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Health State Evaluation of Continuous Girder Bridge Based on Fuzzy Analytic Hierarchy Process

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Key words: fuzzy analytic hierarchy process; evaluation of bridge conditions; grade of technical state; continuous girder bridges; degree of membership

Abstract: Based on fuzzy analytic hierarchy process, The model of bridge health evaluation is established using the quantification relations between the bridge technical state evaluation grade and degree of membership function of bridge health evaluation, making use of the computed result of various index of degree of membership value and weight, obtains all levels of fuzzy evaluation collection. According to the maximum membership principles to evaluate the technical state grade of bridge structure the corresponding level, and with its result to instruct the decision-making of bridge maintenance and strengthening.

Introduction

After the bridge being completed in construction, there are the latent danger as a result of design or constructional deficiency, either be influenced the natural factors such as climate and environment and so on, either damaged due to increase daily traffic flow and loading action. To improve service-life and reliability of bridge structure, the service bridge should need a diagnosis for regular and long-term status, monitoring and evaluation of the bridge for the existence of structural damage and hazard, take corresponding measures in a timely manner for a variety of defective bridges [1, 2]. By mean of the fuzzy analytic hierarchy process (AHP) to estimate the bridge health state and guide the decision-making of bridge maintenance and strengthening.

Continues beam superstructure health evaluation system

Making use of AHP to establish bridges health evaluation model, with multi-level fuzzy comprehensive evaluation and scoring combined， analysis of bridge health evaluation to determine the various factors and the degree of membership, through fuzzy computing to evaluate the health state of bridge.

There are many factors to affect the strength and stability of the bridge, according to the specification, establish its evaluation system that may affect the evaluation index and sub-goals of reinforced concrete continues girder superstructure. The evaluation index system is shown in Fig.1.

Fuzzy Analytic Hierarchy Process Evaluation Models

Literature [3] elaborates the method of Fuzzy AHP comprehensive evaluation. When the bridge carries on the comprehensive evaluation, the influence factors will be broken down into several levels and established different levels of the factor sets to show $U=\{u_1,u_2,\cdots,u_n\}$.There are m remarks in all possible review, signed evaluation sets to show $V=\{v_1,v_2, \cdots,v_m\}$, According to the technical condition evaluation grade of bridge specification, there are five grades corresponding bridge health state, they are good, Fair, poor, bad, dangerous.

According to the evaluation sets， establish a fuzzy mapping from factor sets *U* to evaluation sets *V* for single index evaluation, namely $f: U \rightarrow V$, $f(u_i)=(r_{i1}, r_{i2}, ..., r_{im})$, $i=1,2, \ldots,n$, Where $f(u_i)$=remark fuzzy vector about factor u_i; r_{ij}=the degree which factor u_i possess remark v_j. the fuzzy mapping *f* may derive out the fuzzy relation from *U* to *V*, and compose the fuzzy evaluation matrix of $U \times V$, namely $R = R_f = \left(r_{ij}\right)_{n\times m}$.

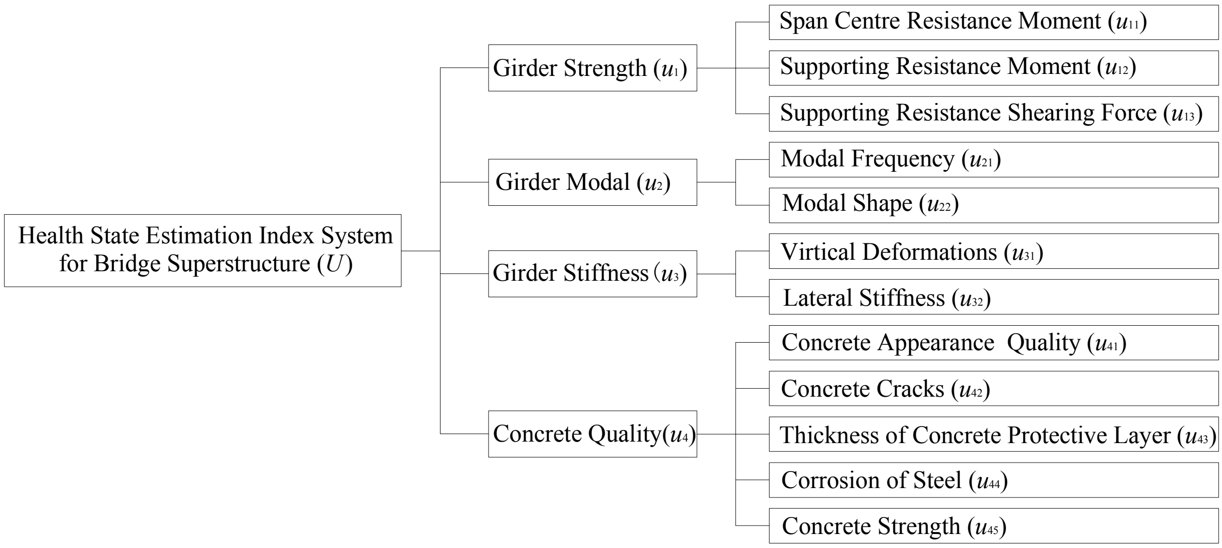

Fig.1 Reinforced concrete continues girder evaluation index system

In order to obtain the influence of every index for the comprehensive evaluation, determine the weight of every index and compose the weight fuzzy vector $A = \left(a_1, a_2, \cdots, a_n\right)$. By selecting the appropriate fuzzy operator, get a fuzzy evaluation vector $B = A \circ R = \left(b_1, b_2, \cdots, b_m\right)$, Where $A =$ the weight distribution of the various factors；“$\circ$”is fuzzy operator according to the need of practical problems, select a specific method of fuzzy comprehensive evaluation. In consideration of the influence of different index in the evaluation process, fuzzy operator $(\bullet, +)$ is adopted, namely $b_j = \sum_{i=1}^{n} a_i \bullet r_{ij,}(j = 1, 2, \ldots m)$, where $\sum_{i=1}^{n} a_i = 1$ is required. According to the evaluation sets and the principle of the maximum degree of membership, the grade of the bridge health status can be determined and adopt the appropriate maintenance method.

Determination of index Weight and degree of membership

Determination of index weight. The determination of index weight is one of fuzzy comprehensive evaluation key questions, the weight of various factor should accord with the actual situation as far as possible, the common methods have Delphi Method, the expert investigation method and the analytic hierarchy process (AHP) [5,6,7,8] ,these methods have characteristics of practicality, systematicness and simplicity and so on. AHP is adopted to determine the weight of every influence factor in this paper.

Degree of membership function. The triangle fuzzy distribution function is adopted to express various factors degree of membership function in this paper. It is shown in Fig. 2.

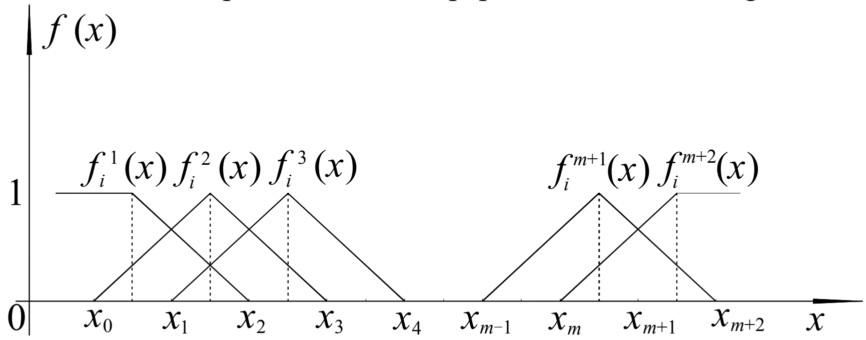

Fig.2 The triangle fuzzy distribution function

Regarding the member index i random observed value x, the membership function $f_i^k\left(x\right)$ may be figured out from Fig. 2, it pertains to the evaluation collection $k\left(k=1,2,\cdots,m\right)$

$$f_i^1\left(x\right)=\begin{cases}1, x<\lambda_0\\ \left(x_3-x\right)/\left(x_3-\lambda_0\right), x\in\left[\lambda_0,x_2\right]\\ 0, x>x_2\end{cases}$$
$$f_i^k\left(x\right)=\begin{cases}0, x\notin\left[x_{k-2},x_{k+1}\right]\left(k=2,\cdots,m+1\right)\\ \left(x-x_{k-2}\right)/\left(\lambda_{k-1}-x_{k-2}\right), x\in\left[x_{k-2},\lambda_{k-1}\right]\\ \left(x_{k+1}-x\right)/\left(x_{k+1}-\lambda_{k-1}\right), x\in\left[\lambda_{k-1},x_{k+1}\right]\end{cases} \tag{1}$$
$$f_i^{m+2}\left(x\right)=\begin{cases}0, x<x_m\\ \left(x-x_m\right)/\left(\lambda_{m+1}-x_m\right), x\in\left[x_m,\lambda_{m+1}\right]\\ 1, x>\lambda_{m+1}\end{cases}$$

Where $\lambda_k=\left(x_k+x_{k+1}\right)/2$, it is the value that the degree of membership function of the number k evaluation collection is equal to 1, then the degree of membership function of the number i index about the number k evaluation collection is $f_i^k(\bullet), i=1,2,\cdots,n; k=1,2,\cdots,m$, the range of the degree of membership function is $\left[x_1,x_{m+1}\right]$,it is divided into m districts, respectively $\left[x_1,x_2\right]$,…, $\left[x_{k-1},x_k\right]$,…, $\left[x_{m-1},x_m\right]$,$\left[x_m,x_{m+1}\right]$, $x_k\left(k=1,2,\cdots,m,m+1\right)$, The value of each interval is generally determined according to the actual situation or the results of qualitative research..

Threshold value of evaluation index. According to code for Maintenance of highway bridges and culvers and specification of inspection and experiment [9], Threshold value of bridge health evaluation index can be gained corresponding evaluation collection. Specific threshold values are shown in Table 1.

Tab.1 Health State Evaluation Index System for Service Continuous Girder Bridge

Factor Sets		Evaluation Sets				
First factor sets	Secondary factor sets	Good	Fair	Poor	Bad	Dangerous
Girder Strength	Span centre resistance moment(η^a)	(0,0.7]	(0.7,0.8]	(0.8,0.9]	(0.9,1]	(1, +∞)
	Supporting resistance moment(η)	(0,0.7]	(0.7,0.8]	(0.8,0.9]	(0.9,1]	(1, +∞)
	Supporting Resistance Shearing Force(η)	(0,0.7]	(0.7,0.8]	(0.8,0.9]	(0.9,1]	(1, +∞)
Girder modal	Modal Frequency(η)	[1.2,+∞)	[1.15,1.2)	[1.1,1.15)	[1.1,1)	[0,1)
	Modal shape/(%)	[90,+∞)	[80,90)	[70,80)	[60,70)	(60,0)
Girder stiffness	Virtical Deformations(η)	(0,0.7]	(0.7,0.8]	(0.8,0.9]	(0.9,1]	(1, +∞)
	Lateral Stiffness(η)	[1.09,+∞)	[1.06,1.09)	[1.03,1.06)	[1,1.03)	[0,1)

Concrete quality	Concrete appearance quality/(%)	[0,5)	[5,10)	[10,15)	[15,20)	[20,+ ∞)
	Concrete cracks/(mm)	[0,0.15)	[0.15,0.23）	[0.23,0.31)	[0.31,0.4)	[0.4, +∞)
	Thickness of concrete protective layer/(mm)	[8,+∞)	[6,8)	[4,6)	[2,4)	[0,2)
	Corrosion of steel/(mV)	(-50,0）	(-117,-50]	(-183,-117]	(-250,-183]	(-∞,-250]
	Concrete strength(η)	[1.5,+∞)	[1.33,1.5)	[1.17,1.33)	[1,1.17)	[0,1)

[a]Check coefficient, it is the ratio of measured value to theoretical one

Case study

A concrete continuous girder bridge in a highway, its superstructure concretes surface showed many cracks as a result of construction quality after the bridge operation. Those cracks have the possibility to affect the bridge health state. Therefore the safety performances of bridge need to be evaluated[10][11]. According to the field measurement index, the bridge superstructure evaluation model system（Fig. 1）has been established and every index test result are shown in Table 2 when the bridge is evaluated.

Tab.2 Measured Values Bottom Evaluation Index

Subgoals	u_{11}	u_{12}	u_{13}	u_{21}	u_{22}	u_{31}	u_{32}	u_{41}	u_{42}	u_{43}	u_{44}	u_{45}
Measured Values	0.75	0.70	0.72	1.17	90	0.8	1.05	7	0.15	8	-30	1.56

Eq. (1) can figure out the degree membership function of index according to the measurement values. As for concrete crack u_{42}, its number domain value will be extended to $u_{42}^0 = 0.05$， $u_{42}^4 = 0.5$ ，and then the degree membership function of concrete crack will be available. Put the measurement values of concrete crack into its the degree membership function, figure out the value of membership function for the five evaluation collection, respectively 0, 0, 0.38, 0.92, 0.286. In a similar way, the degree of membership function value of other indexes can be calculated. The literature [7] may get the index weight of the evaluation matrix. According to the calculated each index value of degree of membership and weight, may get fuzzy evaluation collection at all levels, the result are shown in Table 3.

Tab.3 Fuzzy Hierarchy Comprehensive Evaluation Process

First factor sets	Weight	Secondary factor sets	Weight	Fuzzification vector	Secondary fuzzy evaluation	First fuzzy evaluation
Girder Strength	0.36	Span centre resistance moment	0.450	(0.16,0.87,0.32,0,0)	(0.476,0.680,0.191,0,0)	$\begin{pmatrix} 0.516 \\ 0.947 \\ 0.242 \\ 0.029 \\ 0.009 \end{pmatrix}^T$
		Supporting resistance moment	0.325	(0.78,0.3,0,0,0)		
		Supporting Resistance Shearing Force	0.225	(0.67,0.53,0.21,0,0)		
Girder modal	0.281	Modal Frequency	0.500	(0.12,0.91,0.24,0,0)	(0.16,0.9,0.1,0,0)	
		Modal shape	0.500	(0.2,0.89,0,0,0)		
Girder stiffness	0.231	Virtical Deformations	0.677	(0.2,0.92,0.32,0,0)	(0.22,0.897,0.273,0,0)	
		Lateral Stiffness	0.333	(0.26,0.85,0.18,0,0)		
Concrete quality	0.18	Concrete appearance quality	0.125	(0.42,0.83,0.21,0,0)	(0.669,0.332,0.14,0.016,0.05)	
		Concrete cracks	0.175	(0,0,0.38,0.92,0.286)		
		Thickness of concrete protective layer	0.100	(0.87,0.34,0.21,0,0)		
		Corrosion of steel	0.250	(0.87,0.33,0.11,0,0)		
		Concrete strength	0.350	(0.89,0.32,0,0,0)		

Based on maximum membership principle, this bridge superstructure achieves good health state grade (0.947), and partial to better (0.516). This shows that the crack has little affected on the carrying capacity of the bridge structure, in spite of appearance many surface cracks, and there are still certain safety reserves for the bridge structure. The structure surface crack may be due to non-force causes, such as temperature, maintenance conditions and so on. To appearance crack may take normal maintenance measures besides structure surface patching.

Conclusion

The evaluation index system of bridge health state may be established by means of the factors analysis of reinforced concrete continues girder bridge health state in service.

Using AHP method to determine the weight may reduce the uncertainty of the evaluation results and the evaluation subjective factors further reflect the objective reality.

Based on Triangular membership function, it is feasible and effective that the fuzzy AHP is used to evaluate the bridge health state, and with the actual situation of the bridge in service more consistent.

According to the principle of maximum membership degree and fuzzy evaluation results at all levels, may analyze the reason which the bridge health state descends, and thus makes the decision-making for the bridge structure element local maintenance and strengthening.

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