Durability Evaluation Method of Reinforced Concrete Beam Bridge Based on Extension Interval Number Theory

Fangping Liu\textsuperscript{1,2}, Wentao Yi\textsuperscript{2}

\textsuperscript{1}School of Civil Engineering, Hexi University, Gansu 734000, China; \textsuperscript{2}School of Civil Engineering, Chongqing Three Gorges University, Chongqing 404020, China;

Correspondence should be addressed to Fangping Liu; 115090140@qq.com

Abstracts: In this paper, a method for evaluating the durability of reinforced concrete simple supported beam bridge was proposed based on the extension interval number theory and analytic hierarchy process. Firstly, the multi-layer durability evaluation model of simply supported beam bridge is established, which includes sub index layer, index layer, project layer and target layer. Then, the interval number of extension theory is used to replace the number of points to construct the judgment matrix in the model, which solves the fuzzy and uncertainty problems of the traditional AHP expert experience judgment. Due to the uncertainty of the factors affecting the bridge, the normal correlation function is constructed, and the correlation degree of each evaluation element to each grade is used as the basis for the quantitative evaluation of the bridge. Each layer is evaluated based on the results of the following assessment. The bridge durability can be obtained through the level by level evaluation. Finally, an example of a beam in Chao-yang bridge is used to illustrate the method and process of evaluation. The results are reliable and applicable. The assessment process proved that the method presented here is an effective one to solve the paradox in bridge evaluation, where qualitative and quantitative coexistence takes place.

1. Standard Definition

1.1. Evaluation model
Project layer is divided according to the structure and stress characteristics of simply supported beam bridge. Based on the field investigation and testing of the several simple supported beam bridges, the durability damage index is determined. Finally, the evaluation model of the durability of reinforced concreted simple supported beam bridge is established, as shown in Figure 1.

1.2. Grade standard, meaning and countermeasure
Referring to the literature \[1\], the criteria for the evaluation of a reinforced concrete simple bridge and its components can be divided into five grades, as shown in Table 1. The durability damage assessment of the bridges can be divided into five grades. The meaning and countermeasures are listed in Table 2.

1.3. Index grading standard
On the basis of the analysis of the literature, the collection of reinforced concrete structural test data and the previous engineering test data classification, the grading standards for the durability damage index of each evaluation element are shown in Table 3. The standards are shown in Table 4 and Table
5. **Table 1: Meaning and gradation of evaluation divisions**

| Evaluation divisions (Rj) | Technical condition | Grade          |
|--------------------------|---------------------|----------------|
| ≤0                       | best (in very good condition) | first level |
| ≤1                       | better              | second level   |
| ≤2                       | good                | third level    |
| ≤3                       | bad                 | fourth level   |
| ≤4                       | worse               | fifth level    |
| ≤5                       | worst (in very dangerous condition) |            |

**Figure 1: Evaluation Model**

- **Table 2: Meaning and countermeasure of evaluation grade**

| Grade       | Technical condition score (Dr) | Technical condition meaning | countermeasure                                                                 |
|-------------|--------------------------------|-----------------------------|-------------------------------------------------------------------------------|
| first level | Dr≥88                          | best (in very good condition), better | normal maintenance                                                             |
| second level| 88 > Dr≥60                     | good                        | minor repair                                                                  |
| third level | 60 > Dr≥40                     | bad                         | medium repair, control traffic according to the circumstances                  |
| fourth level| Dr<40                          | Worse                       | heavy repair or reform and control traffic                                    |
| fifth level |                                | worst (in very dangerous condition) | close traffic, special repair or reconstruction                               |
Table 3: Evaluation criteria of durability damage index (crack width unit: mm)

| Evaluation element | Evaluation index       | Evaluation grade and value interval |
|--------------------|------------------------|-------------------------------------|
|                    |                        | first level | second level | third level | fourth level | fifth level |
| concrete crack     | stress cracks          | [0, 0.1)    | [0.1, 0.3)   | [0.3, 0.7)  | [0.7, 1.0)   | (≥1.0)     |
|                    | non stress cracks      | [0, 0.2)    | [0.2, 0.4)   | [0.4, 1.0)  | [1.0, 1.5)   | (≥1.5)     |
| concrete corrosion  | area corrosion rate    | [0, 0.05)   | [0.05, 0.15) | [0.15, 0.25)| [0.25, 0.4)  | (≥0.4)     |
| rebar corrosion     | cross-section loss rate| [0, 0.01)   | [0.01, 0.05) | [0.05, 0.15)| [0.15, 0.2)  | (≥0.2)     |
| protective layer    | longitudinal cracks    | [0, 0.1)    | [0.1, 0.5)   | [0.5, 1.5)  | [1.5, 2.0)   | (≥2.0)     |

Table 4: Grading criteria of support damage index

| Evaluation grade | Evaluation grade and value interval |
|------------------|-------------------------------------|
| first level      | second level                        |
| Value interval   | (0, 20)                             |
| Damage condition | basically intact                    |

| Evaluation grade | Evaluation grade and value interval |
|------------------|-------------------------------------|
| second level     | hinge joint                         |
| Value interval   | (20, 40)                            |
| Damage condition | damage slight, bridge bearing aging light |

| Evaluation grade | Evaluation grade and value interval |
|------------------|-------------------------------------|
| third level      | hinge joint                         |
| Value interval   | (40, 60)                            |
| Damage condition | damage slight, bridge bearing aging serious |

| Evaluation grade | Evaluation grade and value interval |
|------------------|-------------------------------------|
| fourth level     | hinge joint                         |
| Value interval   | (60, 80)                            |
| Damage condition | damage serious, bridge bearing aging serious |

| Evaluation grade | Evaluation grade and value interval |
|------------------|-------------------------------------|
| fifth level      | hinge joint                         |
| Value interval   | (80, 100)                           |
| Damage condition | damage serious, bridge bearing failure |

Table 5: Grading criteria of transverse connection damage index

| Evaluation grade | Damage condition | Value interval |
|------------------|------------------|----------------|
| first level      | There was no obvious change in the joints between the main girders | (0, 20) |
| second level     | rigid connection  | Slight water seepage at joints, slight corrosion of concrete, crack width no more than 0.2mm | [20, 40) |
|                  | hinge joint      | The seam has not been moved up and down, there is slight crack, and the width is not more than 0.25mm, the welding plate is corroded |
| third level      | rigid connection | The joint seepage is obvious, the protective layer is peeled off, the aggregate exposure is serious, the crack width (0.2 ~ 0.3) mm | [40, 60) |
|                  | hinge joint      | There is a slight upper and lower dislocation at the joint, the crack width (0.25 ~ 1) mm, the corrosion of welded steel plate is obvious |
| Fourth level     | rigid connection | The water seepage is very obvious, the protective layer is peeled off seriously, the aggregate is exposed seriously, and the seam width is greater than 0.3mm | [60, 80) |
|                  | hinge joint      | The joints are obviously up and down, the crack width is greater than 1.0mm, and the welding steel plate is corroded seriously |
| Fifth level      | rigid connection | The water seepage is serious, the concrete is loose, the aggregate is exposed, the steel bar is corroded seriously | [80, 100) |

2. Evaluation Method

2.1. Initial weights determination
The weights of the factors are determined by comparing the constructed judgment matrix. In order to fully quantify the fuzziness of expert judgment, this paper uses interval numbers instead of the point numbers to construct judgment matrix, and combined the weight solution and the consistency test of judgment matrix.

2.1.1. Construct interval number judgment matrix.
The establishment of judgment matrix is a formal process that transforms the original data into a direct comparison. In this paper, the reciprocal 1-9 scale proposed by SAATY[5] is used as the basis for constructing the interval number judgment matrix. In a certain criterion, the judgment matrix

\[ A = (a_{ij})_{n \times n} \]

is constructed through intercomparisons the relative importance of each element on the same
layer by the experts. The judgment matrix $A^{ij} = <a_{ij}^-, a_{ij}^+>$ is the positive reciprocal matrices, and $i, j = 1, 2, \cdots, n$, $a_{ij} = <a_{ij}^-, a_{ij}^+>$ is the matrix element represented by interval numbers, $a_{ij}^-$ and $a_{ij}^+$ are the upper and lower ends of the $i$ row and the $j$ column of the judgment matrix. The median number of interval number $<a_{ij}^- + a_{ij}^+>/2$ is the integer of the 1-9 scale used in the comparative analysis of the analytic hierarchy process.

If there are $T$ experts to participate in the construction of the interval number judgment matrix, and the judgment matrix of $K$ layer factors given by expert $t$ to a factor of the $K-1$ layer is $A^{ij} = <a_{ij}^-, a_{ij}^+>$, then, the comprehensive judgment matrix of all factors of the $K$ layer given by $T$ experts on a factor of the $K-1$ layer is $A^{ij} = <a_{ij}^-, a_{ij}^+>$. The expression of element $a_{ij}$ is:

$$a_{ij} = <a_{ij}^-, a_{ij}^+> = <1/t \sum_{t=1}^{T} a_{ij}^-, 1/t \sum_{t=1}^{T} a_{ij}^+>$$ (1)

For the interval number judgment matrix of the $K$ layer, $A = <a_{ij}^-, a_{ij}^+>$, where the upper and lower point matrix is:

$A^- = a_{ij}^-$, $A^+ = a_{ij}^+$.  

2.1.2. Calculate the weight vector of interval number judgment matrix. The weight vector of interval number judgment matrix $A = <a_{ij}^-, a_{ij}^+>$ with satisfactory consistency is calculated by the following steps.

1) Calculate the normalized eigenvector $x^-$ and $x^+$ of the largest eigenvalue in the upper and lower point matrix $A^-$ and $A^+$. The normalized eigenvector $x^-$ and $x^+$ also needs to have positive components.

2) According to $A^- = <a_{ij}^->$, $A^+ = <a_{ij}^+>$, the value of $k$, $m$ is calculated as follows:

$$k = \sqrt{\frac{1}{n} \sum_{i,j} a_{ij}^-}, \quad m = \sqrt{\frac{1}{n} \sum_{i,j} a_{ij}^+}$$ (2)

The $k$ and $m$ in the formula (2) satisfy $kx^- \leq mx^+ (i,j = 1, 2, \cdots, n) .

3) Consistency of interval number judgment matrix. If $0 < k \leq 1 < m$ then the consistency of judgment matrix is better. When the consistency is low, the expert should be rejudged until the requirements are met.

4) The weight vector of interval number judgment matrix is calculated as follows:

$$S = (S_1, S_2, \cdots, S_n)^T = <kx^-, mx^+>$$ (3)

In formula, $S_n$ is the interval weight vector of the factor $n$ in the $k$ layer to a factor of the upper layer [6-7].

2.1.3. Weight determination.

As can be seen from the front, each element of the $k$ layer (assuming that there are a total of $n$ elements in the $k$ layer) has a weight of $S_i^+ = (kx^+, mx^+)$, which is represented by interval numbers. Then the importance of interval number $S_i^+ = <S_i^+, S_i'^+>$ than $S_i'^+ = <S_i^-, S_i'^->$ is calculated by the following formula:

$$V(S_i^+ \geq S_i'^+) = \frac{2(S_i^+ \cdot S_i'^+)}{(S_i^+ \cdot S_i'^+) + (S_i'^- \cdot S_i'^-)}$$ (4)

In the formula above $i = 1, 2, \cdots, n$, and $i \neq j$ .

Take $j$, to meet any of the $i = 1, 2, \cdots, n$, and $i \neq j$, have $V(S_i^+ \geq S_i'^+) > 0$ set up. Then take $p_i^j = 1$, $p_i^j = V(S_i^+ \geq S_i'^+)$. The normalized value of single ordering weight of all $n_0$ factors in the $k$ layer to a factor of the upper layer is $p_i^j = \rho_1^j, p_i^j, \cdots, \rho_n^j$ [8].
2.2. Index layer evaluation

2.2.1. Determination of element evaluation value based on interval correlation degree. In the durability evaluation of reinforced concrete bridges, there is no one-to-one relation between the change of the factors and the evaluation indexes. It cannot be solved by the accurate mathematical model. In addition, some factors cannot be expressed with precise quantity, they can only be described by a fuzzy language. So the correlation function and interval number in the extension theory are introduced into the evaluation of the element value. Because the bridge material, the geometry characteristic and the degeneration parameter etc. are the statistical variables, it is very difficult to accurately evaluate the performance of bridges or members. There is a certain correlation between the evaluation indexes and the grades therefore, the "interval correlation degree" is used as the basic parameter to evaluate the grade of elements in evaluation model.

The factors such as the material properties of the bridge are basically obey the normal distribution [9-10], and the damage index is mainly determined by the material properties. So according to the Liapunov theorem, it can be considered that the damage index of the bridge is similar to the normal distribution. There are two factors that influence the correlation degree of a certain evaluation factor: ①The distance between the evaluation index values and the corresponding grade intervals; ②The interval size of the corresponding evaluation grade. So, we can construct the normal correlation function to calculate the correlation degree, and then standardizing the correlation degree of the evaluation grade. So there:

\[ f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(x-x_1)^2}{2\sigma^2}\right) \]  

(5)

Assuming that the value of the evaluation index \( x_j \) of element \( j \) is relative to grade \( n \) is \( K'_n \). So, \( K'_n \) is calculated as follows:

When \( x_j \leq x_{j1} \):
\[ K'_n = \frac{1}{2}, K'_n = 0, n \neq 1 \]

(6)

When \( a_{j} \leq x_j \leq b_{j} \):
\[ K'_n = \left\{ \begin{array}{ll}
\left(\frac{b{a}+a{b}}{2}\right) + f(b) \times 3 \quad & x \in [a, b], n \neq 5 \\
\left(\frac{b{a}+a{b}}{2}\right) + f(b) \times 3 \quad & x \in [a, b], n = 5
\end{array} \right. \]

(7)

When \( x_j \geq a_{j} \):
\[ K'_n = \left(\frac{a{b}+a{b}}{2}\right) + f(b) \times 3 \quad & x \geq a_{j}, n \neq 5 \\
K'_n = \left(\frac{a{b}+a{b}}{2}\right) + f(b) \times 3 \quad & x \geq a_{j}, n = 5
\]

(8)

After standardized treatment, the correlation degree:
\[ K_n = K'_n / \sum_{n=1}^{5} K'_n, n = 1,2,3,4,5 \]

(10)

According to the engineering and test experience, mean square error can be taken as:
\[ \sigma = \frac{\left(b_{j} - a_{j}\right)}{m} \]

(11)

In the above formula, \( K_n \) is the correlation degree of evaluation index for element \( j \) relative to grade \( n \); \( x_j \) is the value of evaluation index \( j \); The upper and lower bounds of \( j \) element \( n \) evaluation interval; \( n \) is the evaluation level, divided into 1 ~ 5; \( m \) is the variance coefficient. According to the engineering test and the discrete degree of each element, it is considered that the value of \( m \) is between 10 and 14. The value in this paper is taken as 12.

2.2.2. Weight correction of evaluation elements based on stripping variable weight method.

The index layer and its subordinate elements are not necessarily independent of each other, and the elements with large damage can more reflect the defect of the higher layer elements. Therefore, the weight corrected by considering the different damage contributions of each element in the index layer.
on the evaluation of the upper elements. In previous studies, the results of the variable weight calculation in some evaluation areas are inconsistent with the development of structural damage [11]. In this paper, the stripping variable weight method is proposed. When it is used to modify the weights of the lower layer elements belonging to the same upper element, the weight of the modified element is temporarily separated from the total weight of the upper element, and the weight of other elements is corrected by the residual weight. This process is repeated from severe to minor, depending on the degree of element damage. After modification, the relationship between the element state and each grade is:

$$\sum_{j=1}^{n} k_{jj} = \frac{\sum_{j=1}^{n} w_j}{\sum_{j=1}^{n} w_j}$$  \hspace{1cm} (12)

In formula (12), the correction weight \( w_j \):

$$w_j = \eta_j w_j \left( \sum_{j=1}^{k} w_j - \frac{k}{\sum_{j=1}^{k} w_j} \right) \left( \sum_{j=1}^{k} w_j - \frac{k}{\sum_{j=1}^{k} w_j} \right)$$  \hspace{1cm} (13)

The weight of each element is modified according to the correction coefficient \( \eta_j \), from large to small. Taking into account the maximum \( \eta_j \) between 2 ~ 3 is appropriate and in order to prevent the weight imbalance after correction, therefore, the correction coefficient of the element is calculated by formula (14):

$$\eta_j = 1 + \sum_{n=1}^{k} 2(n-1)k_{jj} / 5$$  \hspace{1cm} (14)

According to the formula (14), the state of the element is worst when the \( \eta_j \) is 2.6, so the weight correction range is from 1 to 2.6.

If an element is corrected by formula (13), and the weight satisfies \( w_j > \sum_{j=1}^{k} w_j \), it shows that the sum of the weights of the lower elements has exceeded the weight of the subordinate elements. Then the correction coefficient is no longer introduced, and the elements are corrected by formula (15) again. The weights of this element and the remaining elements are:

$$w_j = w_j \left( \sum_{j=1}^{k} w_j - \frac{k}{\sum_{j=1}^{k} w_j} \right) \left( \sum_{j=1}^{k} w_j - \frac{k}{\sum_{j=1}^{k} w_j} \right)$$  \hspace{1cm} (15)

2.3. Project layer and target layer evaluation

Due to the relative independence between the project layer elements of the evaluation model, the element does not consider weight correction. The correlation degree is obtained by weighted average. In order to unify with the literature [1], the evaluation result of project layer is expressed by \( R_j \), the evaluation result of target layer is expressed by the whole bridge durability condition score \( D_r \).

The correlation degree of project layer and target layer is calculated according to the following formula:

$$K_{rr} = \frac{\sum_{j=1}^{n} \left( w_j^r k_{rr} \right)}{\sum_{j=1}^{n} w_j^r}$$  \hspace{1cm} (16)

$$R_j = \sum_{n=1}^{k} 5(n-1)k_{rr} / 4$$  \hspace{1cm} (17)

$$D_r = 100 - \sum_{j=1}^{n} R_j w_j / 5$$  \hspace{1cm} (18)

3. Evaluation Example

In this paper, an example of a beam in the Chao-yang bridge and is used to illustrate the method and process of evaluation. The Chao-yang bridge is a three span simple supported beam bridge each span consists of seven beams. One of the beams was selected to be evaluated. After testing, we found that it was damaged because of human and environmental effects, mainly manifested as: protective layer
peeling, steel corrosion and exposure. The durability damage index of the beam is as follows, bending (stress) crack: 0.15mm; date-stone crack: 0.45mm; inclined crack in web: 0.35mm; concrete corrosion rate at 13%; steel corrosion rate (middle span) at 2%. According to the durability evaluation of the reinforced concrete simple supported beam bridge and based on the interval correlation degree, the process is as follows.

3.1. Determining the initial weight of the example
Firstly, the relative importance of each index is determined, that is to say, a two-two comparison judgment matrix is constructed. In order to reflect the uncertainty and fuzziness of each evaluation index, the mode of interval number judgment matrix is adopted in this paper. The judgment matrix of each evaluation index in project layer established by experts is shown in table 6. For example: the value of element \(a_{24}\) (Second row fourth column element) in table 6 is \([3, 4]\), its meaning is if compared "cross connection" and "pier", its importance is between 3 and 4. Other elements of the upper triangle have the same meaning, and the elements of the lower triangle are determined according to the reciprocal of the triangular elements.

The comparison of the elements in each level is made step by step from top layer to bottom layer, the interval number judgment matrix in the evaluation model can be obtained. The following is the importance of the evaluation index of the project layer to the target layer. The specific calculation process is as follows. It is necessary to note that this article focuses on the introduction of the method, so that other layers of computing process is ignored (Table 6 as an example, other table omitted):

Table 6 is calculated according to formula (1), the upper and lower point matrix \(A\) and \(A^+\) can be obtained. Then it calculated according to formula(2). The following results can be obtained:

\[
\begin{align*}
&x_m = (0.3965, 0.2402, 0.1396, 0.0880, 0.0359) \\
&x_\bar{m} = (0.4743, 0.3084, 0.1683, 0.0969, 0.0364) \\
&k = 0.9001 < 1 < m = 1.0843
\end{align*}
\]

According to the relationship between \(k\) and \(m\), the consistency of interval judgment matrix is better.

Then it can be obtained by formula (3):

\[
S_1=<0.3965, 0.4743>, S_2=<0.2402, 0.3084>, S_3=<0.1396, 0.1683>, S_4=<0.0880, 0.0969>, S_5=<0.0359, 0.0364>
\]

Then it can be obtained by formula (4):

\[
V=(S_1 \geq S_5)=11.2033, V=(S_2 \geq S_5)=7.9296, V=(S_3 \geq S_5)=9.0727, V=(S_4 \geq S_5)=12.9650.
\]

Therefore, \(P_1=11.2033, P_2=7.9296, P_3=9.0727, P_4=12.9650, P_5=1.\) The single ordering weight value of the project layer on the target layer is \(P= (0.2657, 0.1880, 0.2151, 0.3074, 0.0237)\). 

3.2. Sub-index layer and index layer evaluation of the example
According to the inspection results and calculation method of formula (5) ~ (11), the concrete crack of the main beam is evaluated, and the results are shown in Table 7. According to the evaluation results of concrete cracks and other elements inspection results, the main beam index layer can be evaluated. Then the weight is corrected by the method of peeling variable weight, and the corresponding formula are (12) ~ (15). The results of evaluate calculation and weight correction are shown in Table 8. Similarly, other parts of the evaluation and weight correction results are shown in Table 9 ~ 13.
### Table 7 Concrete crack evaluation table of main beam

| Evaluation element                  | Initial weight | Index value | Correlation degree of each evaluation grade |
|-------------------------------------|----------------|-------------|--------------------------------------------|
|                                     |                |             | first level | second level | third level | fourth level | fifth level |
| Bending crack                       | 0.82           | 0.15        | 0.201      | 0.718        | 0.081       | 0.000        | 0.000       |
| Date-stone crack                    | 0.82           | 0.45        | 0.007      | 0.129        | 0.864       | 0.000        | 0.000       |
| Inclined crack in web               | 0.82           | 0.35        | 0.070      | 0.517        | 0.413       | 0.000        | 0.000       |

### Table 8 Evaluation table of main beam

| Evaluation element                  | Initial weight | Index value | Correlation degree of each evaluation grade | Modified weight |
|-------------------------------------|----------------|-------------|--------------------------------------------|-----------------|
| Concrete corrosion                  | 4.12           | 0.06        | 0.336                                      | 0.660           | 0.004       | 0.000       | 0.000       | 3.89 |
| Concrete crack                      | 2.46           | 0.093       | 0.455                                      | 0.453           | 0.000       | 0.000       | 0.000       | 3.80 |
| Rebar corrosion                     | 15.22          | 0.02        | 0.218                                      | 0.592           | 0.190       | 0.000       | 0.000       | 14.37 |
| Protective layer damage             | 4.77           | 0.2         | 0.096                                      | 0.821           | 0.084       | 0.000       | 0.000       | 4.51 |

### Table 9 Concrete crack evaluation table of cap beam

| Evaluation element                  | Initial weight | Index value | Correlation degree of each evaluation grade |
|-------------------------------------|----------------|-------------|--------------------------------------------|
|                                     |                |             | first level | second level | third level | fourth level | fifth level |
| Bending crack                       | 1.08           | 0.06        | 0.591      | 0.405        | 0.005       | 0.000        | 0.000 |
| Inclined crack in web               | 1.08           | 0.55        | 0.001      | 0.058        | 0.942       | 0.000        | 0.000 |

### Table 10 Evaluation table of cap beam

| Evaluation element                  | Initial weight | Index value | Correlation degree of each evaluation grade | Modified weight |
|-------------------------------------|----------------|-------------|--------------------------------------------|-----------------|
| Concrete corrosion                  | 2.16           | 0.13        | 0.235                                      | 0.628           | 0.372       | 0.000       | 0.000       | 3.35 |
| Concrete crack                      | 1.96           | 0.13        | 0.296                                      | 0.232           | 0.474       | 0.000       | 0.000       | 2.59 |
| Rebar corrosion                     | 13.52          | 0.015       | 0.278                                      | 0.622           | 0.100       | 0.000       | 0.000       | 12.11 |
| Protective layer damage             | 3.87           | 0.1         | 0.303                                      | 0.652           | 0.045       | 0.000       | 0.000       | 3.46 |

### Table 11 Concrete crack evaluation table of pier and abutment

| Evaluation element                  | Initial weight | Index value | Correlation degree of each evaluation grade |
|-------------------------------------|----------------|-------------|--------------------------------------------|
|                                     |                |             | first level | second level | third level | fourth level | fifth level |
| Crack under the mat                 | 1.32           | 0.25        | 0.020      | 0.587        | 0.393       | 0.000        | 0.000       |
| Faults and fractures                | 1.32           | 0.1         | 0.425      | 0.553        | 0.022       | 0.000        | 0.000 |

### Table 12 Concrete corrosion evaluation table of pier and abutment

| Evaluation element                  | Initial weight | Index value | Correlation degree of each evaluation grade |
|-------------------------------------|----------------|-------------|--------------------------------------------|
|                                     |                |             | first level | second level | third level | fourth level | fifth level |
| Dissolution corrosion               | 3.72           | 0.16        | 0.000      | 0.409        | 0.585       | 0.005       | 0.000       |
| Freeze-thaw corrosion               | 3.72           | 0.12        | 0.016      | 0.654        | 0.330       | 0.000       | 0.000       |
Table 13 Evaluation table of pier and abutment

| Evaluation element         | Initial weight | Index value | Correlation degree of each evaluation grade | Modified weight |
|----------------------------|----------------|-------------|--------------------------------------------|-----------------|
|                            |                | first level | second level | third level | fourth level | fifth level |                |
| Concrete corrosion         | 7.44           | 0.008       | 0.532       | 0.458      | 0.003       | 0.000       | 11.78          |
| Concrete crack             | 2.64           | 0.223       | 0.570       | 0.208      | 0.000       | 0.000       | 1.58           |
| Rebar corrosion            | 13.04          | 0.01        | 0.934       | 0.066      | 0.625       | 0.000       | 7.81           |
| Protective layer           | 7.62           | 0.45        | 0.006       | 0.631      | 0.364       | 0.000       | 9.57           |

3.3. Project layer evaluation

If the subordinate elements of each project layer element were weighted and summed, we can get the correlation degree of each elements of the project layer and each evaluation grade. The calculated evaluation value are given in Table 14.

Table 14 Evaluation form of project layer

| Project layer element | Initial weight | Correlation degree of each evaluation grade | Evaluation division value | Technical condition grade |
|-----------------------|----------------|--------------------------------------------|---------------------------|--------------------------|
| Main beam             | 26.57          | 0.197 0.621 0.182 0.000 1.231             | second level              |                          |
| Cross connection       | 18.80          | 0.000 0.992 0.008 0.000 1.260             | second level              |                          |
| Capping beam          | 21.51          | 0.000 0.277 0.581 0.179 0.000 2.470       | third level               |                          |
| Piers and abutments   | 30.74          | 0.254 0.446 0.458 0.002 0.000 1.710       | second level              |                          |
| Support               | 2.37           | 0.000 0.994 0.006 0.000 1.258             | second level              |                          |

3.4. Target layer evaluation

According to the results of the final evaluation of each element of the project layer, the correlation degree between the overall state of the bridge and the evaluation grade one to five is (0.130, 0.571, 0.310, 0.039, and 0.000). According to the formula (18), the durability score of the bridge is 95.59, and the durability of the bridge can be classified as grade one by reference to table two.

3.5. Countermeasure

Based on the above evaluation results, the integrity of the bridge is better from the perspective of durability, and it has great value to continue to use. But at the same time, we also need to make reasonable maintenance and reinforcement of the bent cap.

4. Conclusion

In this paper, the interval number is introduced into the analytic hierarchy process to evaluate the structural durability of concrete simple supported beam bridge. The method has the following characteristics:

(1) Taking into account the relative importance of each evaluation index is fuzzy, in this paper, the range of evaluation indexes is given by expert experience. Therefore, this uncertainty is quantified, and finally provides convenience for the evaluation.

(2) This paper introduces the interval numbers in the theory of extension instead of point numbers to construct judgment matrix, the relative importance of each evaluation index is quantified according to the evaluation experts' thinking. It solves the problem of fuzziness and uncertainty in expert experience judgment of traditional analytic hierarchy process.

(3) Due to the uncertainty of the factors affecting the bridge, the normal correlation function is constructed in this paper, and the correlation degree of each evaluation element to each evaluation grade is used as the basis for the quantitative evaluation of the bridge. Considering the different
contributions of different damage to the evaluation results, the weight is corrected by the stripped variable weight method.

(4) The index layer element and sub-index layer element is evaluated using correlation degree. The correlation degree and the evaluation division value are both used to represent the defect state of the elements of the project layer. The whole bridge durability condition, that is the target layer, is represented by the grade and the condition score. Finally, the durability evaluation of reinforced concrete simple supported beam bridge is realized.

Acknowledgments
This project was supported by the Project of Chongqing science and Technology Committee (cstc2018jcyjAX0360), Scientific and Technological Research Program of Chongqing Municipal Education Commission (KJQN201901207).

References:
[1] JTG H11-2004, Code for Maintenance of Highway Bridges and Culvers[S]
[2] SAATY T L. The analytic hierarchy process [M]. New York: Mc Graw-Hill, 1980.
[3] Gao Jie, Sheng Shao-han. A study on the extension AHP method [J]., 2002, 20(5):6-11.
[4] Zhu Jian-jun, Liu Shi-xin, Wang Meng-guang. Novel Weight Approach for Interval Numbers Comparison Matrix in the Analytic Hierarchy Process[J]. System Engineering-theory practice, 2005, 4: 29-34.
[5] Xu Ze-shuai, Da Qing-li. Possibility degree method for ranking interval numbers and its application[J] Journal of Systems Engineering, 2003, 18(1): 67-70.
[6] David V. Jáuregui, Tuyen Nguyyengoc and Kenneth R. White. Floor System Evaluation of a Riveted Steel Arch Bridge [J]. Practice Periodical on Structural Design and Construction, 2008(13):67~77
[7] Ferhat A, Dan M F. Bridge Rating and Reliability Correlation: Comprehensive Study for Different Bridge Types [J]. Journal of Structural Engineering, 2004, 130( 7): 1063~1074
[8] Baidurya B, De-gang Li, Michael C,etal. Reliability-Based Load and Resistance Factor Rating Using In-Service Data [J]. Journal of Bridge Engineering, 2005, 10( 5):530~543