main bridge anchorage, cable tower, cable system, cable saddle, steel box girder, deck system, drainage system, upper and lower structure of approach bridge, deck system, etc.

2.2 Geological Conditions

The project area is located in the Qing, Tibet, Yunnan, Myanmar and Indonesia "Dai-zi" structural system. The central Yunnan depression is the Dayio-Tai-depression in the northwest, which is the center of the depression. The structural line is near NS-NE trending, the faults are not developed, the folds are gentle and open, and the dips are more or less horizontal. The east side of the Dayao Sag is the Yongren ~ Zhaojiadian wide gentle syncline, and the west side of the syncline is the Zhaojiadian bowl syncline. The strata around the syncline are inclined to the center of the basin with a dip Angle of 20 ~ 30°. The core strata are Zhaojiadian Formation and the two sides are Jiangdi River Formation.

2.3 Climatic and environmental conditions

Bridge site area belongs to the subtropical dry climate, the dry hot valley climate is obvious, the annual average temperature of the Jiangdi River bridge section is 18.9 ~ 20.8℃, the extreme maximum temperature is 44℃, the extreme minimum temperature is -4℃.General winter without summer and spring long, winter without cold summer warm, a year two seasons dry and wet, less rainfall spring and summer drought, sufficient sunshine short frost period.

2.4 Topographic and geomorphic conditions

The Jiangdi River Valley crossed by the Jiangdi River Bridge is V-shaped, with asymmetrical topography on both sides. The strata of Yongren Bank are inclined, and the natural surface slope is relatively gentle. The slope is in the stepped form of steep and gentle transition, and there are 4 level platform terraces of different sizes, and the anchor tower is located on the 3 and 4 level terrace platforms.

Several shallow gullies are developed on the bank slope of Yongren, and the local terrain is cut by gullies and develops steep slopes or steep ridges, ranging from 3 to 50m in height. There is the possibility of bank collapse or topsoil collapse on the slopes on both sides of gullies.

2.5 Features of bridge position

The geological structure of the bridge site is relatively undeveloped, but the cutting depth under the river bottom bridge is large, the trench cutting in the cable tower and anchorage area on both sides is relatively shallow (ranging from 3 to 5 m), the bad geological development is not developed within 150 m of the bridge axis, and the foundation of the site and tower anchor and other structures is relatively stable.Due to the typical distribution of "red bed soft rock" (mudstone, argillaceous siltstone) in the bridge site area, the rock quality is relatively soft, and the engineering landslide may occur after the project excavation.

2.6 Construction technology maturity

The bridge uses the four new technologies to promote the project construction safely and efficiently. In the construction, it actively responds to the call and promotes the application of the "four new" technology and subject research. Through advanced technology and equipment, high-tech means to achieve the goal of quality, construction period and efficiency[6].In the process of organizing construction, we actively apply the "four new" technology and subject research to promote the safe and efficient construction of the project.

2.7 Wind load status

The project area is rich in wind resources. Under the influence of monsoon, the average wind in spring and summer can reach level 6, with gusts of 7-8, and blue warning of wind is frequent. During the construction of Jiangdi River Bridge, there are a lot of aerial operations, such as pier column (tower) construction, catwalk construction, formwork installation and removal, and cable hoisting, etc., which require operators and machines to work at high altitude for a long time, among which catwalk construction has the greatest risk of accidents. The height difference between the main span of Jiangdi River Bridge and the valley is 350m. During the construction of the catwalk, the canyons on both sides are steep, and the wind load has a great impact on the high-altitude work. If it falls, it will cause serious safety accidents and economic losses.

2.8 Import and export construction status

Jiangdi River Bridge Dayao Bank connects Shaalam tunnel exit, two steep cliffs and steep slope development, bank slope of nearly 45 °. A number of shallow gullies with length ranging from 0.5 to 2.5km and bottom width ranging from 0.3 to 3m are developed on the steep and unstable slope where Yongren Bank connects the ridge. The bank slope is between 0° and 40°, and the local terrain is cut by gully and develops steep ridges, ranging from 3 to 50m in height. There is the possibility of bank collapse or topsoil collapse on the slopes of both sides of gully. The construction situation of inlet and outlet is relatively complicated, which has a great impact on the construction safety.

3. Standard evaluation of the Guidelines

The overall risk assessment of highway bridge engineering construction safety is a static assessment, which is to estimate the safety risk level of the bridge engineering according to the pregnant environment and risk factors before the start of construction[7].

Evaluation process of the Guide: 1) Conduct survey and collect basic data; 2) Analyze whether the evaluation system of the Guide can reflect the difficulties and characteristics of the project and the improper adjustment; 3) Assign the risk value of each evaluation index in turn according to the specific situation of the project, and sum up the overall risk value; 4) Determine the overall risk level according to the classification standard.

After scoring according to the index, the total risk score R is calculated, and the risk grade is determined according to the bridge risk assessment grade table. The calculation formula is as follows:

$$R = A_1 + A_2 + A_3 + A_4 + A_5 + A_6 \qquad (1)$$

The scores assigned in the formula (1) are as follows: A_1 scale of bridge construction; A_2 Geological conditions; A_3 Climatic and environmental conditions; A_4 Topography and landform; A_5 Bridge location characteristics; A_6 Construction technology maturity.

The Jiangdi River Bridge shall be evaluated according to the standards of the Guide. The results are shown in Table 1.

Table 1: Construction risk assessment table of Jiangdi River Bridge

Evaluation indicators	classification	score	score	Scoring basis and explanation
Construction Scale (A1)	LK>150 m or L>1000 m	4 to 5	4	Total length L=1668.00 m, LK=920 m>150 m
Geological Conditions (A2)	There are undesirable geological disasters, but they are not frequent or there are special rock and soil, which affect the construction safety	2-3	2	There are bad geological hazards of unloading belt and red bed soft rock, which affect the construction safety
Climatic and Environmental Conditions (A3)	The climate environment condition is general, may affect the construction safety, but not significantly	2-3	2	The high temperature in summer, the large temperature difference in the morning and evening, and the spring breeze in winter have a great influence on the bridge construction
Topographic and geomorphic conditions (A4)	Valleys, intermountain basins, mountain passes and other dangerous areas	4 to 6	6	The bridge is located on a deep canyon, which affects the safety of construction
Bridge position Characteristics (A5)	Land: Cross the road bridge	3-6	3	Across the village road, close to the residential area
Construction process maturity (A6)	Apply four new technologies	2-3	3	Four new technology
Total risk score	20			
Overall risk level	**Level IV (Very high risk)**			

4. Cloud model evaluation

4.1 Cloud model theory

Definition of cloud model concept: Suppose U is a quantitative theory domain represented by precise numerical values, and C is a qualitative concept on U. If quantitative value x∈U, and x is a random realization of qualitative concept C, and the certainty u（x） ∈ [0,1] of x to C is a random number $u: U \rightarrow [0,1], x \in U, x \rightarrow (x)$ with stable tendency, then the distribution of x on the theory domain U is called cloud, and every x is one cloud droplet[8].

4.2 Cloud model calculation

According to the guide and the actual engineering situation, recently the river extra large bridge, the construction scale, geological conditions, climate conditions, topography condition, the characteristics of the bridge, the construction technology, wind load and import and export of construction conditions analyze and judge the eight indicators, assessment according to the following steps in order to get specific parameter values, The maximum deviation weighting method was used to obtain the weights of each evaluation index.

1) Construct bridge construction safety risk assessment index system.

2) Determine the risk rating standard.

3) Calculate the cloud digital characteristic values of different risk levels and generate the cloud model diagram.(E_x, E_n, H_e)

4) Determine the weight of each index (maximum deviation weighting method).

The score matrix of each evaluation index was standardized to obtain the matrix $B = (b_{ij})_{m \times n}$, and the weight $\omega = [\omega_1, \omega_2, \ldots, \omega_n]^T$ of each evaluation index was obtained from Equation (2) by constructing the deviation function $D(W) = \sum_{j=1}^{n} D_j(W) \sum_{j=1}^{n} \sum_{i=1}^{m} \sum_{k=1}^{m} d(b_{ij}, b_{kj})\, \omega_i$.

$$\omega_j = -\frac{\sum_{i=1}^{n}\sum_{k=1}^{n} d(b_{ij}, b_{kj})}{\sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{m} d(b_{ij}, b_{kj})}, \quad j = 1,2, \ldots n \qquad (2)$$

5) According to the forward cloud generator, the certainty of each evaluation index belonging to the

cloud model of different risk levels is calculated. Combined with the weight coefficient, the comprehensive certainty is calculated according to Equation (3)[9].

$$P = \sum_{i=1}^{n} \omega_i \times \mu_i \qquad (3)$$

Where: μ_i is the degree of certainty; ω_iIs the weight coefficient of the evaluation index; n is the number of evaluation indicators. In this paper, n is equal to 8.

The results are shown in Table 2 and Table 3:

Table 2: Score value and weight of each evaluation index of bridge

Name of the bridge	Construction scale	Geological conditions	Climatic environmental conditions	Topographic and geomorphic conditions	The characteristics of the bridge	Construction technology	Wind load condition	Import and export construction status
Jiangdi River Bridge	4	2	2	6	3	3	3	2
The weight	0.234	0.203	0.016	0.172	0.078	0.141	0.109	0.047

Table 3: Safety risk assessment results of highway bridge construction

bridge The name of the	Degree of synthetic certainty	Cloud model evaluation results	Bridge number	Degree of synthetic certainty	Cloud Model Evaluation The results of
	P (IV)	P (III)	P (II)	P (I)	
Jiangdi River Bridge	0.4686	0.0027	0	0	IV

According to the maximum comprehensive certainty calculated by the normal cloud model, the construction safety risk level of Jiangdi River Bridge belongs to the extremely high risk (grade IV), and its comprehensive certainty is 0.4686, which should be included in the scope of special risk assessment.

By comparing the evaluation results of the standard assessment of the Guide with those of the cloud model, it can be seen that it is difficult to determine the specific risk level of the risk value assessed by the standard assessment of the Guide. Different experts will have a small range of floating values according to their own experience and cognition, which will directly affect the risk assessment level of the bridge. Construction safety risk assessment based on cloud model can avoid the interference caused by external environment and human factors. At the same time, according to the actual engineering situation, the index that has a significant impact on the construction safety is added, and each evaluation index value is divided into a more detailed interval. By establishing a mathematical model, the risk level of the bridge can be determined objectively and reasonably.

5. Conclusion

Through the case of Jiangdi River Bridge project, this paper compares the standard evaluation of the Guide with the results of cloud model method, and draws the following conclusions:

1) According to the actual engineering situation of Jiangdi River Bridge, two risk assessment indexes of wind load condition and inlet and outlet construction condition are added. For Bridges with different characteristics and types, risk assessment indexes in line with the actual conditions are added, which can make the assessment results more scientific and accurate.

2) The risk assessment of Jiangdi River Bridge was carried out according to the Guidelines and the cloud model. The risk value was 20 and the overall risk level was IV according to the Guidelines. According to the maximum comprehensive certainty calculated by the normal cloud model, its comprehensive certainty is 0.4686. By horizontal comparison of P (III), P (II) and P (I), the overall risk level can be clearly determined as level IV.

3) Compared with the standard evaluation of the Guide, the cloud model evaluation method makes full use of the advantages of fuzziness and randomness of the cloud model, which can reduce the influence of subjective factors in a more scientific and reasonable way. Therefore, it is of great practical value to apply cloud model to highway and bridge construction safety risk assessment.

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