Evaluation and Analysis of Typical Disease Risk Matrix of Concrete Slab Beam Bridge

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Abstract: In view of the current technical status assessment of concrete slab beam bridge, the problem of the disease severity can not be objectively and accurately reflected. This paper takes the typical disease of the concrete slab bridge as the research object to carry out the risk matrix evaluation. In order to eliminate the risk matrix in the risk matrix, we introduce the Borda order value method to establish a qualitative and quantitative comprehensive risk assessment model. On this basis, based on the analytic hierarchy process (AHP), the weight of risk factors is calculated to form a typical disease risk assessment system of plate girder bridge, which can reduce the influence of subjective factors in the bridge technical evaluation process.

1. Introduction

In recent years, in the regular inspection of existing highway bridges, it has been found that concrete slab girder bridges have cracked concrete slabs, joint seam damage, missing and deterioration of slab rubber bearings, longitudinal cracks and spalling of bridge deck pavement (As shown in Figure 1-4). These typical diseases will directly affect the durability and applicability of the bridge and pose a major safety hazard to the bridge structure[1-3].

The risk matrix assessment is a mathematical model that takes into account the risk probability and risk impact level as key evaluation indicators[4]. A qualitative and quantitative comprehensive risk assessment model is established by combining the risk matrix method and the Borda order value method[5]. On the basis of this, the risk factor weights are calculated by the analytic hierarchy process (AHP) to form a typical disease risk assessment system for the plate girder bridge. The risk assessment and daily maintenance of the plate girder bridge is of great significance.

Fig.1 Steel bar exposed
Fig.2 Beam end cracking
Fig.3 Bridge floor crack
Fig.4 Reaming cracking, seepage
2. Risk matrix based typical disease assessment method for bridges

2.1 Choice of assessment method
The risk assessment is based on the risk identification, and the risk assessment model is established by taking the risk probability and risk impact level as the key indicators [6]. At present, there are many methods for risk assessment, which can be roughly divided into three categories: qualitative analysis, quantitative analysis, qualitative and quantitative comprehensive analysis [7]. This paper chooses qualitative and quantitative comprehensive analysis method for evaluation.

2.2 Model establishment
The risk matrix $RA$ is comprehensively evaluated by two key indicators: risk probability $P$ and risk impact level $I$, satisfying the functional relationship: $RA = f(P, I)$, assuming that the number of risk factors involved in the concrete slab girder bridge is $n$. The typical damage of concrete slab girder bridge risk assessment is to judge the importance of this risk factor and choose the most critical risk factor. Therefore, the objective function of the maximum risk level can be expressed by the formula 1:

$$\max_{i=1}^{n} RA_i = \max_{i=1}^{n} f(P_i, I_i)$$

Fig. 5 Evaluation model of typical disease risk matrix of concrete slab girder bridge

The risk matrix evaluation model establishment process is shown in Figure 5. In order to mitigate and eliminate the impact of risk on risk level judgment [8], propose the concept of Borda order value. Finally, the risk factor weights are obtained through the Analytic Hierarchy Process (AHP) to facilitate the evaluation of the overall risk level.

2.3 Risk probability
The risk probability is evaluated by quantitative analysis method. For the concrete slab girder bridge of the Jiangsu section of the Beijing-Shanghai Expressway, the statistical analysis of the bridge disease is carried out and the probability distribution of each risk factor is measured. According to the risk probability, the probability is given from I~V to express different levels of assignment, different risk probabilities and their corresponding definitions are shown in Table 1.

| Risk occurrence probability range (%) | Definition or description | Assignment |
|---------------------------------------|---------------------------|------------|
| 0~10                                  | Generally does not happen | I          |
| 11~40                                 | Is unlikely to happen     | II         |
| 41~60                                 | May happen                | III        |
| 61~90                                 | Very likely to happen     | IV         |
| 91~100                                | Almost certainly happen   | V          |

2.4 Risk impact
The determination of the risk impact level is generally obtained through the form of expert opinion consultation and feedback. According to the risk impact level from small to large, the A~E is assigned different levels. The different risk impact levels and their corresponding definitions are shown in Table 2.
### Table 2 Definition of risk impact level

| Risk impact level | Definition or description | Assignment |
|-------------------|---------------------------|------------|
| Essential         | Once the risk occurs, the structure of the concrete slab bridge will be permanently destroyed. | A |
| Serious           | Once the risk occurs, the structural performance of the concrete slab bridge will be seriously degraded. | B |
| Moderate          | Once the risk occurs, the structural performance of the concrete slab beam bridge will be partially reduced, which will have a moderate impact on the overall structural health of the bridge. | C |
| Small             | Once the risk occurs, the structural performance of the concrete slab girder bridge will be slightly reduced, and the impact on the overall structural health of the bridge will be small. | D |
| Ignorable         | Once the risk occurs, the impact on the overall health of the bridge is negligible. | E |

### 2.5 Risk level

The risk assessment matrix is a judgment matrix established by risk probability and risk impact level as the key indicators. The risk probability is taken as the matrix column, and the risk impact level is taken as the row of the matrix. The risk matrix of each risk influencing factor can be judged from the constructed risk matrix. The risk level is divided into five levels, which are: low, lower, medium, higher, and high. The results of the risk assessment matrix are shown in Table 3.

### Table 3 Risk Assessment Matrix

| Risk probability /% | Ignorable | Small | Moderate | Serious | Essential |
|---------------------|-----------|-------|----------|---------|-----------|
| 0~10                | low       | low   | lower    | lower   | medium    |
| 11~40               | low       | low   | lower    | medium  | higher    |
| 41~60               | lower     | lower | medium   | higher  | higher    |
| 61~90               | lower     | medium| higher   | high    | high      |
| 91~100              | medium    | higher| higher   | high    | high      |

### 2.6 Borda order value method

The Borda ordinal value method classifies risks according to their importance according to multiple evaluation criteria[9]. The number of risk factors is $N$, and $M_j$ represents the $j$th ($j \leq 5$) probability levels (I ~ V), $N_j$ represents the $j$th risk impact level (A~E), $S_j$ and $T_j$ respectively represent the number of risk factors under the probability level and risk impact level. If the probability level of a risk factor belongs to $M_j$, the risk impact level belongs to $N_j$, the corresponding risk probability order value and risk impact level order value can be expressed by formulas 2 and 3, and the Borda number of each risk element can be expressed by formula 4. The Borda numbers are arranged in descending order and assigned Borda order values of 0, 1, ..., $N$.

\[
P_j = B_j + \frac{(1+S_j)}{2}
\]

\[
I_j = C_j + \frac{(1+T_j)}{2}
\]

\[
b_j = (N-P_j) + (N-C_j)
\]

In addition, $B_j$ is the number of probability levels to which the risk probability is greater than $M_j$, and $C_j$ is the number of probability levels to which the risk impact level is greater than $N_j$.

### 2.7 AHP-based risk weight determination
The determination of risk weight is a key process for risk assessment from qualitative to quantitative [10]. The calculation of risk weight mainly includes three steps: a. constructing a judgment matrix, b. multiplying by line and performing prescribing (the number of times of the number of risk elements), c. numerical normalization.

3. Application case

The investigation of the diseases of concrete slab girder bridges commonly used in Jiangsu Province was conducted, and the main diseases of concrete hollow slab girder bridges were summarized. The statistics of concrete slab girder in the Jiangsu section of the Beijing-Shanghai Expressway are counted. The risk probability of each typical disease is shown in Table 6.

| Table 4 Typical disease risk probability of concrete slab girder bridge |
|----------------------------------------------------------|
| Risk factor (type of disease) | Number of holes Number of diseased holes/hole Ratio Probability level |
|------------------------------|-------------------------------------------------|
| Bridge deck                  |                                                 |
| Paving cracks and damage     | 3278                                           | 67.83% | IV |
| Transverse crack             | 1286                                           | 26.61% | II |
| Vertical crack               | 154                                            | 3.19%  | I  |
| Broken joint                 | 1578                                           | 32.65% | II |
| Discharge hole blocked       | 2311                                           | 47.82% | III |
| Superstructure               |                                                 |
| Concrete damage, exposed     | 2783                                           | 57.58% | III |
| Lateral crack on the bottom of the plate beam | 1740                                           | 36.00% | II |
| Longitudinal crack of the bottom of the plate beam | 480                                            | 9.93%  | I  |
| Reaming cracking, seepage    | 2026                                           | 41.92% | III |
| Support                      |                                                 |
| Take off                     | 476                                            | 9.85%  | I  |
| Cracking, deformation        | 1567                                           | 32.42% | III |
| Steel plate corrosion        | 1143                                           | 23.65% | II |
| Broken stone                 | 363                                            | 7.51%  | I  |

Combined with the actual bridge disease investigation results quantitative analysis to determine the probability of bridge disease risk and the corresponding level. Bridge inspectors and bridge disease research experts are invited to qualitatively evaluate the risk impact levels of different risk factors. The Borda ordinal value method is used to calculate the risk value and risk impact level respectively. The results of the evaluation of typical disease risk matrix of concrete slab girder bridge are shown in Table 5.

| Table 5 Evaluation table of typical disease risk matrix of concrete slab girder bridge |
|----------------------------------------------------------|
| Serial number  | Risk factor (type of disease) | Risk probability | Risk impact level | Risk level | Risk probability order value | Risk impact order value | Borda number | Borda order value |
|----------------|-------------------------------|------------------|-------------------|------------|-------------------------------|------------------------|--------------|-------------------|
| 1              | Paving cracks, damage         | IV               | C                 | higher     | 1                             | 6.5                    | 20.5         | 1                 |
| 2              | Transverse crack              | II               | D                 | low        | 7.5                           | 9.5                    | 11           | 5                 |
| 3              | Vertical crack                | I                | D                 | low        | 11.5                          | 9.5                    | 7            | 8                 |
| 4              | Broken joint                  | II               | E                 | low        | 7.5                           | 12                     | 8.5          | 7                 |
| 5              | Discharge hole blocked        | III              | E                 | lower      | 3.5                           | 12                     | 12.5         | 4                 |
| 6              | Concrete damage, exposed      | III              | C                 | medium     | 3.5                           | 6.5                    | 18           | 2                 |
7. Lateral crack on the bottom of the plate beam
8. Longitudinal crack of the bottom of the plate beam
9. Reaming cracking, seepage
10. Take off
11. Cracking, deformation
12. Steel plate corrosion
13. Broken stone

According to the Borda sequence value calculated in Table 5, the order of typical risk factors for concrete slab girder bridges can be determined. Reaming cracking, seepage and cracking, deformation and paving cracking are the most critical issues. Through the analytic hierarchy process (AHP) calculation, it can be concluded that the weight distribution results of typical disease risk factors of concrete slab girder bridge are shown in Fig. 6.

**Fig.6 Weight distribution of typical disease risk factors of concrete slab girder bridge**

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### 4. Conclusion

The risk matrix method and Borda sequence value method are combined to establish a qualitative and quantitative comprehensive risk assessment model. On this basis, the AHP is used to calculate the risk factor weights to form a typical disease risk assessment system for the plate girder bridge. Bridge risk assessment and daily maintenance are of great significance.

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### References

1. Fenghua Zhou. (2013) Discussion on Disease Analysis and Maintenance Management Countermeasures of Urban Bridges. Journal of Qingdao Technological University, 34(04): 51-55.
2. Junqing Lei . (2005) Analysis of Bridge Safety Durability and Disease Accidents. Chinese Journal of Safety Science, 02: 89-93+1.
3. Yuhui Xiao ,Lihong Shen . (2004) Analysis of the Causes of Concrete Bridge Diseases and Countermeasures. China Foreign Highway, 01: 39-42.
[4] Dengfeng Zheng. (2012) Application of risk assessment system based on risk matrix and LOPA in oil and gas pipelines. China Safety Production Science and Technology, 8(10): 76-81.
[5] Aven T, Heide B. (2009) Reliability and validity of risk analysis. Reliability Engineering and System Safety, 94: 1862.
[6] Franks A P, Maddison T. (2006) A simplified method for the estimation of individual risk. Process Safety and Environmental Protection, 84(B2): 101.
[7] Hillson D, Webster R M. (2007) Understanding and managing risk attitude. Gower Publishing Company, Burlington
[8] WU D D, KEFAN X, HUA L. (2010) Modeling technological innovation risks of an entrepreneurial team using system dynamics: An agent-based perspective. Technological Forecasting and Social Change, 776: 857-869.
[9] Congbo Li, Fei Liu, Xianchun Tan et al. (2010) Risk Assessment Method for Green Manufacturing Based on Risk Matrix and Fuzzy Set. Computer Integrated Manufacturing Systems, 16(01): 209-214.
[10] Chunling Gong. (2006) Construction risk analysis and countermeasure research of long-span cable-stayed bridge. Tongji University