Study on Risk Assessment of Bridge Construction Based on AHP-GST Method

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Abstract. AHP-GST method for bridge risk assessment is proposed. The expert scoring method is used to get the risk assessment data sample, and the analytic hierarchy process (AHP) is combined with the grey system theory. The risk possibility is calculated by analytic hierarchy process, and the weight matrix of each risk objective layer is obtained. The grey system theory is used to judge the severity of the risk, and the whitening value weight matrix of each index is obtained. Five kinds of risk weights are calculated and the engineering risk grade is determined according to the principle of maximum membership. Taking Jiangshun Bridge as an example, the AHP-GST method is used to evaluate the risk of the bridge's substructure in construction stage. The result of risk assessment is consistent with that obtained by the current guidance method, which shows that the method is reasonable and can be applied to the risk assessment of bridge construction.

1. Introduction
There are many foreseeable and unpredictable risks in the construction stage of the bridge, so it belongs to high risk industry[1]. At present, many experts at home and abroad have carried out the analysis to the bridge construction risk. There are many vivid examples in the actual engineering, some experiences and achievements have been obtained consequently. The commonly used methods are Analytic hierarchy process (AHP) and Grey system Theory (GST). The AHP method takes the research object as a system, assigns the value according to the actual situation, and then uses the decomposition method, comparative judgment method and comprehensive thinking mode for data decision-making [2]. In each level, the influence degree of each factor on the result is quantitative and very clear, so the AHP method becomes a further important tool for the system analysis which is developed after the analysis of the mechanism and the statistical analysis[3]. The grey system theory (GST method) has been applied in many fields since it was put forward by professor Deng Julong[4] in 1982. The GST method is a method to study the internal structure and parameters of object thing. It is considered that these variables change within a certain range, even if there is uncertainty in these random variables. But after certain technical treatment, the regularity could be found[5][6].

For the quantitative research of risk grade evaluation for bridge in construction stage, AHP and grey system theory are very practical and effective. However, the single research method cannot comprehensively consider the situation of multiple factors acting together, so the accuracy is poor. In
order to improve the objectivity, scientificity and effectiveness of the construction stage, taking Jiangshun bridge across Xijiang River in Guangdong Province as an example, the expert scoring method is used to get the scoring value, the analytic hierarchy process (AHP) and the grey theory method are used to analyze and calculate the scoring value, and the MATLAB mathematical software is used to analyze the operation of the model. The risk grade of the substructure of Jiangshun Bridge during the construction period is obtained, and the corresponding risk countermeasures are worked out. This method can reflect the influence degree of each risk effectively, at the same time consider the common action of various factors synthetically, and provide the basis for the actual project construction risk assessment.

2. Construction of structural Analysis Model by AHP-GST method

Bridge construction is a huge and systematic project. In bridge risk assessment, it is necessary to judge the possibility and severity of the risk, and the risk grade can be considered as the combination of the possibility and severity of the risk. The calculation flow of AHP-GST is shown in figure 1.

![Figure 1. AHP-GST method structure flow chart](image)

2.1. Using AHP method to judge the possibility of risk.

To judge the possibility of risk, it is necessary to identify the risk of the bridge. The first step is to collect the relevant information of the bridge, analyze and classify the items that may affect the safety of the structure during the bridge construction stage, find out the risk factors, and make the risk factors orderly and hierarchical. The second step is to establish the structural hierarchy model according to the nature of risk factors and the subordinate relationship between each risk factor[7].

Inviting 10 experts to compare the third tier of risk sources with each other and the evaluation matrix of the third tier for the second tier is obtained, the matrix shows the importance of the factors
among themselves, which should combine all the evaluation results of multiple experts, so it is necessary to sum up the scores of each expert and check the consistency of the score results. The main reason is that each expert focuses on different areas of research and therefore cannot have exactly the same views on the same subject. Generally, the judgment results will not have too big deviation, but it is possible that the individual result has the big discrepancy. Therefore, it is necessary to eliminate the judgment results with large deviations. The result of the final selection is processed and the corresponding eigenvalues and eigenvectors are obtained.

After calculating the weight value of the third layer about the second layer, the weight value of the second layer about the first layer should be calculated, and the principle of the method is the same. Furthermore, the weight matrix W of the third layer to the first layer, namely, the target layer, is calculated. In this part, the qualitative problem is quantified by determining the weight matrix of risk factors and combining qualitative analysis with quantitative calculation[8].

2.2. Using the GST method to judge the risk severity.

According to the actual situation of the bridge construction, the experts are invited to carry out comprehensive scoring on each evaluation factor, the experts should have a good understanding of the actual construction, objectively score the risk factors according to their own working experience and professional theoretical knowledge to obtain the bridge risk severity score matrix.

According to the measurement theory and the relevant data and specifications of bridge risk[9], innovation is made here, the risk assessment grade of bridge construction is divided into 5 levels[10]. The corresponding evaluation levels vector are \( V=(V_1, V_2, V_3, V_4, V_5) \), through the evaluation level \( V \), the risk status of bridge construction stage is classified and evaluated. The relative threshold of grey system theory is divided into upper limit, middle value and lower limit. In this paper, the maximum, intermediate and minimum values of the sample matrix are taken so that each value corresponds to the upper limit, intermediate value and lower limit of the threshold. According to the above classification of risk levels, there are five risk levels. In grey theory, because the objects of evaluation are different, the whitening function is modified. The upper limit level corresponds to a class of grey class values, and the middle level includes two, three, four kinds of grey class values. The lower order corresponds to five classes of grey class values.

In this paper, on the basis of the corresponding evaluation sample matrix and the basic grey theory, the corresponding grey statistic values of each evaluation factor belonging to different whitening functions are obtained, and the weight values of each grey class statistical value \( V \) are obtained. Based on the analysis of the above methods, the judgment matrix of risk possibility and severity is obtained, and the evaluation results of the project are solved. The solution formula is as follows:

\[
X = (X_1, X_2, \cdots, X_k) = W \cdot V = (W_1, W_2, \cdots, W_k)
\]

The value of \( X \) can be calculated from the above formula. According to the principle of maximum membership, the result value is corresponding to the evaluation grade, and the range of the evaluation result of the project can be clearly known.

3. Engineering example

3.1. Engineering background.

Jiangshun bridge is a cable-stayed bridge in Guangdong province, it is 2290m long and 39m wide (including sidewalks on both sides). The main bridge of Jiangshun bridge is H type double tower cable-stayed bridge with span arrangement of \((60+176+700+176+60)\)m. The main bridge is 1172 meters long and the main span is 700 m long. The main tower foundation adopts bored pile plus round dumbbell cap foundation, the main tower is set up and the beam is lower. Parallel high-strength steel
wire cable and steel anchor beam are used for cable anchorage. The main girder is steel box girder structure, half floating supporting system, and concrete box girder is used for counterweight beam. The above evaluation model can be used to evaluate the risk in the construction stage of the substructure of the Jiangshun bridge in order to ensure the safety of the construction.

3.2. Risk factor identification.
The first step, through the relevant drawings of Jiangshun Bridge and the professional management personnel and experts on the construction site, the risk factors during the construction of the bridge include three risk factors of foundation construction, main tower construction and superstructure construction. Considering that the construction of the substructure of the bridge is more complex and difficult than other structures, the risk is high, so only the risk of the substructure is analyzed in this example. In the stage of construction of the substructure, the risk factors can be divided into three levels: pile foundation engineering, double-wall steel cofferdam project and bearing platform project[11][12]. Similarly, these second risk factors can be divided into third levels of risk factors. The specific levels are shown in figure 2.

3.3. Using AHP to calculate the weight value of risk factors of each layer.
According to the above risk factor evaluation set, the expert questionnaire is made, and 10 experts are invited to score separately. For the evaluation judgment on the second layer of the third layer of pile foundation construction A1, one expert compares each other with each other through two factors. The matrix is shown in figure 3:

![Risk identification structure diagram.](image-url)
Figure 3. Evaluation matrix of risk possibility.

Orthogonalization of each column of the above matrix, the eigenvector is calculated as follows: W=[0.343, 0.144, 0.165, 0.061, 0.144,0.144], the maximum eigenvalue is 6.2075, the conformance test showed that CI=0.0415, CR=0.0335<0.1[13], the calculation results meet the test requirements so the group data are valid.

Using the formula \(Ax=\lambda_{max}x\) to solve the eigenvalue \(\lambda_{max}\), the eigenvector \(W' = (W_{11}, W_{12}, W_{13}, W_{14}, W_{15}, W_{16})\) is obtained. The consistency test of the judgment matrix is carried out according to the consistency test method, and the results are shown in Table 1.

### Table 1. Pile foundation construction risk weight table.

| Expert number | W_{11} | W_{12} | W_{13} | W_{14} | W_{15} | W_{16} | \(\lambda_{max}\) | CI | CR | Consistent test |
|---------------|-------|-------|-------|-------|-------|-------|----------------|---|---|----------------|
| 1             | 0.343 | 0.144 | 0.165 | 0.061 | 0.144 | 0.144 | 6.208         | 0.041 | 0.033 | Pass           |
| 2             | 0.332 | 0.217 | 0.119 | 0.064 | 0.139 | 0.129 | 6.163         | 0.032 | 0.026 | Pass           |
| 3             | 0.263 | 0.174 | 0.175 | 0.072 | 0.165 | 0.151 | 6.163         | 0.033 | 0.026 | Pass           |
| 4             | 0.309 | 0.242 | 0.155 | 0.053 | 0.102 | 0.138 | 6.281         | 0.056 | 0.045 | Pass           |
| 5             | 0.295 | 0.255 | 0.127 | 0.112 | 0.102 | 0.109 | 6.416         | 0.083 | 0.067 | Pass           |
| 6             | 0.292 | 0.286 | 0.120 | 0.063 | 0.120 | 0.120 | 6.132         | 0.026 | 0.021 | Pass           |
| 7             | 0.299 | 0.224 | 0.166 | 0.057 | 0.142 | 0.113 | 6.311         | 0.062 | 0.050 | Pass           |
| 8             | 0.329 | 0.187 | 0.103 | 0.061 | 0.160 | 0.160 | 6.255         | 0.051 | 0.041 | Pass           |
| 9             | 0.206 | 0.206 | 0.106 | 0.100 | 0.192 | 0.192 | 6.307         | 0.061 | 0.049 | Pass           |
| 10            | 0.210 | 0.191 | 0.165 | 0.230 | 0.086 | 0.118 | 6.725         | 0.145 | 0.117 | Fail           |

The data of the 10th expert, which does not passed through the uniform inspection in the table, are eliminated, the average value of the rest of the data is assigned by experts to the risk assessment for this stage: W_{11}=0.296, W_{12}=0.215, W_{13}=0.137, W_{14}=0.071, W_{15}=0.141, W_{16}=0.140.

In the same way, by using the analytic hierarchy process mentioned above, the importance judgment matrix and their weights are calculated for the construction of double-wall steel cofferdam A_{2} and the bearing platform A_{3}. The results are as follows: W_{21}=0.266, W_{22}=0.094, W_{23}=0.160, W_{24}=0.131, W_{25}=0.350, W_{31}=0.204, W_{32}=0.408, W_{33}=0.143, W_{34}=0.246.

In the same way, the first level of the bridge construction risk is analyzed, and the expert scoring data are obtained, and the average value of the data is assigned by the expert to the risk assessment in this stage. That is: W_{1}=0.505, W_{2}=0.302, W_{3}=0.193. So we can get the weight set of all the factors in the overall consideration process:W={W_{A_{11}}, W_{A_{12}}, W_{A_{13}}, W_{A_{14}}, W_{A_{15}}, W_{A_{16}}, W_{A_{21}}, W_{A_{22}}, W_{A_{23}}, W_{A_{24}}, W_{A_{25}}, W_{A_{31}}, W_{A_{32}}, W_{A_{33}}, W_{A_{34}}}.  

3.4. Determination of whitening weight of all indicators by GST method.

Although there is some subjectivity in expert scoring, synthesizing the opinions of many experts can make the results more objective and in line with the actual situation of the bridge. The score is 0~10, and the greater the risk, the higher the score. The sample matrix of the 15 risk assessment factors is shown in figure 4.
Figure 4. Evaluation matrix of risk severity. Figure 5. Risk severity evaluation weight.

The scoring results of the experts are statistically calculated to determine the grey weight matrix. Taking the score of $A_{11}$ as an example, the corresponding statistical values of the index in five whitening weight functions can be obtained.

A class of statistics: $n_{ij} = f_1(u_{i1}) + f_1(u_{i2}) + f_1(u_{i3}) + \ldots + f_1(u_{i9}) + f_1(u_{i10}) = 8.556$, by using the same method, various statistical values of the index can be calculated: $n_{12}=9, n_{13}=4.6, n_{14}=0, n_{15}=0$. The total grey class statistics of $A_{11}$ can be calculated according to each statistic value, it is $n_{A11}=8.556+9+4.6+0+0=22.156$. The weight values of the various assessments are: $V_{11}=0.386, V_{12}=0.406, V_{13}=0.208, V_{14}=0, V_{15}=0$. The assessment weights for all five indicators are summarized as shown in figure 5.

3.5. Results of evaluation.
Evaluation matrix $X=W\cdot V=(0.230, 0.280, 0.303, 0.175, 0.012)$. The results show that the risk level of the first kind of risk is 0.230, the risk of the second categories is 0.280, the third category is 0.303, the fourth class is 0.175, and the fifth category is 0.012. According to the maximum subordinate principle, the construction risk grade of the substructure of the bridge can be determined as "three types", so we should pay some attention to it, take some countermeasures to avoid the occurrence of risk accidents.

4. Conclusion and prospect
The risk assessment of bridge construction plays an extremely important role in the actual construction and operation of the bridge. This paper takes Jiangshun bridge as a practical example to verify the AHP-GST method. In order to achieve scientificity, reliable and effective evaluation results.

1) Innovations have been made in the evaluation indicators, so the construction risk of the substructure of Jiangshun bridge is classified into three categories: pile foundation construction, steel cofferdam construction and bearing platform construction. Risk rating standards have been innovated, the evaluation level is divided into five categories, the risk grade is more differentiated, the content is more specific. The evaluation method is also innovated, the AHP-GST method is put forward, it makes an effective combination of the likelihood and severity of the risk. The evaluation results in this paper are in agreement with the calculation results of the standard method. The prediction method of bridge construction risk based on AHP-GST method can be used as an effective way to control the risk of bridge construction project, and take effective measures in advance.

2) The method of predicting bridge construction risk based on AHP-GST method has been well verified in the special risk assessment of cable-stayed bridge substructure, and it can be tried to verify whether this method is also applicable in different span bridge types.
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