Safety evaluation for bridge crane based on FTA and AHP

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Abstract. Starting from the development status of the lifting machinery industry, this paper analyzes the data about safety accidents of bridge cranes, and identifies the assessment indicators affecting the safety performance of bridge cranes based on fault tree analysis (FTA), including fatigue factors, human factors, environmental factors, and management factors. Then, the weights of safety evaluation indicators are determined based on analytic hierarchy process (AHP). Finally, the safety evaluation system is established and demonstrated with use case diagram and role flow chart.

1 Introduction

There are millions of bridge cranes in China, a large number of which have exceeded the service life and the metal structures of many cranes have various crack defects. If an accident occurs, it will cause personal injury and property loss. With the development of modern science and technology, bridge cranes need not only high load capacity under complex working environment, but also to reduce the cost of raw materials for manufacturing. In a word, it is necessary to evaluate the safety performance in order to prevent crane accidents. Therefore, this paper aims to establish a safety evaluation system for bridge crane.

2 Establishment of safety evaluation system for bridge crane

Fatigue crack damage is one of the main failure forms of crane metal structures. In daily use, parts of hoisting machinery will cause problems such as abrasions and failures of safety protection devices. During the service period, the bridge cranes are subjected to environmental impacts. Long-term overload and other unexpected situations, and the fatigue of metal materials will weaken the function of bridge cranes. When the damage is accumulated to a certain extent, the girders will fail. Therefore, this paper combines fault tree analysis (FTA) to determine the fatigue factors that affect the safety of bridge cranes, as shown in Figure 1.

Besides the fatigue factors, human factors, environmental factors, and management factors also affect the safety performance of bridge cranes. The safety assessment indicators of bridge cranes are proposed in Table 1.
3 Determination of the weights for safety assessment indicators

The weight of each factor is obtained by using AHP. The procedure is as follows: (1) Model a hierarchy decision model; (2) Establish a judgment matrix; (3) Synthesize these judgments to yield a set of overall priorities for the hierarchy; (4) Check the consistency; (5) Draw a final decision, as shown in Figure 2.

Set up the hierarchy structure of safety evaluation index system. The hierarchy architecture is divided into three levels: the target layer, the rule layer, and the scheme layer as shown in Figure 3.

![Figure 3. Hierarchy structure of bridge crane fatigue evaluation index system.](image)

Establish a judgment matrix. First, this paper uses AHP to build a judgment matrix for peer indicators. Suppose there are n indicators, {A1, A2, ..., Ai, ..., Aj, ..., An}, $a_{ij}$ indicates the ratio of the importance of the index Ai to the index Aj, that is, the element in judgement matrix A. $a_{ij}$ takes 1, 3, 5, 7, 9 five scales: 1 means that the index Ai is as important as the index Aj, the importance of index Ai is increasing than that of index Aj with the increase of the numbers.

Synthesize these judgments to yield a set of overall priorities for the hierarchy. After the completion of the judgement matrix, the second-level indexes are sorted and the root weight method is applied to normalize the index to get the initial weights of the indexes. This step includes calculating single-level weights and multi-level weights. This paper chooses the root weight method to calculate the maximum eigenvector of the judgment matrix. The process is as follows.

1. Calculate the product of each row element of the judgment matrix A, the formula is as follows.

$$m_i = \prod_{j=1}^{n} a_{ij}$$  \hspace{1cm} (1)

2. Calculate the n roots of each row element of the judgment matrix separately, and the initial weights of the indexes at all levels are obtained after normalization, the formulas are as follow.

$$w_i = \sqrt{m_i}$$  \hspace{1cm} (2)
Determine hierarchy and influencing factors
Establish a judgment matrix
Calculate single-level weights
Check the single-level consistency
Calculate multi-level weights
Check the consistency
Draw a final decision

Software function requirements and performance requirements are determined based on the above analyses. The functional modules of the bridge crane safety evaluation system are divided into five modules: information acquisition module, information storage module, information query module, parameter change module and system management module. Each module has a specific functional division and different functional requirements for different user identities.

According to the established model, the users and administrators’ permissions are different, and the corresponding application processes are also different. Administrators can log in directly without registration, and can modify indicator parameters. The users enter the main interface by logging in or registration, and can view, modify, add, delete the stored bridge crane information, and so on. The specific process is shown in Figure 4.

4 Design of safety evaluation system for bridge crane

Table 2. A case of the pairwise comparison and priority calculation (CR=0.046).

<table>
<thead>
<tr>
<th>Metal mechanisms</th>
<th>Operation mechanism</th>
<th>safety device</th>
<th>Geometric means</th>
<th>Normalized priorities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal mechanisms</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>$\sqrt[3]{1 \times 2 \times 3} = 1.817$</td>
</tr>
</tbody>
</table>
5 Summary
This paper presents a safety performance assessment model for bridge cranes and uses the analytic hierarchy process (AHP) to determine the weights of the indicators in the model. At the same time, this article uses information software to achieve the safety assessment of bridge cranes. The software can make the assessment of bridge cranes more convenient and faster, and provides a basis for the management and maintenance of bridge cranes.

6 Acknowledgment
This work was financially supported by the Program of Science Foundation of General Administration of Quality Supervision and Inspection of Jiangsu Province (KJ175940). The supports are gratefully acknowledged.

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