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Application of Risk Assessment Methods in the Construction Phase of Large-Span Bridges

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Abstract. The construction of large-span bridges represents the technological level of bridge construction in a country, and plays a positive role in the country's economic development and technological advancement. However, there are many problems in the construction of large-span bridges, such as wind vibration during the construction phase, management of personnel, equipment, and materials, and environmental impacts during the construction period. Applying risk assessment methods to the construction phase of large-span bridges can effectively solve these problems, and risk assessment provides scientific basis for bridge design optimization, construction decision-making, and operation and maintenance management, improving the safety and durability of large-span bridges, and has important theoretical value and practical significance for ensuring the sustainable development of bridge engineering. This article analyzes the application of three cutting-edge risk assessment methods in the construction phase of large-span bridges through examples. The current risk assessment methods still have certain limitations, and this article explores and reflects on the future development direction of risk assessment systems.

Keywords: Risk assessment, Large-span bridges, Applied research, Analytic hierarchy process, Fuzzy comprehensive evaluation

1. Introduction

Bridges are the infrastructure of transportation and are closely related to economic and social development. China has always been a major bridge country, and with the development of the times, more and more large-span bridges have emerged. Large-span bridges, with their strong spanning capacity and elegant appearance, are playing an increasingly important role in the construction of transportation networks. From suspension bridges, cable-stayed bridges to arch bridges, the structural forms of large-span bridges are constantly innovating, the span records are continuously refreshed, and the construction technology is gradually developing towards complexity refinement. Due to technological limitations and other factors, there are risks in personnel, management, materials, environment, and other aspects in the construction of large-span bridges. BP neural network analysis method, analytic hierarchy process, fuzzy comprehensive evaluation method and other risk assessment methods have played an indispensable role in the construction phase of large-span bridges as excellent means of prediction and evaluation. During the construction period, after identifying risks, using these three methods can determine the weights of various risk factors,

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provide data and information for organizations or individuals, help them make more reasonable and scientific decisions, and also assist enterprise or project managers in better utilizing resources to increase decision quality. This paper combines practical engineering cases to carry out in-depth research on the application of risk assessment methods in the construction stage of large-span bridges. By sorting the risk characteristics of the construction stage of large-span bridges and analyzing the advantages and disadvantages of the existing assessment methods, the aim is to help the construction of large-span bridges China to develop more safely and efficiently.

2. Problems in the construction phase of large-span bridges

There are high requirements for the wind resistance of the bridge body during the construction process of large-span bridges. In the construction of bridge main beams, the main wind vibration problems include flutter and vibration. Flutter, a highly threatening self-excited divergent vibration, is more likely to occur on long-span suspension bridges. Shaking is a forced vibration triggered by atmospheric turbulence components. Although its amplitude is limited, its frequency of occurrence is high, which can cause fatigue accumulation in the structure and have adverse effects on comfort and safety performance. Flutter is generally considered the main factor causing structural insecurity, and due to the presence of some construction equipment on the main beam, the vibration of the main beam should also be taken into account and prevented [1]. There are also other problems in the construction of large-span bridges, such as the easy occurrence of equipment, materials, and personnel falling from heights; welding and other electrical construction at some nodes may cause electric shock; inadequate safety monitoring and prevention, inadequate implementation of personnel operation skills and training, etc.

3. Overview of risk assessment methods

3.1. Analysis of BP neural network

Backpropagation (BP) network is a multi-layer feedforward network composed of an input layer, a hidden layer, and an output layer. Its composition structure diagram (can be seen in Fig.1) is based on the neural topology structure (can be seen in Fig. 2). The input from the left dendrite and the output from the right axon are essentially functions of the input vector x to the output vector y [2]. It comprehensively overcomes the challenge of learning the weights of implicit units in multi-layer architectures. It is mainly used for pattern recognition and classification, function approximation fitting, and data compression.

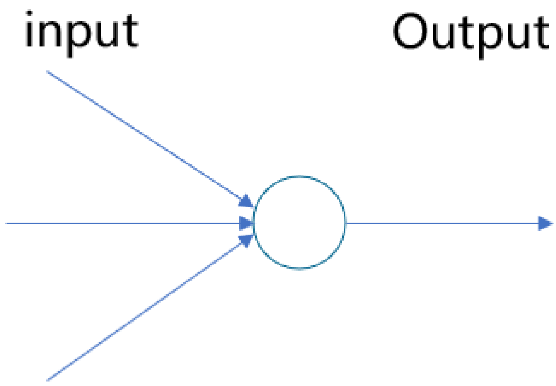

Figure 1. Schematic diagram of neuron topology (picture credit: original)

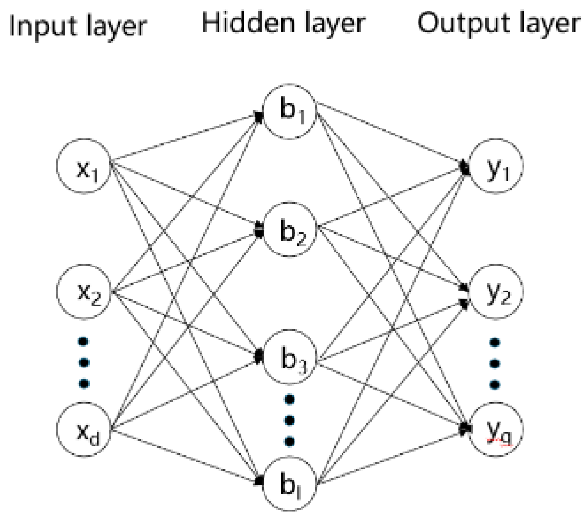

Figure 2. Schematic diagram of BP neural network structure (picture credit: original)

Case: The Pangzi Bridge in the G580 and Kang Highway projects is located on the border of Hotan, Xinjiang. The main bridge adopts a 100m+100m prestressed concrete continuous rigid frame bridge layout. The maximum cantilever extension is 93 meters, and the bridge deck width is 9 meters. The safety indicators for bridge risk assessment were analyzed from four aspects: personnel concrete strength factors, equipment materials, inaccurate management monitoring data, environmental canyon wind, sunlight, and earthquakes, including formwork, bracket assembly, construction lateral load, and pier verticality. The corresponding risk level values are shown in Table 1.

Table 1. Hazard levels corresponding to risk values [3]

Risk value	Hazard level and response measures
0~0.2	Negligible, extremely low risk
0.2~0.4	Low risk, within an acceptable range
0.4~0.6	Moderate risk, requiring attention
0.6~0.8	High risk, certain measures need to be taken
0.8~1	High risk, unacceptable

Calculate the comprehensive weight vector, input the collected data as the training set into the neural network for simulation and learning, and set sufficient iterations and training times. After meeting the error requirements, substitute the sample for testing. After detecting that the fitting meets the requirements, the comprehensive weight vector of the risk assessment indicators is input into the above network, and the risk value is 0.348 [3]. According to the table, the risk of this project is relatively low.

From the case, it can be seen that by using the detected data as the training set and inputting it into the BP neural network structure, the network can be trained to meet the usage requirements. The BP neural network algorithm itself will provide feedback and optimize it. This error backtracking optimization mechanism greatly reduces the occurrence of errors and makes the results more accurate. However, this method also has some key drawbacks: it is prone to getting stuck in the

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dilemma of local optima, has low training efficiency, and the design of the network architecture largely relies on the designer's experience.

3.2. Analytic Hierarchy Process

Facing the Analytic Hierarchy Process (AHP), complex problems are decomposed into many related factors, and a hierarchical structure is constructed based on their relationships. They are compared pairwise to determine the order of their importance. The Analytic Hierarchy Process is mainly divided into three steps. Firstly, a hierarchical model can be established, or factors and objects can be considered and plotted as a structural diagram, tree diagram, or table based on the evaluation objectives. Secondly, compare all factors in pairs and construct a judgment matrix. The element aij that constitutes the judgment matrix represented by formula (1) is the degree of importance of i relative to j. The scaling method for determining the matrix elements *aij* is shown in Table 2.

$$a_{ij} = \frac{the\ importance\ of\ i}{the\ importance\ of j} \tag{1}$$

Table 2. Scaling method for determining matrix elements a_{ij} [4]

scale	meanings
1	The i-th factor has the same impact as the j-th factor
3	The i-th factor has a stronger impact than the j-th factor
5	The i-th factor has a stronger impact than the j-th factor
7	The i-th factor has a significantly stronger impact than the j-th factor
9	The i-th factor has an extremely strong impact compared to the j-th factor
2,4,6,8	Intermediate value for judging adjacent two elements

Next, the consistency test of the judgment matrix is performed using formulas (2) and (3) to calculate the weight vectors for single rank and total rank. The total rank consistency ratio and logical consistency are used for testing. If CR<0.1, a decision can be made; otherwise the judgment matrix needs to be reconstructed [5].

$$CR = \frac{CI}{RI} = \frac{a_1CI_1+a_2CI_2+\cdots+a_nCI_n}{a_1RI_1+a_2RI_2+\cdots+a_nRI_n} \tag{2}$$

$$CI = \frac{\lambda\max-n}{n-1} \tag{3}$$

As an example, the Liugou precast box girder bridge in the section from Youyu to Pinglu on the Xizhong Expressway stands in a rugged and varied terrain. The entire bridge of this project stretches for 260 meters, and its structural layout includes 11 piers and abutments. The construction route of the project passes through farmland and villages along the way, with undulating natural terrain. This transportation bottleneck poses a certain degree of challenge to the transportation of materials required for construction. In order to verify whether the expert scoring has logical consistency, according to formulas (2) and (3), the maximum eigenvalue λ max calculated is 4.1, and the consistency index C.I. is 0.0333. The consistency ratio is much smaller than 0.1, so the result is valid [6]. Analyze the safety indicators of bridge construction from the aspects of personnel, materials, equipment, and environment. The personnel aspect includes safety awareness, personnel

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skill assessment pass rate, on-site training frequency and operator experience. The equipment and material aspect includes equipment failure rate material qualification rate and equipment maintenance and upkeep status. The manage aspect includes the completeness of emergency plans implementation rate of safety management system supervision and inspection mechanism. The environment aspect includes weather conditions geological data and construction environment.

Table 3. Weight and score of risk assessment indicators [6]

Evaluation	Weight	rating	weight × rating
Environmental risk	0.41	60	24.6
Equipment and material risks	0.25	85	21.25
Manage risk	0.22	75	16.5
Personnel risk	0.12	70	8.4

The weights and scores of risk assessment indicators are shown in Table 3. According to the comparison of weight multiplied by score, it can be concluded that environmental risk has the greatest impact on this project, while personnel risk has the relatively smallest impact. The analytic hierarchy process can be used to draw a conclusion that the project needs to focus on the environment, monitor the wind speed and temperature in real time, stop working at heights in case of strong wind above level 6 or rainstorm, and take reinforcement measures for weak foundation to prevent uneven settlement. Select specialized machinery for equipment and materials to ensure performance meets load requirements. Daily inspection of key equipment, preparation of backup generators, pump trucks and other emergency equipment to prevent sudden power outages or mechanical failures. Strictly inspect materials such as steel, concrete, and prestressed reinforcement, and retain quality assurance certificates and reinspection reports.

The advantages of Analytic Hierarchy Process are reflected in its systematicity and practicality. In terms of systematicity, it regards the overall bridge system as the object and follows a logical thinking path of decomposition, comparison, evaluation, and synthesis to formulate decisions. After mechanism analysis and statistical analysis, it has become an important emerging tool in the field of system analysis. In terms of practicality, it cleverly integrates qualitative and quantitative analysis, which can address many practical problems that traditional optimization techniques find difficult to tackle, and has a wide range of applications. Simplicity: The calculation process is convenient, the results are clear and concise, and decision-makers can quickly get started and proficiently apply them. The Analytic Hierarchy Process also has certain limitations: firstly, it is limited by established options and can only select the best one, making it difficult to conceive more outstanding new solutions; Secondly, the comparison, evaluation, and result calculation in the method are relatively rough, which makes it inadequate for problems that require high precision. From a subjective perspective, from building a hierarchical architecture model to proposing an evaluation matrix, human subjective judgment plays a crucial role in this process, and the weight allocation for each level of elements is based on subjective judgment, which may weaken the universal applicability of the conclusions in specific contexts [7].

3.3. Fuzzy comprehensive evaluation method

The comprehensive evaluation is a comprehensive consideration process which focuses on the evaluation of objects facing various different factors in practical application. These factors are often difficult to by unified quantitative standards and may have different and significant effects on the

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evaluation goal. In traditional analytic hierarchy process framework, the pairwise comparison matrix used to determine the weight itself has inherent uncertainty. To solve this problem, many domestic and foreign scholars have proposed suggestions, in the method of introducing fuzzy set theory has been widely concerned. This improved method is called fuzzy analytic hierarchy process. Moreover, someone proposed that fuzzy logic reasoning can be used to evaluate the status of bridges [8, 9]. The risk value of fuzzy comprehensive evaluation is shown in formula 4 [3].

$$B = \omega \cdot \overrightarrow{S} \tag{4}$$

In this formula B ——Normalized evaluation result vector

ω ——Weight vector of evaluation results

S——Evaluation indicator relationship matrix

The steps of the fuzzy comprehensive evaluation method mainly include establishing an indicator set and a decision set, where the elements are the risk factors of bridge construction, the safety level of each risk, and then listing the fuzzy comprehensive evaluation matrix. Finally, the established model is comprehensively evaluated.

Case: The Pinglu Canal Grand Bridge has a total length of 938 meters and a main bridge span of 200 meters. It was built on the Dapu Expressway to cross the Pinglu Canal. Select the safety evaluation indicators for the Pinglu Canal Grand Bridge and establish a set of indicators for human, material, environmental, management, and technical factors [10]. Adopting a questionnaire survey to evaluate the importance of on-site construction safety risks, and then establishing an evaluation set, bridge construction safety is divided into five levels: safe (S1), relatively safe (S2), generally safe (S3), unsafe (S4), and very unsafe (S5). Establish a matrix based on the survey results, calculate the comprehensive weights and membership degrees of all indicators, and then evaluate the current status of bridge construction according to the principle of maximum membership degree. The results are shown in Table 4 [11].

Table 4. Calculation results of maximum membership degree for each state [11]

Factor	human	objects	Environment	Management	Technology
Maximum membership degree value	0.3	0.26	0.26	0.29	0.33
Condition	S3	S2	S2	S3	S2

From this, it can be seen that the safety level of personnel and management factors in this project is average and needs to be strengthened, while the safety level of the other three factors is relatively good. By strengthening personnel safety training and conducting hazard rehearsals. Conduct training and assessment, and improve through a combination of program and supervision.

The fuzzy comprehensive evaluation method has the advantages of clear results and systematic organization, and is good at dealing with problems with fuzzy boundaries and difficult quantification, quantifying qualitative problems. For example, compared to the traditional method of evaluating the quality of bridge construction using personnel experience, the fuzzy comprehensive evaluation method quantifies fuzzy factors by establishing membership functions, thereby making appropriate decisions in uncertain environments. It can also optimize various bridge construction plans with uncertain factors, accurately display the actual situation and the advantages and disadvantages of each plan, and is a powerful assistant for dealing with various uncertain problems. The drawback is that the calculation process of this method is quite cumbersome, and subjective

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judgments have a significant impact on determining the weight vectors of various indicators of the bridge. In severe cases, it can even lead to evaluation failure [12].

4. Conclusion

This article introduces three commonly used risk assessment methods during the construction phase of large-span bridges and compares their advantages and disadvantages. The BP neural network analysis method has the advantage of self feedback optimization error, reducing the subjective judgment of traditional methods; The Analytic Hierarchy Process is more concise and practical, making it easier for decision-makers to learn and use; The fuzzy comprehensive evaluation method is good at dealing with problems that are difficult to quantify and fuzzy. All three have parts that require manual analysis and decision-making in the process, and need to be combined with other methods such as AHP, which cannot completely eliminate the errors of subjective judgment. In the future, it may be possible to further explore the potential of machine learning algorithms, combine interdisciplinary methods, and optimize existing risk assessment systems through multi-method testing to make them standardized processes and reduce human judgment errors and subjective influences.

Currently, there is extensive research on bridge health monitoring and condition assessment methods both domestically and internationally. However, in practical bridge applications, the mainstream is still a single monitoring or management system. Most current monitoring systems can only collect massive amounts of data, but are unable to effectively process and analyze it in depth, and it is difficult to establish warning mechanisms. The risk assessment method for large-span bridges can achieve early warning by introducing new technologies such as drones and non-destructive testing equipment, and using artificial intelligence for monitoring.

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