Risk estimation of large complex bridge construction based on factor analysis

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Abstract: This paper investigates and analyzes the risk factors of large-scale complex bridge construction through questionnaire survey and Delphi method, and obtains the risk factors and basic data that affect the construction of large complex bridges. On this basis, according to the principle of factor analysis, using SPSS V21.0 software to statistically analyze the basic data, the main factors affecting the construction risk of large complex bridges and their importance index are obtained, which provide a basis for the development of control decisions. The application of the example shows that the method given in this paper is simple in operation and the result is clear. According to the size of the factor importance index, measures can be taken to deal with major risks to ensure the smooth construction of the bridge.

1. Introduction
Bridges are buildings that span mountains, rivers and lakes. They can break the barriers of natural conditions, promote economic development, and bring great convenience to people's travel. However, there are a lot of safety risks in the construction and service period of the bridge. Zheng Yuanxun calculated the frequency of bridge accidents in the past 15 years and pointed out that with the rapid development of bridge construction, the frequency of bridge accidents generally shows an upward trend. Zhao Shaogje conducted statistics on bridge collapse accidents in China in the past 20 years. Among the 151 accident samples, the number of collapses during the construction period reached 50. Liu Xiila pointed out that the risk of the construction structure during the construction period is much higher than the service period. During the construction process, the characteristics of the bridge are different according to the different construction methods. Due to the temporary support of the stressed members during the construction period, the internal force distribution of the bridge structure is uneven, combined with the influence of the natural environment and human uncertainty, the construction process. Project risk is difficult to control. Gong Chunling summarized the risk factors of bridge construction period, including internal factors, external factors and human factors. Internal factors mainly include internal function, material properties, geometric parameters. External factors include natural climate, external load. Human factors mainly include management, design, construction, modeling, statistics. When several risk factors cross each other, the risk probability will increase greatly. Zhang Jiel pointed out that the carrying capacity of long-span bridges is in a low
state during construction and construction. Any risk factors may cause unsafe accidents, and Access is used to establish a dynamic risk source census database. Zhou Yingjie[6] evaluated the safety risk of bridge construction period by establishing a grey correlation evaluation model, and evaluated the safety level of the risk source. Liu Yingfu[7] applied the fuzzy comprehensive evaluation model to evaluate the bridge based on the research of advanced risk management at home and abroad. Liu Qingchang[8] combined the ant colony algorithm with BP neural network and used the ant colony algorithm to optimize the BP neural network model to study the risk of bridge construction period. Cho T[9] applied the finite element method to establish the construction period management model, and quantitatively evaluated the safety risk of the bridge construction process by monitoring the force limit state of each node in real time. Peng K[10] applied a comprehensive hierarchical analysis method and cloud model to propose a cloud clustering group decision-making method. The main risk factors and risk losses were determined by expert scoring method, and the cloud generator was used to calculate the digital features of experts, thereby quantitative assessment of security risks. Sun Y[11] uses artificial neural network technology to quantitatively analyze the risk during bridge construction. The finite element analysis results are used as the neural network training sample data, and Monte Carlo simulation is used to calculate the structural damage probability of various dangerous sections during construction.

At present, the methods for evaluating the safety risks of long-span bridges are: analytic hierarchy process, fuzzy comprehensive evaluation method, Monte Carlo simulation method, grey entropy correlation method and BP neural network method. There are few studies on the safety risks of long-span bridge construction period, and the evaluation criteria have not been unified. These methods are based on the evaluation of all risk factors. Some factors in the bridge risk assessment have little impact on the bridge construction. It is necessary to select the key factors affecting the bridge construction for quantitative evaluation, discharge the interference of non-key indicators, and improve the accuracy of the safety risk assessment. In this paper, the factor analysis method is used to analyze the risk factors of long-span bridge construction period, and the high-dimensional matrix is reduced to a low-dimensional matrix by means of dimensionality reduction, and the key risk factors are selected. The main principle of factor analysis is to extract the comprehensive variables, while ensuring that the variables are not related. Each variable is represented by a common factor, and the common factor can reflect some information about the original variable.

2. Determination of major risk factors
Table 1. Safety factors of long-span bridge construction

| Serial number | Risk factor | Serial number | Risk factor |
|---------------|-------------|---------------|-------------|
| V1            | Project plan accuracy | V25          | Design and construction relationship |
| V2            | Site drainage     | V26          | New bridge design problem          |
| V3            | Water supply      | V27          | Accuracy of design data            |
| V4            | Apply new technologies, new materials and new methods | V28          | Effectiveness and legitimacy of the design content |
| V5            | Drowning, electric shock, heatstroke injury | V29          | Delays in design changes, modifications, and approvals |
| V6            | The construction process is not mature | V30          | Ice, snow, freezing and thawing, temperature difference |
| V7            | Fall injury       | V31          | Insufficient survey |
| V8            | Regulatory management is not in place | V32          | Construction regulations and approval procedures |
| V9            | Unreasonable construction plan | V33          | Legal norms do not last |
| V10           | Insufficient personal protection awareness | V34          | Landslide, water level increase |
| V11           | Mechanical collision, hitting damage | V35          | Personnel change problem |
| V12           | Construction personnel quality | V36          | Construction unit and supervision project do not cooperate |
| V13           | Climate factors such as fires and typhoons | V37          | Managerial quality |
| V14           | Geological factors such as earthquakes and floods | V38          | Special workers are not high technology |
| V15           | Mistakes in installation and commissioning of construction equipment | V39          | Improper handling of details |
| V16           | Construction machinery and power failure | V40          | Falling fall damage |
| V17           | equipment production capacity | V41          | Toxic gas leak damage |
| V18           | Construction equipment matching or qualification issues | V42          | Complex natural geological conditions |
| V19           | Team level is not high | V43          | Management method is not appropriate |
| V20           | Improper maintenance and repair of machinery | V44          | Job steps are not standardized |
| V21           | Quality and specifications of raw materials and finished products | V45          | Personnel mistakes |
| V22           | Insufficient safety training | V46          | Influence of site settlement on structures |
| V23           | Technical staff quality | V47          | Traffic accident injury |
| V24           | Design and construction of temporary facilities | V48          | Safety emergency measures are not perfect |

2.1. Principles for determining risk factors for large and complex bridge construction

In the construction process of long-span bridges, any structural members may have unstable factors. In order to avoid safety accidents during the construction of the bridge and ensure the reliability of the bridge structure, the safety risk factors for the whole process of large-scale complex bridges are constructed. Census and identify key risk factors based on comprehensiveness, scientificity, comparability and measurability.

(1) Comprehensiveness

Large-scale complex bridge construction process is cumbersome, construction period is long, and it
needs to undergo different environmental changes and structural force system transformation. There may be safety hazards in any step or stage of the whole construction process, and comprehensive risk survey and expert experience are adopted. Combined method, risk factors are identified throughout the construction process.

(2) Scientific

The determination of the risk factors of large and complex bridges mainly adopts the Delphi method. The Delphi method is also called the expert scoring method. It mainly collects the feedback from the experts in the industry and makes repeated feedback corrections, which finally forms a stable opinion. Generally, about 20 experts are selected, and each expert is required to be in contact with each other. Experts are required to score the problems investigated, and then the results of each expert are collated, and then feedback is returned. Experts are required to re-score and repeat the operation until reaching a unified opinion.

(3) Comparability

The comparability of risk factor identification of large complex bridge construction is an important feature of risk factor determination. There are certain differences among different risk factor identification methods. In this paper, the method of questionnaires combined with Delphi method can better identify the risk factors of large and complex bridge construction. Compared with other types of identification methods, this method has better ergodicity and can comprehensively identify risk factors.

(4) Testability

The measurability of risk factors means that the specific size of the risk is presented by means of numerical quantification to achieve the purpose of visualization, thereby reducing the blindness in the process of risk identification.

2.2. Method for determining risk factors of large complex bridge construction

From the natural environment in which the project is located (including the geology, hydrology, climate), the construction organization design and construction plan adopted, the organization and management level of the construction team and the technical level, social environment and human environment (coordination attitude of local government) The public's support for the project, folk customs, folk customs, the service level of the owners and the level of cooperation of the contractors, in-depth investigation and analysis of the whole process of bridge construction, establish a comprehensive census form of risk factors. However, in the actual construction process, not every risk factor will affect the safety of large and complex bridge construction. Some factors have weak disaster-causing ability and will not evolve into risk events. Some risk factors reflect the same risk event. Therefore, a large number of risk factors need to be identified and analyzed[12].

Using the Delphi method, experts can filter and assign risk factors according to the actual situation of the project, and quantify each risk factor index into specific values to judge the risk factors affecting the construction of large complex bridges. Finally, the risk factor questionnaire of experts is summarized[13], and the safety risk factors of large and complex bridge construction are obtained. In actual engineering, this factor can be increased or decreased according to the actual project.

3. Bridge construction risk assessment model based on factor analysis

3.1. Principle of factor analysis

Factor analysis is a statistical method that converts multiple variables with complex relationships into fewer unrelated factors by means of dimensionality reduction. There are \( p \) variables \( x_1, x_2, \ldots, x_p \).

First, the original variables are normalized so that the mean of each variable is 0, the standard deviation is 1, and the original variable is linearized with \( k(k<p) \) factors \( F_k \). Combination representation[14], That is as follows.
\[
\begin{align*}
  x_1 &= a_{11}F_1 + a_{12}F_2 + \ldots + a_{1k}F_k + \varepsilon_1 \\
  x_2 &= a_{21}F_1 + a_{22}F_2 + \ldots + a_{2k}F_k + \varepsilon_2 \\
  \vdots \\
  x_p &= a_{p1}F_1 + a_{p2}F_2 + \ldots + a_{pk}F_k + \varepsilon_p \\
  X &= A\mathbf{F} + \varepsilon
\end{align*}
\]

Among them, \(a_{ij}\) — factor load, reflect the degree of correlation between \(X_i\) and \(F_j\). \(\varepsilon\) is a special factor used to represent parts of the common factor that cannot be explained.

\(h_i^2\) is the commonality of variable \(X_i\), \(S_j\) is the factor variance contribution indicator, and the expression is as follows:

\[
\begin{align*}
  h_i^2 &= \sum_{j=1}^{k} a_{ij}^2 \\
  S_j &= \sum_{i=1}^{n} a_{ij}^2
\end{align*}
\]

### 3.2. Factor extraction and factor loading matrix solution

The factor load matrix solution is the focus of the factor analysis method. The solution method is the principal component analysis method. The principal component analysis is a method to transform the original variables \(x_1, x_2, \ldots, x_p\) into another set of unrelated variables \(y_1, y_2, \ldots, y_m\) by coordinate transformation, which is expressed as follows:

\[
\begin{align*}
  y_1 &= u_{11}x_1 + u_{12}x_2 + \ldots + u_{1k}x_k \\
  y_2 &= u_{21}x_1 + u_{22}x_2 + \ldots + u_{2k}x_k \\
  \vdots \\
  y_p &= u_{p1}x_1 + u_{p2}x_2 + \ldots + u_{pk}x_k
\end{align*}
\]

Among them, \(u_{1k}^2 + u_{2k}^2 + u_{3k}^2 + \ldots + u_{pk}^2 = 1\) \(\quad (k = 1, 2, 3, \ldots, p)\)

1) Data standardization processing

\[
X^*_j = \frac{x_j - \bar{x}_j}{s_j}
\]

\[
x_j = \frac{1}{n} \sum_{i=1}^{n} x_{ij}, \quad s_j = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_{ij} - \bar{x}_j)^2}, \quad i = 1, 2, 3, \ldots, n, \quad n \text{ is the number of sample points, } j = 1, 2, 3, \ldots, p, \quad p \text{ is the number of sample original variables.}
\]

2) Calculate the covariance matrix \(R\) of the normalized matrix \([X^*_j]_{n \times p}\).

3) Find the first \(m\) eigenvalues of \(R\), \(\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_m\), and the corresponding eigenvectors \(u_1, u_2, u_3, \ldots, u_m\), which are orthogonal.

Find the factor load matrix of \(m\) variable:
3.3. Application examples

For the large-span complex bridge of Zhongkai Expressway, factor analysis method is used to calculate the importance index of risk factors. The data is statistically processed by IBM SPSS Statistics V21.0 software, and the bridge construction risk is quantitatively evaluated in order.

3.3.1. Risk investigation and data compilation. Refer to Table 1 to establish a large-scale complex bridge construction risk checklist, and combine the Delphi method to screen and assign each risk factor. Among them, 25 questionnaires were issued, 15 valid questionnaires were retrieved, and 34 risk factors were sorted and classified. They could be divided into 6 types of factors. The valid data was sorted and input into IBM SPSS Statistics V21.0 software. The risk factors are analyzed[15], and the output results are shown in Table 2-3.

| Serial number | Risk factor                                      | Cronbach's alpha $\alpha$ | Releaseable variance ($\%$) | Significant level $p$ | KMO    |
|---------------|-------------------------------------------------|---------------------------|-----------------------------|-----------------------|--------|
| F1            | Personnel safety risk factor                    | 0.747                     | 73.297                      | 0.01                  | 0.669  |
|               | Construction machinery safety factor            | 0.761                     | 52.666                      | 0.01                  | 0.707  |
| F3            | External environmental risk factors             | 0.800                     | 63.171                      | 0.01                  | 0.544  |
| F4            | Improper risk factors                           | 0.772                     | 68.240                      | 0.04                  | 0.632  |
| F5            | Construction technology influencing factors     | 0.804                     | 74.148                      | 0.00                  | 0.661  |
| F6            | Construction process management factors         | 0.894                     | 70.623                      | 0.00                  | 0.690  |

3.3.2. Data Analysis Process. (1) Applicability test

The main purpose of factor analysis is to extract representative factors from a large number of risk factors. In order to verify the applicability of the factor analysis method, the factor correlation test should be carried out first. The commonly used methods are KMO measure and Bartlett's spheroid test. The KMO measure value is required to be greater than 0.5 and the P value level is less than 0.05. After testing, the KMO value is 0.651>0.5, and the significance level $p$ value is 0.01<0.05, which meets the requirements. It is suitable to evaluate the safety risk of large complex bridge construction by factor analysis.
Table 3. Correlation coefficient value and releaseable variance ratio of main construction risk factors for long-span bridges

| Serial number | Risk factor | Important index | Risk factors (impacting factor) | Risk level | Project factor load | Project correlation coefficient | Releaseable variance ratio (%) | Cumulative percentage (%) |
|---------------|-------------|-----------------|---------------------------------|------------|--------------------|--------------------------------|---------------------------------|--------------------------|
| F1            | Personnel safety risk factor | 60.92           | Fall, fall injury, Mechanical collision, hitting damage | 5          | 0.900              | 0.955                          | 0.864                          | 15.909                  | 15.909                   |
|               |             |                 | Falling fall damage, Drowning, electric shock, heatstroke | 4          | 0.864              | 0.857                          |                                |                          |                          |
|               |             |                 | To highest, Traffic accident injury | 5          | 0.669              | 0.678                          | 0.916                          | 0.797                   | 0.572                    |
|               |             |                 | Improper maintenance and repair of machinery | 2          | 0.572              | 0.470                          |                                |                          |                          |
|               |             |                 | Construction machinery and power failure | 1          | 0.728              | 0.927                          |                                |                          |                          |
|               |             |                 | Insufficient production capacity | 2          | 0.727              | 0.784                          |                                |                          |                          |
| F2            | Construction machinery safety factor | 57.77           | Improper maintenance and repair of machinery | 3          | 0.648              | 0.768                          |                                |                          |                          |
|               |             |                 | Construction machinery and power failure | 5          | 0.747              | 0.702                          |                                |                          |                          |
|               |             |                 | Building materials quality problem | 3          | 0.619              | 0.888                          |                                |                          |                          |
|               |             |                 | Ice, snow, freezing and thawing, temperature difference | 4          | 0.525              | 0.754                          |                                |                          |                          |
| F3            | External environmental risk factors | 68.26           | Landslide, water level increase | 4          | 0.686              | 0.663                          | 0.816                          | 0.912                   | 12.756                  | 42.175                   |
|               |             |                 | Typhoon, heavy rain, fire impact | 5          | 0.912              | 0.893                          | 0.593                          | 0.736                   | 0.878                    |
|               |             |                 | Earthquake, tsunami, flood impact | 4          | 0.857              | 0.589                          |                                |                          |                          |
|               |             |                 | The quality of construction workers is not high | 3          | 0.773              | 0.867                          |                                |                          |                          |
|               |             |                 | Insufficient personal protection awareness | 3          | 0.914              | 0.862                          |                                |                          |                          |
| F4            | Improper risk factors | 69.05           | Team level is not high | 4          | 0.716              | 0.874                          | 0.538                          | 0.878                   | 11.659                  | 53.834                   |
|               |             |                 | Personnel mistakes | 5          | 0.538              | 0.545                          |                                |                          |                          |
|               |             |                 | Job steps are not standardized | 1          | 0.643              | 0.859                          |                                |                          |                          |
|               |             |                 | Improper handling of details | 4          | 0.728              | 0.655                          |                                |                          |                          |
|               |             |                 | Special workers are not high technology | 4          | 0.788              | 0.784                          |                                |                          |                          |
|               |             |                 | Insufficient survey, New technologies, new materials, new method applications | 2          | 0.86               | 0.862                          |                                |                          |                          |
|               |             |                 | Inadequate reliability of temporary facilities | 5          | 0.883              | 0.839                          |                                |                          |                          |
| F5            | Construction technology influencing factors | 54.76           | Inadequate reliability of temporary facilities | 3          | 0.846              | 0.910                          |                                |                          |                          |
|               |             |                 | Construction technology and process are not mature | 2          | 0.572              | 0.478                          |                                |                          |                          |
|               |             |                 | Unreasonable construction plan, Accuracy of construction materials | 3          | 0.538              | 0.487                          |                                |                          |                          |
|               |             |                 | Unreasonable construction plan, Accuracy of construction materials | 1          | 0.644              | 0.824                          |                                |                          |                          |
| F6            | Construction process management factors | 51.70           | Managerial quality is not high | 1          | 0.915              | 0.932                          | 0.604                          | 0.868                   | 11.110                  | 76.479                   |
|               |             |                 | Regulatory management is not in place | 2          | 0.604              | 0.682                          |                                |                          |                          |
|               |             |                 | Management method is not appropriate | 5          | 0.878              | 0.868                          |                                |                          |                          |
|               |             |                 | Insufficient safety training | 3          | 0.736              | 0.707                          |                                |                          |                          |
|               |             |                 | Safety emergency measures are not perfect | 4          | 0.878              | 0.841                          |                                |                          |                          |
(2) Factor extraction

The factor load matrix reflects the correlation between variables and factors, and the variables are extracted by the eigenvalue method. When the eigenvalues of the variables are greater than 1, the variables are retained, and finally the number of specific factors can be obtained. If the absolute value of the factor load $a_{ij}$ is larger in several rows of the $j$th column, it indicates that the factor can explain many variables at the same time, and only a small amount of information can be explained for each variable. This factor is not representative. The maximum variance rotation method is used to rotate the factor load matrix, thereby changing the representative characteristics of the factors, allowing the factor to represent as few variables as possible and having a higher load.

(3) Consistency analysis

Cronbach's Alpha coefficient $\alpha$ is an index to measure the consistency of internal risk factors. Its size reflects the degree to which variables are affected by random errors. Testing $\alpha$ can ensure the reliability of risk factor values. $\alpha$ should not be lower than 0.7. The greater the value, the more reliable the test value [16]. Among them, the Colognebach reliability coefficient $\alpha$ of the six main risk factors meets the requirements.

(4) Construct validity

The construct validity reflects the accuracy of the method. Among the six risk factors, the minimum variance is 0.53 and the maximum is 0.74. The KMO test is used to judge the adaptability of each single factor sample. The criterion of the aggregate validity is that the explanatory power of the measurement item exceeds the error variance. This paper uses the item to represent the total item correlation coefficient, and the variable item-to-total item correlation coefficient value is greater than 0.4.

(5) Risk factor importance ranking

The importance index $A$ of each risk factor is obtained by summing the weighted averages of the risk factors included in each factor and then dividing by the number of scores. Sorting the importance of risk factors can clearly identify the probability of each factor occurring.

$$A = \frac{\sum aX \times 100}{5}$$

$$X = \frac{n}{N}$$

Where $A$ is the risk importance index; $a$ is the important level of the variable; $n$ is the number of the same level in the survey results; $N$ is the total number of survey results.

3.3.3. Analysis of results. Through the factor analysis method, the risk factors of the bridge construction process are calculated and analyzed, and the six main risk factors are sorted according to the importance, the probability of the risk occurrence is visually judged, and the risk factor variable is controlled to reduce the occurrence of the risk event probability.

Among them, the improper operation of the personnel during the construction process has the most serious impact on the safety risk of bridge construction. The risk importance index is as high as 69.05. The construction operation is a key part of transforming the design drawings into reality. The improper construction work directly affects the quality and durability of the bridge. Sexuality, burying safety hazards for the use of bridges. Therefore, during the construction period of bridges, coordination and communication between various construction departments should be promoted, and the technical work of personnel should be done before entering the field. The construction of key parts and nodes should be strictly in accordance with the operating procedures. Through the process control, the safety risk during the construction period is reduced and the expected effect is achieved. The Zhongkai Expressway is located in Guangdong Province and is greatly affected by the natural environment such as typhoon and flood. The external environmental risk importance index is as high as 68.26, which can be observed and simulated through many years of typhoon data. This method can avoid the construction of typhoon peak period and reduce the impact of typhoon on bridge safety construction. Through statistical analysis of local rainfall data, the protection and reinforcement work should be
done before the flood season to ensure the safety of bridge structure. The importance index of the other four risk factors are: personnel safety risk factor 60.92, construction machinery safety factor 57.77, construction technology influencing factor 54.76, construction process management factor 51.70, which also have certain impact on bridge construction period safety risk. According to the size of the influencing factors, the key nodes and parts of the personnel can be reasonably controlled, the blindness of risks can be reduced, the cost can be saved, and the possibility of accidents can be reduced.

4. Conclusion
(1) For the safety problems existing in the construction of large and complex bridges, the main influencing factors are determined through questionnaires and expert scoring methods, and the basic theory of factor analysis is used to analyze the safety risks and quantify the probability of occurrence of risk indicators.
(2) Statistical analysis of basic data by SPSS V21.0 software, calculating the importance scores of six main factors, and sorting by size, and proposing corresponding countermeasure strategies for different safety importance indexes. The operation is particularly important for the safety risk of bridge construction, and the construction personnel's operation steps are controlled.
(3) The risk factor analysis method is used to identify the risk factors in a large complex bridge construction process and determine its priority, so as to control the large-scale complex construction risks in a targeted manner, and verify the applicability of the factor analysis method in the risk assessment of large complex bridges. This method provides a basis for bridge construction safety control.

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