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A RELIABILITY-BASED APPROACH FOR HIGHWAY BRIDGES SUBJECTED TO PROGRESSIVE DETERIORATION

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ABSTRACT

Progressive deterioration (*e.g.*, corrosion) of the ageing bridge infrastructure is the main cause of structural deterioration and early failure of bridge especially in the marine environment. This paper presents a reliability-based approach for predicting the residual life of a bridge subjected to progressive deterioration. Specially, this study mainly focuses on developing a numerical approach for assessing the time-dependent probability of failure of a bridges. The results of study show that the increase of progressive deterioration rates has a great impact on the decrease of bridge residual life. Further, the proposed realibility-based approach demonstrates the potential use for assessing probability of failure as well as predicting the residual life of bridges.
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KEY WORDS: Reliability approach; bridge; progressive deterioration; residual life.

INTRODUCTION

Highway bridges operation and maintenance contribute significantly to the overall annual transportation budget. The total direct cost attributed to structural deterioration of transport infrastructure systems represents billion dollars in US and UK [1-3]. It is widely known that residual life prediction is an essential part of monitoring and maintenance programs of modern large infrastructure systems. For a long expected lifetime structure (*e.g.*, bridge) that last on overage 50-75 years, residual life prediction is a complex problems which associate with large uncertanties in the system's performance through its life. For example, the structure may be subjected to some unpredicted environmental conditions exposure to seawater or saline ground water, and are at risk of chloride-induced corrosion of steel reinforcement, as well as other deterioration mechanisms [4, 5]. Such unpredictable changes could led to a reduced of the service life of bridge structures due to accelerating rates of structural deterioration. As a large uncertainty in the system's performance through its lifetime, an accurate and reliable residual life prediction of a bridge becomes necessary.

Structural deterioration describes the time-dependent accumulation of damage process in any structure as a result of dynamic interaction with external events. In general, degradation process is considered affected by two basic mechanisms; progressive and shock-based degradation. While shock-based degradation (*e.g.* earthquake) describes sudden changes in the structural performance over small time intervals, progressive deterioration (*e.g.* corrosion) is a time-dependent phenomenon which continuously depleted at a rate over structural life time [6-8]. Progressive deterioration is generally driven by internal or external system conditions. It consists of series discrete damage occurrences which can be modeled as a continuous process; that is, loss of system capacity described by a rate that may change over time. In reinforced concrete structures, progressive deterioration is mainly caused by chloride ingress, which leads usually to steel corrosion, loss of effective cross-section of steel reinforcement, concrete cracking, loss of bond and spalling.

For over a decade, extensive researches have been carried out for developing progressive deterioration models [9-12]. Deterioration models establish a relationship between the structural capacity (*e.g.* performance indicator) and time. The main function of bridge deterioration models is to predict the residual life of bridge components. The service life of a bridge is defined as the period of time during which the component can fulfill its performance requirements. Most of progressive deterioration models are developed based on Markov Decision Processes (MDP) and Bayesian probability [13-17]. Although many structural deterioration models have been proposed, there are relatively few studies where the effect of random progressive deterioration using jump process on the residual life of bridges has been reported. Therefore, a reliability-based approach to estimate the bridge residual life caused by progressive deterioration has been

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developed in this study.

PROGRESSIVE DETERIORATION MODEL AND NUMERICAL APPROACH

The performance of a bridge structure throughout its life time subjected to progressive deterioration can be described by a life cycle model as shown in Fig. 1. When a structure is operated in service, damage may starts occurring and accumulating as a result of progressive deterioration until the structure fails. If the structure undergoes repairing or maintaining, the process will restart at the beginning.

In a life cycle model, the performance of a structure throughout its life time is usually described in term of structural capacity (*e.g.* material resistance, drift).The structural life time is defined as the length of time required by a structure to reach a predefined performance threshold values (*e.g.* $u*$ and $v*$). As shown in Fig. 1, the threshold $u*$ describes the minimum structural performance level while the threshold $v*$ is the ultimate structural capacity which refers to structural collapse.

Progressive deterioration describes a countinous process of the system's capacity reduction as a result of a series of discrete damage occurrences in which the actual damage at any point occur within small time interval. This type of deterioration can be evaluated in term of deterministic or random probabilistic models. The progressive deterioration model can be first developed by a continuous deterministic function which usually assumed has a continuous positive rate. This type of deterioration refers to *graceful* deterioration.

Since the time-dependent of deterioration rate is not always available at hands, the progressive deterioration can be approximated by 'jumps' that is a sequence of small countable discrete changes in structural system as shown in Fig. 2. In this case, the deterioration is assumed as a jump process with the size of every jump is random and occurs at a certain fix time interval.

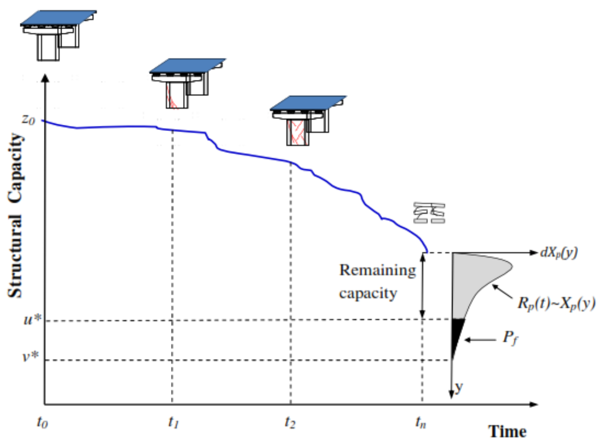

Fig. 1. Life cycle model of a bridge subjected to progressive deterioration

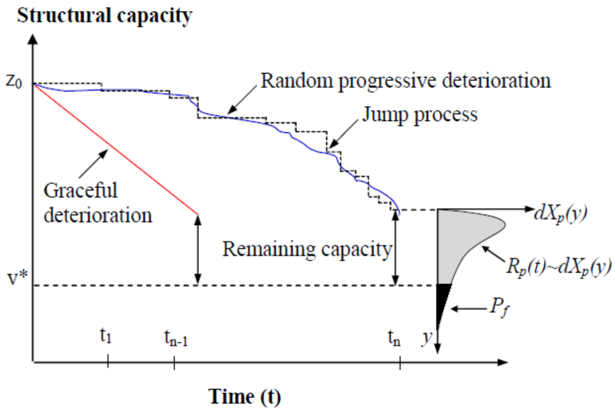

Fig. 2. Modelling progressive deterioration

If P_i describes a sequence of small countable discrete jumps occurring at a constant time interval (Δt_i), the damage accumulation $Q_p(t)$ is given by,

$$Q_p(t) = \sum_{i=0}^{n} Y_i \quad (1)$$

The remaining structural capacity of a structure $R_p(t)$ at a particular time *t* can be computed by,

$$R_p(t) = z_0 - Q_p(t) - v^* \quad (2)$$

Where, z_o is initial capacity of structure and $v*$ is a predefined performance threshold values, respectively. If $R_p(t)$ follows a known probability distribution (X_p), the probability of failure of the bridge (P_f) can be expressed as,

$$P_f = 1 - \int_0^{R_p(t)} X_p(y)dy \quad (3)$$

Assuming that progressive deterioration is statistically independent, the numerical procedure for computing the probability of failure of bridges under progressive deterioration is as follow:

1. Let consider initial damage accumulation $Q_0^p = 0$; Thus, the remaining capacity $R_0^p = z_0 - v^*$;
2. Set $t_n^p = t_{i-1}^p + t_i^p$; and obtain the jump size P_i from distribution;
3. Compute damage accumulation $Q_p(t)$ using Eq. 1;
4. Compute remaining capacity $R_p(t)$ using Eq. 2;
5. Go to Step (2) until reaching a particular time point(t_n^p);
6. Compute probability of failure at time (t_n^p) using Eq. 3.

ILLUSTRATIVE APPLICATION

Consider a case of a bridge that deteriorates continuously with time (*e.g.* corrosion). The jumps sizes were taken as 0.7, 0.8 and 0.9. The initial structure performance is z_0 = 100% with a threshold limit $v*$ = 30%. Assume the remaining structural capacity is governed by an exponential distribution $W(y, \theta)$ with an average rate of 0.05. A numerical procedure using MATLAB program was developed and the average values of probability failure of the bridge were computed.

RESULTS AND DISCUSSION

The random sample paths describing probability of failure of a bridge subjected to progressive deterioration with jump size P_i of 0.7 are shown in Fig. 3. Using numerical approach, various random sample paths can be contructed to simulate the deterioration process. The probability of failure corresponding to the mean of the degradation process is used in this simulation.

Time-dependent probability of failure of the bridge with different progressive jump sizes (*i.e.* 0.7, 0.8 and 0.9) is shown in Fig. 4. It can be seen that the increase of progessive jump size caused by progressive deterioration has significant impacts on the probability of failure and led to a reduced of bridge residual life. In comparison to jump size of 0.7, the jump sizes of 0.8 and 0.9 could reduce the bridge residual life of around 10% and 20%, respectively.

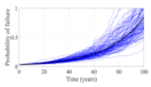

Fig. 3. Random sample paths describing probability of failure of a bridge subjected to progressive deterioration

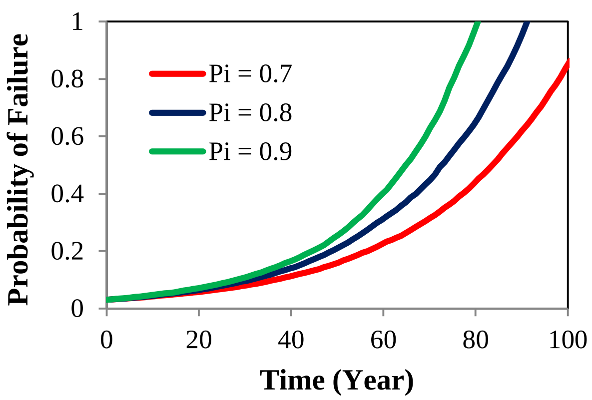

Fig. 4. Effect of jump sizes on bridge residual life

As the bridge ageing, the bridge may be experiencing certain level of deterioration and so the initial capacity of a bridge decreases. Figure 5 shows the comparison of the probability of failure of the bridge under different initial structural capacity. The results show that the loss of initial structural capacity has significant effect on the decrease of the bridge residual life.

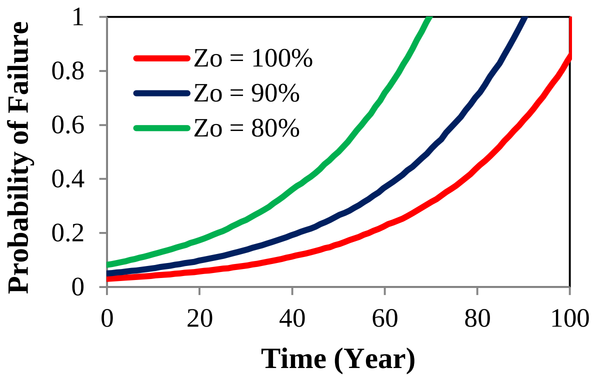

Fig. 5. Effect of initial structural capacities on bridge residual life

CONCLUSIONS

A realibility-based approach for predicting the bridge residual life subjected to random progressive deterioration was presented. In particular, this study mainly focuses on developing numerical approach for assessing time-dependent probability of failure of bridges using a jump process with the size of every jump is random and occurs at a certain fix time interval. The outcomes of the study demonstrate the potential use of the proposed reliability-based approach for assessing probability of failure as well as predicting the residual life of bridges subjected to progressive deterioration.

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