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Quantitative Distribution of Rebar Corrosion Sensor in Reinforced Concrete T-beam Bridge

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Abstract: The Fiber Bragg Grating (FBG) sensor for rebar corrosion is a new type corrosion sensor, a complete monitoring system is consist of the corrosion sensors installed in different places of the structure, if the number of corrosion sensor is given, how to determine the corrosion number installed in different places, it's a quantitative distribution problem. In this study, the quantitative distribution of rebar corrosion sensor in reinforced concrete T-beam bridge is studied. The corrosion sensors are installed in five places: T-beam top flange, ribbed beam, bent cap, bridge pier and abutment and bridge foundation. Based on Analytic Hierarchy Process (AHP), the AHP model of corrosion sensor distribution is proposed in this paper. This scheme reveals the influence on the distribution decision of corrosion sensor and this influence mainly comes from the indexes, the decision weight and the sensors number in different places are obtained.

Key words: Reinforced concrete T-beam bridge, rebar corrosion, sensor, AHP, quantitative distribution

INTRODUCTION

It is world widely concerned in durability of reinforced concrete structures. Corrosion of steel is one of the most important factors which may affect the durability of the reinforced concrete bridge. As a new type corrosion sensor, The Fiber Bragg Grating (FBG) sensor for rebar corrosion with the advantage of insensitive to environmental interference, safe and reliable, good durability is used (Li *et al*., 2007; Li and Wu, 2008; Li *et al*., 2009). In this paper, some efforts have been made in quantitative distribution of fiber Grating sensor for rebar corrosion in reinforced concrete T-beam bridge.

Due to variations in concrete performance, environmental condition and other factors, the steel corrosion rate is not consistent within the same bridge. By placing a number of corrosion sensors in a given concrete T-beam bridge, this inconsistent can be monitored and a corrosion early warning system can be provided. Thus, if the number of corrosion sensor is given, it is a quantitative distribution problem to determine the certain sensors quantity in different position of bridge. In this process, the comprehensiveness, reliability and economy of steel corrosion monitoring system should be taken into account.

To compare alternatives across multiple criteria, the Analytic Hierarchy Process is developed. The methodology is based on defining a decision problem as a hierarchy of goals, criteria and alternatives. The AHP is a decision-making procedure widely used in management for establishing priorities in multi-criteria decision problems (Ryszard and Uden, 2011; Turan, 2009; Awasthi and Chauhan, 2011; Wang and Li, 2008). The AHP is explored as a means of assisting to complete the corrosion sensors quantitative distribution problem in reinforced concrete T-beam bridge.

APPROACH FOR SENSOR QUANTITATIVE DISTRIBUTION

The principle of sensor quantitative distribution: A complete rebar corrosion monitoring system in concrete T-beam bridge is consist of lots of rebar corrosion sensors in different parts. If the total number of sensors is N, thus, the number of sensors N_i in these parts can be expressed as (Zhang and Lei, 2000):

$$N_i = k_i N \quad (1)$$

It is very obvious that the larger the distribution coefficient is, the bigger in quantity the number of sensors is. It's a complicated decision problem to determine the distribution coefficient, there are many important factors which need to be considered, such as the probable corrosion conditions in different parts, the

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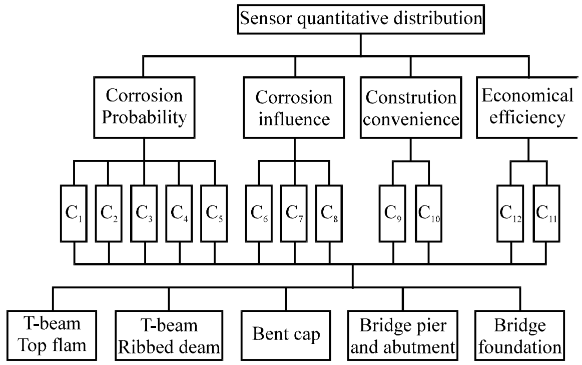

Fig. 1: Decision hierarchy for sensor quantitative distribution

maintenance cost after rebar corrosion and the cost of sensor installation, etc. In this paper, by using an AHP approach, the distribution coefficient can be got and then the different sensor quantity at different places is determined.

The AHP approach: The AHP approach procedure is described as the following steps:

- Determining its goal and structuring the hierarchy. In this study, the goal of the decision "corrosion sensors quantitative distribution" is at the top level of the hierarchy, while the next two levels consists of decision criteria (criteria level and sub criteria level). The lowest level of the hierarchy is made up of the decision alternatives. This hierarchy can be illustrated via a tree diagram, as shown in Fig. 1. The diagram represents a decision problem with two levels criteria and five alternatives and the four kinds of basic evaluation criteria given below were introduced

The main factors can be summarized as follows (in level 2):

- Corrosion probability (U_1)
- Corrosion influence (U_2)
- Installation convenience (U_3)
- Economical efficiency (U_4)

Every section in level 2 can be divided into related parts which called criteria level (level 3) and lists as follows:

- Concrete cover thickness (C_1)
- Chlorine ion content (C_2)
- Carbonization degree (C_3)
- Environment (C_4)
- Concrete crack (C_5)
- Decreased degree of bearing capacity (C_6)
- Importance of different sections (C_7)
- Maintenance cost (C_8)
- Limitation of construction site (C_9)
- Construction difficulties (C_{10})
- Construction period (C_{11})
- Installation cost (C_{12})

- By using the relative scale measurement shown in Table 1 (Qin, 2003; Fallahi *et al.*, 2009), a set of pairwise comparison matrices for each element of the lower levels with one matrix for each element in the upper level are constructed

- Checking for consistency and calculating weights. The AHP employs a consistency ratio measure to check the consistency of judgments. These judgment errors can be detected by a Consistency Ratio (CR), when CR£¼0.1, the judgment errors are tolerable and the weight coefficients of the weight matrix are the weights of lower level element under the upper level element. Otherwise, the pairwise comparisons should be adjusted until matrix satisfies the consistency check

The maximum characteristic value and vector of the estimation matrix are determined in combination with the intrinsic vector method, thus obtaining the estimation matrix a corresponding weight at each level.

- Calculating global weight. Local weights consist of three parts: the weight of each criteria to the goal w^1, the weight of each sub criteria to the criteria w_i^2 (j = 1, 2, 3, 4) and the weight of each nominee to each sub criteria ω^3_k (k =1, 2, 3, 4, 5). From synthesize the above results to achieve the overall weight of each decision alternative and the normalized eigenvector v is the distribution coefficient

APPLICATION

This section shows a specific sample calculation that uses AHP, the concrete T-beam bridge is built over an old river, the standard span is equal to 30 m and the bridge piers are column piers.

Based on the information given above, a paired comparison was performed between every two of the four criteria in order to compare their importance, the experts were asked to evaluate all proposed criteria pairwise. As shown in Table 2, the normalized eigenvector is like $w^1 = (0.4444, 0.2222, 0.1112, 0.2222)$, which represents the related priority of these criteria.

Similarity, the weights of sub-criterion with respect to an element from the upper level of the hierarchy will also be elicited by hierarchy analytic process and shown as follows: w^1_2 = (0.0883, 0.137, 0.1807, 0.297, 0.297), w^2_2 = (0.2857, 0.5714, 0.1429) and w^2_3 = (0.333, 0.667), w^2_4 = (0.667, 0.333). The results are presented in Table 2-6.

Table 1: Relative weighting of criteria

Numerical value	Verbal judgment of preferences
1	Equal importance
3	Weak importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values

Table 2: A~U_i Hierarchy estimation matrix and weight

A	U_1	U_2	U_3	U_4
U_1	1	2	4	2
U_2	2	1	2	1
U_3	4	2	1	2
U_4	2	1	2	1
w^1	0.4444	0.2222	0.1112	0.2222

CR = 0.0054

Table 3: U_1~C_i Hierarchy estimation matrix and weight

U_1	C_1	C_2	C_2	C_3	C_4	C_5
C_1	1	2	2	2	3	4
C_2	2	1	1	2	2	2
C_3	2	2	2	1	2	2
C_4	3	2	2	2	1	1
C_5	3	2	2	2	1	1
w_1^2	0	0.137	0.137	0.1807	0.297	0.297

CR = 0.0054

There are 12 hierarchy estimation matrices and weights of decision alternatives with respect to the sub criterion, for example, the C_2~V_i Hierarchy estimation matrix and weight is shown in Table 7.

As shown in Table 8, w = (0.0392, 0.0609, 0.0802, 0.1319, 0.1319, 0.0635, 0.1269, 0.0317, 0.0370, 0.0742, 0.1481, 0.074), it's the weight of each sub criteria to the goal; v = (0.2618, 0.2549, 0.1444, 0.2282, 0.1107), it's the weight of each alternative to the goal and the sensor distribution coefficient is obtained.

The number of rebar corrosion which would be installed in the concrete T-beam bridge is 30 and the different sensors number in different place can be obtained:

$$N_1 = 30\times0.2618 = 7.854\approx8$$
$$N_2 = 30\times0.2549 = 7.647\approx8$$
$$N_3 = 30\times0.1444 = 4.332\approx4$$
$$N_4 = 30\times0.2282 = 6.846\approx7$$
$$N_5 = 30\times0.2618 = 3.321\approx3$$

Thus, there will be 8 corrosion sensors installed in T-beam top flange and the number of sensors in

Table 4: U_2~C_i Hierarchy estimation matrix and weight

U_2	C_6	C_7	C_8
C_6	1	2	2
C_7	2	1	4
C_8	2	4	1
w^2_2	0.2857	0.5714	0.1429

CR = 0.00000007

Table 5: U_3~C_i Hierarchy estimation matrix and weight

U_3	C_9	C_{10}
C_9	1	2
C_{10}	2	1
w^2_3	0.333	0

Table 6: U_4~C_i Hierarchy estimation matrix and weight

U_4	C_{11}	C_{12}
C_{11}	1	2
C_{12}	2	1
w^2_4	0.667	0.333

Table 7: C_2~V_i Hierarchy estimation matrix and weight

C_2	V_1	V_2	V_3	V_4	V_5
V_1	1	2	4	1	5
V_2	2	1	2	1	3
V_3	4	2	1	4	2
V_4	1	1	4	1	5
V_5	5	3	2	5	1
w^2_5	0.3267	0.1946	0.0898	0.3267	0.0622

CR = 0.0697

Table 8: The scheme level index weights

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	v
v_1	0.2222	0.3267	0.3777	0.3082	0.2563	0.1429	0.0679	0.0802	0.3595	0.2784	0.3595	0.2826	0.2618
v_2	0.2222	0.1946	0.1845	0.0999	0.4603	0.1429	0.1836	0.1604	0.3595	0.2784	0.3595	0.2826	0.2549
v_3	0.2222	0.0898	0.1122	0.0999	0.1051	0.1429	0.1091	0.1121	0.1410	0.2784	0.1410	0.2826	0.1444
v_4	0.2222	0.3267	0.2760	0.4567	0.1438	0.2857	0.3197	0.2670	0.0879	0.1006	0.0879	0.0977	0.2282
v_5	0.1222	0.0622	0.0496	0.0353	0.0345	0.2856	0.3197	0.3773	0.0521	0.0642	0.0521	0.0545	0.1107
w	0.0392	0.0609	0.0802	0.1319	0.1319	0.0635	0.1269	0.0317	0.0370	0.0742	0.1481	0.0745	

ribbed beam, bent cap, bridge pier and abutment and bridge foundation is 8, 4, 7 and 3.

CONLUSION

The study on the quantitative distribution analysis made on rebar corrosion sensor is of significance and also provides a theoretical basis for the design, application and overall optimization of the construction corrosion monitoring system. AHP was applied for corrosion sensors quantitative distribution. The AHP method provides a comprehensive and rational framework for structuring the problem, for representing and quantifying its elements, for relating the elements to the overall goal and for evaluating alternative solutions. Finally, the best quantitative distribution is chosen by AHP to perform the corrosion sensors quantitative distribution problem.

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