Reliability Based Resource Allocation in Bridge Maintenance

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Introduction

There is a need for significant investment to repair civil infrastructures worldwide, which are deteriorating under heavy use, severe exposure conditions, and age. Among these, road and railway transportation associated structures play an important role in ground transportation systems and constitute a considerable investment in infrastructure and directly affect the productive capacity of a country (Kong and Frangopol, 2004; Atashi *et al.*, 2007).

In addition to condition evaluation of bridges individually, there is a need to evaluate the condition of bridge paths to guarantee the safety of the total system. This arises from the fact that failure of one bridge in a bridge path affects the total system, especially in case of disasters. Consequently, it is essential to optimise resources expenditure in bridge paths.

Methodology

Bridges can fail under different types of failure mode. The critical types of failure mode for a selected bridge can be different from one type of bridge to another. Depending on the type of bridge, failure modes are proposed considering critical failure modes of the bridge concerned as shown in Eq. (1).

$$M_i = Z_{R_i} - Z_{S_i} \qquad i = 1, 2..., n \tag{1}$$

Where, M_i is the safety margin for i^{th} mode of failure of the bridge concerned, Z_{R_i} is the strength variable and Z_{S_i} is the load variable. The reliability index (β_i) and failure probability (P_{f_i}) for i^{th} failure mode can be calculated as the first step. Assuming that all failure modes can be combined into a series system for the bridge concerned, it is possible to calculate the system failure probability (P_F) from simple bounds as shown in equation (2) (Christensen and Baker, 1982; Christensen and Murotsu, 1986).

$$\underset{i=1,2}{\overset{n}{Max}} P_{f_i} \le P_F \le 1 - \prod_i^n (1 - P_{f_i}) \tag{2}$$

Where, P_F is the system reliability index of the bridge.

In one route or path, there exist more than one bridge and failure of one bridge makes the road to be ineffective. As this happens, the bridge system located in a route can be considered as a series system. Supposing, there are l number of bridges situated in one path, the path failure probability can be found as below.

$$\underset{i=1,2}{\overset{l}{Max}} P_{F_i} \le P_{Fl} \le 1 - \prod_i^l (1 - P_{F_i}) \tag{3}$$

Where, P_{Fl} is the path failure probability.

For the paths having higher failure probabilities, more resources can be allocated. If path reliability is calculated at different time intervals, preparations can be made on future resource planning.

Numerical example

Assume there are three different routes connecting two cities A and B as shown in Figure 1 and bridges are located as shown in the figure.

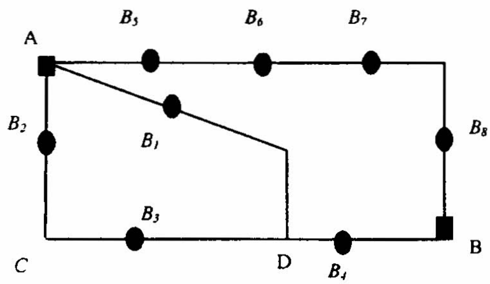

Figure 1. Bridge network between two cities

In general, when a bridge is constructed initially, its reliability index is a high and it reduces with time. Allowable reliability indices are around 2 to 3. Considering these, the reliability indices of different bridges given in Table 1 were assumed.

Table 1. Assumed failure probabilities of bridges

Bridge	System reliability index	System failure probability
B_1	4.94	3.5×10^{-5}
B_2	5.35	4.5×10^{-6}
B_3	4.87	5.5×10^{-5}
B_4	4.81	7.5×10^{-5}
B_5	4.81	7.5×10^{-5}
B_6	4.80	8.0×10^{-5}
B_7	5.03	2.5×10^{-5}
B_8	5.25	1.0×10^{-5}

Initially, from the values of system reliability indices of bridges, system failure probabilities can be found as shown in the third column of Table 1 and using those, path failure probabilities can be found as outlined in Table 2.

Table 2. Path failure probabilities

Path	Lower bound path Failure probability	Upper bound path Failure probability
AEB	8×10^{-5}	19×10^{-5}
ACDB	7.5×10^{-5}	11×10^{-5}
ADB	7.5×10^{-5}	13.5×10^{-5}

Discussion

This paper proposes a way to evaluate bridge paths performances using reliability theory. As shown in the numerical example, different path failure probabilities can be found and using this process, path performance can be evaluated. Depending on the path failure probabilities, resources can be allocated in a comprehensive way.

This is the first publication of the authors regarding the concept of resources expenditure using reliability index. They expect to do more research in this area for greater understanding.

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