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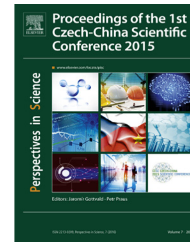

Research on safety assessment method for bridge structure based on variable weight synthesis method☆

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Summary Variable weight synthesis method is a safety assessment method which is using the varied weight principle, based on analytic hierarchy process and combining the theory of grey relevancy, it reduce influence that secondary cause is not obvious in assessment process, and make the result more correct and dependable. In the paper, variable weight principle and the assessment method were expounded in detail.

Variable weight principle and variable weights method

Variable weight principle

In the literature (Bai, 2007; Liu et al., 2004), variable weight synthesis method is the definition of:

(1) Assume that a m-dimensional vector, $W^0 = (W_1^0, W_2^0, \ldots, W_m^0)$, if present $W_j^0 \in (0, 1)$ makes $\sum_{j=1}^{m} W_j^0 = 1$ correct for arbitrary variables $j \in \{1, 2, \ldots, m\}$;

(2) Given a $m-d$ vector of parts keep weight $W(X)\triangle[W_1(X)2W_1(X), \ldots, W_m(X)]$, for given mapping: $W: [0, 1]^m \to (0, 1]$, it makes that:
   (1) $\sum_{j=1}^{m} W_j(X) = 1$
   (2) Assume that $\alpha_j, \beta_j \in [0, 1]$, and $\alpha_j \leq \beta_j$, for arbitrary variables $j \in \{1, 2, \ldots, m\}$, present W_j in regard to x_j in the internal $[0, \alpha_j]$ and $[\beta_j, 1]$ respectively decrease and increase progressively.
   (3) Assume that the vector $S(X)\triangle[S_1(X), S_2(X), \ldots, S_m(X)]$ is a $m-d$ vector of parts variable weight, for the given mapping $S: [0, 1]^m \to (0, +\infty)^m$, for arbitrary variables $j \in \{1, 2, \ldots, m\}$, assume $\alpha_j, \beta_j \in [0, 1]$, and $\alpha_j \leq \beta_j$ present that:
      (1) For arbitrary variables $j \in \{1, 2, \ldots, m\}$ for fixed weights vector $W^0 = (W_1^0, W_2^0, \ldots, W_m^0)$, $W_j(X) = ((W_j^0 S_j(X))/(\sum_{k=1}^{m} W_k^{(0)} S_k(X)))$ in the internal $[0, \alpha_j]$ and $[\beta_j, 1]$ respectively decrease and increase progressively.

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(2) If $0 \le x_i \le x_k \le \alpha_i \wedge \alpha_k$, $S_i(x) \ge S_k(x)$, and $\beta_i \vee \beta_k \le x_i \le x_k \le 1$, then

$$\frac{w^0 \cdot S(x)}{\sum_{j=1}^{m} w_j^0 S_j(x)} \triangleq \left\{ \frac{w_1^0 \cdot S_1(x)}{\sum_{j=1}^{m} w_j^0 S_j(x)}, \frac{w_2^0 \cdot S_2(x)}{\sum_{j=1}^{m} w_j^0 S_j(x)}, \dots, \frac{w_m^0 \cdot S_m(x)}{\sum_{j=1}^{m} w_j^0 S_j(x)} \right\} \quad (1)$$

be called $m-d$ vector of parts variable weight。

Amendment of variable weights method

In the variable weights method, when synthesis assessment the assessed value of hundred-mark system, it will result data with denominator larger, and produce larger round-off error. For convenience of calculations and considering the required precision, to transform hundred-mark system into percentage of system, and then, by adjusting coefficients in the formulas, getting the synthesis assessed value of hundred-mark system. in addition, for some sequences of inspection data, it is impossible to collect all the data, but it is needed to compare the curve of sequences of inspection data, so in this paper, considering base on the grey theory related principle to offset the malconformation and incomprehensive of data (Lan and Shi, 2001). The paper makes the improvement.

$$V = \sum_{j=1}^{m} 100 w_j(x_1, \dots, x_m, w_1^{(0)}, \dots, w_m^{(0)}) x_j \quad (2)$$

In formula: V is the assessed value; $w_j^{(0)}$ is initial weight value of the jth indicators, and $\sum_{j=1}^{n} w_j^{(0)} = 1$; w_j is weight value after variable weight; x_j is the percentage of assessment value of the jth indicators, and

$$w_j(x_1, \dots, x_n, w_1^{(0)}, \dots, w_n^{(0)}) = \frac{w_j^{(0)}((\partial B(x_1, \dots, x_n))/\partial x_j)}{\sum_{k=1}^{n} w_k^{(0)}((\partial B(x_1, \dots, x_n))/\partial x_k)} \quad (3)$$

In formula, $B(x_1, \dots, x_n)$ is balanced function, according to experience of engineering practice, the balanced function is:

$$B(x_1, \dots, x_n) = \sum_{j=1}^{n} x_j^{\alpha} \quad (0 < \alpha \le 1) \quad (4)$$

simultaneous Eqs. (3) and (4), it can get:

$$w_j(x_1, \dots, x_n, w_1^{(0)}, \dots, w_n^{(0)}) = \frac{w_j^{(0)} x_j^{\alpha-1}}{\sum_{k=1}^{n} w_k^{(0)} x_k^{\alpha-1}} \quad (5)$$

so

$$V = \sum_{j=1}^{m} \frac{100 w_j^{(0)} x_j^{\alpha}}{\sum_{k=1}^{n} w_k^{(0)} x_k^{\alpha-1}} \quad (6)$$

α: balance coefficient, according to experience of engineering practice, $\alpha = 0.2$, it can meet most of engineering situation.

The inspection data of bridge can be divided into three categories: the first kind is non-numeric data with describing the state of bridge components only or dividing grade simply; the second is a single numerical; and the third is a data series. It is needed that applies dimensionless method to the third kind data, compare and analyse the two curves of data series. Introduce grey correlativity analysis and calculate non-uniform variation coefficient to get the assessment result, the formula as follows:

$$V = \sum_{j=1}^{m} \frac{100 w_j^{(0)} x_j^{\alpha}}{\sum_{k=1}^{n} w_k^{(0)} x_k^{\alpha-1}} r(x_0, x_i) \quad (7)$$

And $r(x_0, x_i)$ calculate according to the formula as below (5) and (8):

$$r(X_0, X_i) = \frac{1}{n-1} \sum_{k=1}^{n-1} \left[1 + \left| \frac{a^{(1)}(x_0(k+1))}{x_0(k+1)} - \frac{a^{(1)}(x_i(k+1))}{x_i(k+1)} \right| \right]^{-1} \quad (8)$$

Advantage of variable weight synthesis method

Compared with constant weight synthesis method, variable weight synthesis method can make the influence of components with damage badly more prominent. In structure, maybe individual component damage can be lead to the bridge operational be limited, even impact to the safety of the bridge (Gao and Wang, 2000; Lan and Shi, 2001; Wu and Xiang, 1995; Xiang and Wu, 2005; Zhang and Feng, 2001). Comparison with the result of constant weight synthesis method and variable weight synthesis method is given.

Using the data in Tables 2.1 and 2.2, assessment of the health of bridge with variable weight synthesis method and constant weight synthesis method is shown.

(1) Constant weight synthesis method:

$$BCI_2 = 80 \times 0.31 + 80 \times 0.13 + 75 \times 0.14 + 80 \times 0.37 + 5 \times 0.04 = 75.51 > 6$$

The conclusion is ''qualified'';

(2) Variable weight synthesis method ($\alpha = 0.2$):

$$\sum_{k=1}^{m} w_k^{(0)} x^{\alpha-1} = \sum_{k=1}^{9} w_k^{(0)} x_k^{-0.8} = 0.31 \times 0.80^{-0.8} + 0.13 \times 0.80^{-0.8} + 0.14 \times 0.75^{-0.8} + 0.37 \times 0.80^{-0.8} + 0.04 \times 0.05^{-0.8} = 1.5840$$

score V_2:

$$V_2 = \frac{100 w_j^{(0)} x_j^{\alpha}}{\sum_{k=1}^{n} w_k^{(0)} x_k^{\alpha-1}} = \frac{100}{1.5840}(0.2965 + 0.1243 + 0.1322 + 0.3539 + 0.0220) = 58.64$$

The conclusion is ''disqualified''.

Explain: The value of α reflects tolerance of local damage, with the increase of α, tolerance increase.