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Research on Risk Management of Cross-Sea Bridges Based on Analytic Hierarchy Process—Taking Hangzhou Bay Bridge as an Example

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Abstract

Today, as the process of urbanization is accelerating, the country builds an extensive transportation network through bridges and roads, which facilitates the daily travel of the people and greatly promotes the development of the national economy. However, due to the cross-sea bridge spanning the bay, the overall scale, the complex construction environment, and the high technology content, the objective existence of risk factors in the construction process cannot be completely avoided. In the construction of cross-sea bridges, once a construction safety accident occurs, it will cause irreparable losses to the construction of the project. Taking Hangzhou Bay Bridge as an actual case, using the Analytic Hierarchy Process to identify possible risk factors during the life cycle of Hangzhou Bay Bridge, establish a corresponding risk evaluation system to evaluate the importance and probability of risk, and to rank the importance of risks, and control the corresponding construction risks by adopting measures such as risk transfer and risk retention. The research example shows that the project risk of the cross-sea bridge project can be combined with the analytic hierarchy process to identify, analyze and evaluate the importance of the various risks faced by the project, so as to adopt corresponding avoidance methods to reduce the project risk loss and achieve the project construction expectations Target.

Keywords

Sea Bridge, Analytic Hierarchy Process, Risk Management

1. Introduction

Bridge construction has the characteristics of huge engineering volume, large capital investment, complex design structure, and strict construction requirements. These characteristics determine that there are various possible risks in the process of bridge construction [1]. Tan Chunlei [2] *et al.* qualitatively analyzed bridge engineering factors by discussing engineering risk issues, and put forward corresponding countermeasures for enhancing bridge engineering management and safety risks. Zhang Yuefeng [3] and others analyzed the safety problems in bridge construction, and then gave corresponding solutions based on construction experience. Cao Hanjiang [4] combined his own construction experience in typhoon prevention management, analyzed and discussed the impact of typhoon on large-scale cross-sea bridges, and proposed conceptual solutions. Zhang Junwei [5] and others have carried out overall planning and rational implementation of technical issues and process key issues of highway and bridge construction sites from multiple aspects to ensure that the safety management objectives are fully realized. In summary, most of the research on bridge engineering risk management by Chinese scholars focuses on specific problems, using qualitative methods to study losses, and combining their own construction experience to give conceptual basic countermeasures. The application of risk assessment methods in bridge engineering is relatively researched. In view of this, based on the analytic hierarchy process, taking the Hangzhou Bay Bridge as an example, the risk management during the construction of the cross-sea bridge in the complex ocean environment is analyzed.

2. Project Introduction

2.1. Project Overview

The Hangzhou Bay Cross-sea Bridge is located in Zhejiang Province, connecting Jiaxing City and Ningbo City. The length of the bridge is 3.57 × 104 m, and the bridge span of the North Channel The diamond-shaped double-tower steel box cable-stayed bridge with the length set to (70 m + 140 m + 448 m + 140 m + 70 m), the southern channel is designed as a type A single-tower steel box cable-stayed bridge (100 m + 160 m + 380 m), and the steel box beams are all The factory-prefabricated prestressed concrete box girder is used for on-site assembly and splicing, first simply supported and then continuous, the stay cables are all parallel steel wire finished stay cables, and the tower is anchored by tensioning. Both auxiliary piers and transition piers adopt inverted rectangular and rounded cross-sections.

2.2. Geographical Environment

The bridge is located in the Quaternary sedimentary layer. The soil is mainly sub-sand, sub-clay, silty clay, fine sand, silt sand, medium-fine sand, etc. It belongs to the coastal plain mixed stratum, and the upper soft soil layer is 20 - 45 m thick. The soft soil layer has the characteristics of high water content, high compressibility, thixotropy, and low bearing capacity. In addition, shallow biogas generally exists in the sedimentary layer of the bridge site, the gas layer is widely distributed, the pressure range is 0.4 Mpa - 0.5 Mpa, the buried depth of the gas layer is about 45 - 60 m, and the content of methane and other flammable gases is as high as 85%. If handled improperly, engineering hazards are prone to occur.

2.3. Climatic Conditions

The weather conditions of the Hangzhou Bay Cross-sea Bridge are very complicated, with small-scale disastrous weather, tornadoes, thunderstorms, and typhoons occurring from time to time. According to relevant data, the Hangzhou Bay Bridge has a maximum tidal range of 7.57 m, an average tidal range of 4.65 m, and an average annual velocity of 2.39 m/s. The seawater flow direction is turbulent and the tide field is complicated.

3. Identification of Risk Factors of Hangzhou Bay Bridge

There are many risk factors that affect the construction of the bridge. According to the characteristics of the long construction period, large project investment, and complex and changeable environment of the cross-sea bridge, it ranges from political factors, economic factors, technical factors, management factors, natural factors, etc. To identify the risk factors of the Hangzhou Bay Bridge.

3.1. Policy Risk

The Hangzhou Bay Cross-sea Bridge has a construction period of 48 months. Due to the long construction period, the country's macro-control policies may undergo certain changes during the construction period. Therefore, changes in relevant national policies are a risk that the project may face.

3.2. Economic Risks

3.2.1. Loan Risk

The actual start date of the Hangzhou Bay Cross-sea Bridge was June 2003 and it was completed in June 2007. The total construction period is 48 months, and the total design estimate is 13.8 billion yuan. The bank loan interest rate adjustment table is shown in Table 1.

3.2.2. Market Risk

The main materials used in the whole bridge are shown in Table 2. It can be

Table 1. Bank loan interest rate adjustment table.

Adjust the time	One year to three years (%)	Three to five years (%)
2004.10.29	5.76	5.85
2006.04.28	6.03	6.12
2006.08.19	6.30	6.48
2007.03.18	6.57	6.75
2007.05.19	6.75	6.93

Table 2. The main materials of the full bridge.

Material name	unit	Quantity
Concrete	104 m^3	245
Various types of steel	104 t	82
Steel pipe pile	root	5164
Bored pile	root	3438
Various cast-in-place box beam	hole	157
(50 m + 70 m) precast concrete box girder	sheet	404 + 540

seen from this table that during the construction of the bridge, concrete and steel bars are the main materials. The amount of these materials is large, and the price changes with time, and constitutes the construction the labor cost, mechanical cost, management cost, etc. of the engineering cost also change with time. Among these costs, labor costs fluctuate more than other costs, showing an upward trend year by year. Because these costs change over time. It will become another big risk faced by the construction of engineering projects.

3.3. Design Risk

Design is the most critical part of the entire project construction. It determines the quality of the entire project and the level of investment. Before the Hangzhou Bay Bridge was built in my country, there was no domestic experience in the construction of such a large-span cross-sea bridge to learn from. Therefore, the design of the cross-sea bridge basically started from scratch, not to mention the bridge site of the Hangzhou Bay Bridge. The geographical location and natural climatic conditions of the district all pose challenges to the professional level of engineering designers. In addition to the uncertainty and risk of the bridge design itself, the public accepts it and the impact of the bridge on the surrounding environment is also full of unknowns and risk.

3.4. Construction Risk

3.4.1. Construction Quality Risk

In terms of the Hangzhou Bay Bridge, the bridge construction site is unchanged, but the construction personnel are always mobile, and most of the specific construction operators are migrant workers, whose cultural quality and level are not high, and the construction operations are not standardized. These are the potential risks in the process of bridge construction. When building the bridge, whether a reasonable target system has been established, whether a reasonable organization has been established, whether there are reasonable economic guarantee measures, etc. In the specific construction process, it is reflected in whether the quality of concrete pouring is qualified, whether the splicing of steel box girder is strictly controlled, whether the quality of bored piles is qualified, whether the quality of piers and caps are qualified, whether the prestress system has quality assurance measures, etc. The above only reflects part of the content of the quality management system. Looking at the entire construction process, quality risks are everywhere and all the time.

3.4.2. Construction Period Risk

In the process of bridge construction, due to policy changes, insufficient funds, construction quality problems, construction technical problems, etc., the construction period may be extended accordingly. Therefore, the construction period is also a potential risk in the construction process.

3.4.3. Construction Safety Risks

During the construction process, the main causes of safety accidents can be divided into two categories. The first category is due to insufficient technical explanations, failure to conduct safety education and training for employees, irregular operations during the construction process, and weak safety awareness of construction personnel., The other type is caused by the unsafe state of the object, such as the collapse of the building and the breaking of the rope, which may lead to a series of safety accidents.

3.5. Manage Risk

The construction of the Hangzhou Bay Bridge project involves many stakeholders, such as construction units, construction units, supervision units, design units, survey units, etc. As the construction progresses, how to coordinate the interests of all parties and deal with them Disputes over the interests of the parties mobilize the enthusiasm of all parties to achieve a "mutual benefit and win-win" situation. This has extremely high requirements on the experience level of managers. If the ability and level of the management personnel cannot solve the management problems encountered during the construction process, it is likely to cause the project to stagnate.

3.6. Contract Risk

In the construction of Hangzhou Bay Bridge, the construction period is long. There are many uncontrollable objective risk factors in the construction period. Real-time construction contracts need to be signed as the construction project progresses. Some contract terms may change over time. Lead to contract disputes. This leads to economic losses and extension of the construction period, which hinders the construction of the bridge.

3.7. Environmental Risks

Destructive weather events often occur in the site area of the Hangzhou Bay Bridge. Once disasters such as typhoons, tornadoes, and storms occur, they will not only cause unpredictable economic losses and delays in construction, but may even cause casualties. In addition, the bridge piers are often exposed to corrosive seawater and are subject to seawater erosion and erosion. If the quality of the bridge piers is unqualified, it is likely to cause the bridge to collapse.

4. AHP

The Analytic Hierarchy Process (AHP method for short) refers to a decision-making method that decomposes factors that are always related to decision-making into goals, criteria, and plans, and then conducts quantitative and qualitative analysis on this basis. There are still many shortcomings in risk management in our country. The analytic hierarchy process can be used to reasonably divide the existing risks and control the risks within a reasonable range. Risks exist in the whole process of construction, and there are certain complexity, which will aggravate the difficulty of eliminating risks. The analytic hierarchy process is to comprehensively evaluate various risks, simplify risk analysis, and promote the improvement of risk management level [6].

4.1. Establishment of Risk Evaluation Index System

By consulting a large amount of literature, based on the analytic hierarchy process, combined with the identification and analysis of construction risks that may occur during the construction of the Hangzhou Bay Bridge, a risk index evaluation system is established, as shown in Figure 1 below.

4.2. The Construction of the Intermediate Judgment Matrix

Taking into account the differences in the importance of each factor, the importance of the influencing factors is compared according to the evaluation criteria of the relative importance of the factors, and the values are assigned according to the assignment principles in Table 3. Combining the characteristics of this bridge

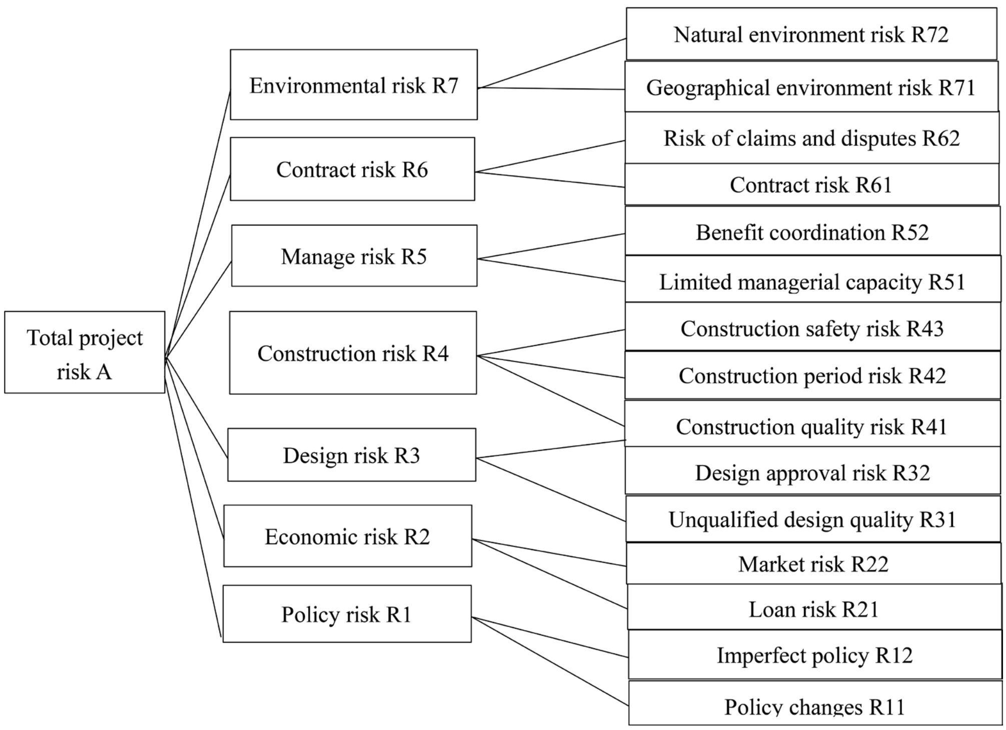

Figure 1. Risk evaluation index system.

Table 3. Factors pairwise comparison importance evaluation criteria and assignment.

(Rij assignment)	meaning
1	i, j are equally important
3	The i factor is slightly more important than the j factor
5	The i factor is obviously more important than the j factor
7	The i factor is more important than the j factor
9	The i factor is extremely important than the j factor
2, 4, 6, 8	The intermediate value of the above two adjacent judgments, such as "2", is between equal importance and slightly important

Table 4. Judgment matrix.

index	R1	R2	R3	R4	R5	R6	R7
R1	1	1/5	1/5	1/9	1/7	1/5	1
R2	5	1	1	1/9	1/5	1	7
R3	5	1	1	1/9	1/7	1	7
R4	9	9	9	1	1	7	9
R5	7	5	7	1	1	5	9
R6	5	1	1	1/7	1/5	1	9
R7	1	1/7	1/7	1/9	1/9	1/9	1

project and adopting the evaluation method of expert scores, each influencing factor is assigned, and the corresponding judgment matrix(OR) is obtained as shown in Table 4.

4.3. Calculation of the Weight of Each Influencing Factor in the Middle Layer

Solve the largest eigenvector of the judgment matrix and its corresponding eigenvector, and the eigenvector can be used as the weight vector. For judgment matrices that are inconsistent within the allowable range, use the eigenvector corresponding to the largest eigenvalue as the weight vector: and calculate the weight vector according to steps (1)-(4).

$$AW = \lambda_{\max} W$$

(I) Calculate the product M_i of each row element of the matrix

$$M_i = \prod_{j=1}^{n} b_{ij} \quad (i = 1, 2, 3, \cdots) \tag{1}$$

(II) Calculate the nth root of M_i W_i

$$W_i = \sqrt[n]{M_i} \tag{2}$$

(III) Normalize the vector $W = [W_1, W_2, \cdots, W_n]^{\mathrm{T}}$, that is, normalize

$$W_i = W_i \Big/ \sum_{i=1}^{n} W_i \tag{3}$$

(IV) Calculate the largest characteristic root of the judgment matrix

$$\lambda_{\max} = \sum_{i=1}^{n}\left[[OB][W]\right]/nw \quad (4)$$

Calculate the middle layer instance according to Table 4, the specific calculation steps are as follows.

a) Calculate M_i and W_i

$$M_1 = 1\times 1/5\times 1/5\times 1/9\times 1/7\times 1/5\times 1 = 1/7875,\ \overline{W_1} = \sqrt[7]{1/7875} \approx 0.27758$$

$$M_2 = 5\times 1\times 1\times 1/9\times 1/5\times 1\times 7 = 7/9,\ \overline{W_2} = \sqrt[7]{7/9} \approx 0.96473$$

$$M_3 = 5\times 1\times 1\times 1/9\times 1/7\times 1\times 7 = 5/9,\ \overline{W_3} = \sqrt[7]{5/9} \approx 0.91946$$

$$M_4 = 9\times 9\times 9\times 1\times 1\times 7\times 9 = 45927,\ \overline{W_4} = \sqrt[7]{45927} \approx 4.63457$$

$$M_5 = 7\times 5\times 7\times 1\times 1\times 5\times 9 = 11025,\ \overline{W_5} = \sqrt[7]{11025} \approx 3.77992$$

$$M_6 = 5\times 1\times 1\times 1/7\times 1/5\times 1\times 9 = 9/7,\ \overline{W_6} = \sqrt[7]{9/7} \approx 1.03655$$

$$M_7 = 1\times 1/7\times 1/7\times 1/9\times 1/9\times 1/9\times 1 = 1/35721,\ \overline{W_7} = \sqrt[7]{1/35721} \approx 0.22366$$

b) Normalize $W = \left[W_1, W_2, \cdots, W_n\right]^{\mathrm{T}}$

$$W_1 = 0.27758/(0.27758+0.96473+0.91946+4.63457+3.77992+1.03665+0.22366) \approx 0.023$$

$$W_2 = 0.96473/(0.27758+0.96473+0.91946+4.63457+3.77992+1.03665+0.22366) \approx 0.082$$

$$W_3 = 0.91946/(0.27758+0.96473+0.91946+4.63457+3.77992+1.03665+0.22366) \approx 0.078$$

$$W_4 = 4.63457/(0.27758+0.96473+0.91946+4.63457+3.77992+1.03665+0.22366) \approx 0.392$$

$$W_5 = 3.77992/(0.27758+0.96473+0.91946+4.63457+3.77992+1.03665+0.22366) \approx 0.319$$

$$W_6 = 1.03655/(0.27758+0.96473+0.91946+4.63457+3.77992+1.03665+0.22366) \approx 0.088$$

$$W_7 = 0.22366/(0.27758+0.96473+0.91946+4.63457+3.77992+1.03665+0.22366) \approx 0.019$$

c) Calculate $\lambda_{\max}$

$$[OR][W] = \begin{bmatrix} 1 & 0.2 & 0.2 & 0.11 & 0.14 & 0.2 & 1 \\ 5 & 1 & 1 & 0.11 & 0.2 & 1 & 7 \\ 5 & 1 & 1 & 0.11 & 0.14 & 1 & 7 \\ 9 & 9 & 9 & 1 & 1 & 7 & 9 \\ 7 & 5 & 7 & 1 & 1 & 5 & 9 \\ 5 & 1 & 1 & 0.14 & 0.2 & 1 & 9 \\ 1 & 0.14 & 0.14 & 0.11 & 0.11 & 0.11 & 1 \end{bmatrix} \begin{bmatrix} 0.023 \\ 0.082 \\ 0.078 \\ 0.392 \\ 0.319 \\ 0.088 \\ 0.019 \end{bmatrix} = \begin{bmatrix} 0.18 \\ 0.60 \\ 0.59 \\ 3.15 \\ 2.44 \\ 0.65 \\ 0.15 \end{bmatrix}$$

$$\lambda_{\max} = 53.971/7 = 7.710142857$$

4.4. Check the Consistency of the Judgment Matrix at the Middle Level

$$\mathrm{CI} = (\lambda_{\max} - n)/(n-1)$$

The maximum characteristic root of n-order matrix A is $\geq n$, when $= n$, A is a consistent matrix. When CI = 0, matrix A is completely consistent. The closer the CI is to 0, the stronger the consistency of matrix A.

According to the average random consistency index value Table 5, check the average consistency index RI, and calculate CI/RI. When CI/RI<0.1, it can be considered that the consistency of the judgment matrix is satisfied, otherwise the judgment matrix needs to be rebuilt.

4.5. Underlying Risk Judgment and Consistency Test

The calculation method of the bottom layer risk weight is the same as that of the middle layer, and the importance of the risk factors of the bottom layer risk with respect to the weight of the middle layer needs to be calculated layer by layer. Multiply the weights of each layer of the bottom layer risk by the relative weight of the middle layer one by one, or assign it according to the actual situation, to get the total ranking of risk levels. And use the same method as 3.4 to check the consistency of the underlying risk. If the consistency check of the underlying risk meets the requirements, the obtained indicator weight is the final weight of the indicator.The policy judgment matrix of the underlying risk is shown in Table 6, and the judgment matrix of economy, management, law, and natural environment is the same as Table 6. The examples are not listed here. The judgment matrices of construction and design are shown in Table 7 and Table 8. The calculation results are shown in Table 9 and Table 10.

Table 5. Average random consistency index RI.

1	2	3	4	5	6	7	8	9
0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

CI = 0.118357142, RI = 1.32, CR = 0.089664502 < 0.1 Meet the consistency test.

Table 6. Policy risk judgment matrix.

index	R11	R12
R11	1	1
R12		1

Table 7. Design risk judgment matrix.

index	R31	R32
R31	1	7
R32		1

Table 8. Construction risk judgment matrix.

index	R41	R42	R43
R41	1	5	1
R42		1	1/5
R43			1

5. Risk Response

5.1. Construction Risk Response

According to Table 9 and Table 10, construction risks are the top priority during the entire construction period, and construction risks need to be strictly controlled. According to the type of risk response, it is divided into four categories, including risk reduction, risk transfer, risk retention, and risk prevention. It is embodied in the construction process that risk mitigation takes active risk treatment measures to reduce the possibility of loss or reduce the severity of loss before risk loss occurs. Such as detailed examination and demonstration, selection of personnel to participate in inspections, meticulous installation, scientific debugging, etc. to reduce uncertainty. Risk transfer is mainly embodied in subcontracting

Table 9. Risk ranking of the middle layer of Hangzhou bay bridge.

Middle-level risk	Intermediate weight	Sort
Policy risk R1	0.023	6
Economic risk R2	0.082	4
Design risk R3	0.078	5
Construction risk R4	0.392	1
Manage risk R5	0.319	2
Contract risk R6	0.088	3
Environmental risk R7	0.019	7

Table 10. Risk ranking of the bottom layer of Hangzhou bay bridge.

Underlying risk	Bottom weight	Sort
Risk of imperfect policy R11	0.011500	7
Policy change risk R12	0.011500	7
Loan risk R21	0.041000	5
Market risk R22	0.041000	5
Unqualified design quality R31	0.068250	3
Design approval risk R32	0.009750	8
Construction quality risk R41	0.173860	1
Construction period risk R42	0.035672	6
Construction safety risk R43	0.173860	1
Limited managerial capacity R51	0.159500	2
Benefit coordination R52	0.159500	2
Contract risk R61	0.044000	4
Risk of claims and disputes R62	0.044000	4
Geographical environment risk R71	0.009500	9
Natural environment risk R72	0.009500	9

the construction contract and transferring the risk to the subcontractor. The risk is retained because the construction party has contracted the entire project and assumes legal responsibility for the entire project. Risk prevention is mainly embodied in the protective measures of the construction site before construction. For example, on-site protective measures such as fences and construction warning tapes are set up at the construction site to prevent casualties and cause economic and legal disputes.

5.2. Manage Risk Response

The management risk is less important than the construction risk. Therefore, the control of the management risk is also quite important. The main reasons for the management risk include the limited ability of the management personnel and the coordination of the parties. The main method to solve the management risk Have established a reasonable and complete organization and management structure, establish a scientific and effective management system, designate a dedicated person to communicate with all parties in a timely and effective manner, transmit opinions from all parties in a timely manner, actively seek solutions, and coordinate effectively through a scientific organizational structure Interests of all parties. Meetings are held periodically, and people with experience or ability are selected to preside over the meeting, so that everyone is highly unified in thought, and experts are invited to come to guide and solve related professional problems.

5.3. Contract Risk Response

Contract risk is second only to management risk. The reduction of contract risk is mainly through signing project subcontracts with subcontractors to transfer risks to each subcontractor. Thereby reducing the risk pressure of the construction party.

5.4. Response to Economic Risks

Economic risks are mainly reflected in loan risks and market risks. The Hangzhou Bay Bridge construction cycle is as long as 4 years. During these 4 years, the interest rate has changed many times. Although the loan interest rate has shown a trend of rising many times, if bond financing from external sources is used And equity financing has higher interest rates, which is undesirable, while financial leasing can only solve the problem of the use of machinery and equipment, but cannot fundamentally solve the problem of funds. In summary, only through bank financing can solve the problem of funds. problem.

5.5. Design Risk Response

The design company can transfer part of the design risk to the engineering insurance company by purchasing engineering insurance. In order to have a high degree of public acceptance of the design, it should consult the public through interviews, questionnaire surveys, etc. in advance, and design as much as possible. A bridge that is highly accepted by the public meets traffic requirements.

5.6. Policy Risk Response

This type of risk does not change with the subjective wishes of the contractor and the owner. Although this type of risk has great uncertainty, all parties involved in the construction of the project can pay close attention to changes in domestic and foreign policies and make them as early as possible. Corresponding preparations are made to actively respond to the occurrence of such risks.

5.7. Environmental Risk Response

Like policy risks, this type of risk does not transfer with the transfer of people's will, and the degree of uncontrollable changes is higher than policy risks.

6. Conclusions

Because bridge construction projects have the characteristics of large investment and long construction period, they often face a variety of unforeseen risks, so it is of great significance to conduct risk research on them. At present, the risk assessment of construction projects mainly adopts qualitative methods, and it is difficult to quantify the risks of construction projects. The analytic hierarchy process is a research method that combines qualitative and quantitative research. It ranks the risks that cannot be quantified. People provide a basis for scientific decision-making.

1) Based on actual engineering cases, it is verified that the analytic hierarchy process can be applied to the analysis and evaluation of uncertain risks in the construction of cross-sea bridge projects, which can be used as a reference for risk management in the life cycle of similar construction projects.

2) Using a combination of expert investigation and scoring method and analytic hierarchy process, it can better carry out qualitative and quantitative analysis of construction project risks. The established risk evaluation system is scientific and effective, and can provide decision-makers with accurate decision-making information and facilitate decision-making. Employers conduct reasonable adjustments during the life cycle of the construction project to avoid the risk of serious losses to the project during the construction process.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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