검측비용을 고려한 PC박스 거더의 신뢰성 분석

Reliability Analysis of Prestress Concrete Box Girder Bridges Considering Inspection Cost

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ABSTRACT

In recent years, the deterioration of infrastructures is especially considered. In prestress concrete bridges, one of the important mechanisms of deterioration is the corrosion of the post-tensioned tendon due to environmental agents. In this study, the reliability analysis is performed for a prestress concrete box girder bridge under the pitting corrosion attack with considering the inspection and failure cost. The variation of life-time performance depending on inspection methods have to be quantified. The inspection methods with different accuracy of corrosion detection are presented and applied for model of reliability analysis. The computer program for analysis reliability index of the structure as well as updating process is obtained. An existing bridge is applied for illustrating the influence of inspection cost on the behaviors of structure. Subsequently, the benefit of inspection has shown to predict the time to failure of structure.

Keywords: *Reliability-based design optimization probability of failure reliability index steel box girder bridge, probabilistic constraint*

1. Introduction

Corrosion in post-tensioned concrete (PC) bridge systems causes an immanent threat to the safety of passengers and vehicles. In recent years, failures of PC bridges that are over 30 years old have mainly been caused by the corrosion of post-tensioned tendons (Schupack, 1994b; Micheal, 1998; Schoker, Breen and Kreger 2001). In the UK and Belgium, the collapse of three bridges has been reported due to corroded post-tensioned tendons (Breen and Kreger 2001). Tendon corrosion has been recorded as the reason for the collapse of the Ynys-y-Gwas Bridge in West Glamorgan-UK (Micheal, 1998). During the service time of a bridge, tendon corrosion can seriously affect the reliability of the structure and can reduce its strength resistance, resulting in system failure (Salas et al. 2004; Nurbeger, 2002; Milne et al. 2003; ACI 222. 2r, 2001). Structural damage can occur intermediately without any signs, and it cannot be prevented.

Pitting corrosion is another corrosion mechanism, and is particularly essential in the corrosion of

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tendons of post-tensioned concrete bridge members. The pit corrosion is an autocatalytic or self-propagating process, causing a reduction in strength due to the loss of the tendon area. This paper focuses on the influence of inspection cost on the PC structure that subjected to the pitting corrosion of post-tensioned tendon. An existing bridge is applied for analyzing the influence of the inspection cost in prediction the lifetime of structure. Subsequently, the benefits of inspection have been discussed to predict the time to failure of structure.

2. Reliability analysis formulation for a PC box girder bridge

When the pit propagates, there will be a loss of tendon cross section area. For the calculation of residual area according to time, the pit is considered as the circle arc as illustrated in Fig. 1 (Asko 2006). The loss of cross section area can be expressed as follows

$$A_{pit}(t) = \begin{cases} A_1 + A_2 & p(t) \le \dfrac{D_0}{\sqrt{2}} \\ \dfrac{\pi D_0^2}{4} - A_1 + A_2 & \dfrac{D_0}{\sqrt{2}} \le p(t) \le D_0 \\ \dfrac{\pi D_0^2}{4} & p(t) \ge D_0 \end{cases} \tag{1}$$

$p(t)$ is the depth of the pit(mm)

$$p(t) = r_{corr} \alpha t \tag{2}$$

where r_{corr} is the corrosion rate(cm/year), t is the time since corrosion initiation(years), and α is the pitting factor accounting for the non-uniform corrosion of rebar. In this study, it is assumed that 30% of tendons at the critical section are corroded. A_1, A_2 can be calculated based on Eq.3 and 4 as shown below.

$$\begin{cases} \theta = 2.\arcsin\left(\dfrac{p(t)}{d_b}\right); a = \dfrac{d_b}{2}\sin(\theta) \\ \phi = \arcsin\left(\dfrac{a}{p(t)}\right) \end{cases} \tag{3}$$

$$\begin{cases} A_1 = \dfrac{\pi . d_b^2 . \theta}{4.180} - a.d_b.\cos\theta \\ A_2 = \dfrac{\pi . p(t)^2 . \phi}{180} - a.p(t).\cos\phi \end{cases} \tag{4}$$

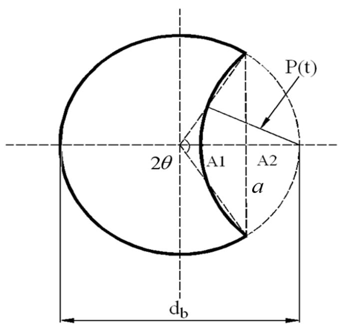

Fig. 1

The flexural limit state equation is formulated based on the AASHTO LRFD code and reliability based-design theory. This study concentrates only on an un-factored dead load and live load in order to evaluate the variation of safety due to corrosion. The limit state equation for moment is

$$f_M(t) = M_n - M_u = 0 \tag{5}$$

where M_u is the un-factored moment due to static and live load, $M_n(t)$ is nominal moment resistance follows AASHTO LRFD. To analyze the influence of inspection on the reliability index, a computer code is developed using Matlab platform. The Bayesian theory is applied to update the mean and standard deviation of corrosion rate.

3. Result and discussion

To investigate the effect of inspection on the annual reliability index, the three case of corrosion rate is considered including three cases, case 1: μr=0.0025mm/year, case2: μr=0.003mm/year and case3: μr=0.0035mm/year. It is assumed the structure is subjected to two inspection levels with respect to the probability of corrosion detection are 30% and 90%. After performing Bayesian updating, the posterior mean and standard deviation are applied to analyze the time-variant reliability index. The deterioration curves of the PC box girder bridge are plotted in Fig. 2a, 2b and 2c with respect to case 1, case 2 and case 3. It can be said that the reliability index decrease according to the time and the most decreasing can be found in the case 3. At the point time 40 years, the inspection is performed for structure to find the pitting corrosion of post-tensioned tendon with different level of accuracy. At the level POD=30%, it seems the error is high and the mean of reliability index can vary within the large distance. However, in the case of POD=90%, the error in calculation the annual reliability index is smaller than the previous case. The standard deviation of the case POD=30% and 90% are 0.000584 and 0.0004271, respectively. This illustrated the benefit of inspections during the lifetime of structure to predict the remaining time of the structure as well as some extend actions such as maintenance, repairing and replacing .

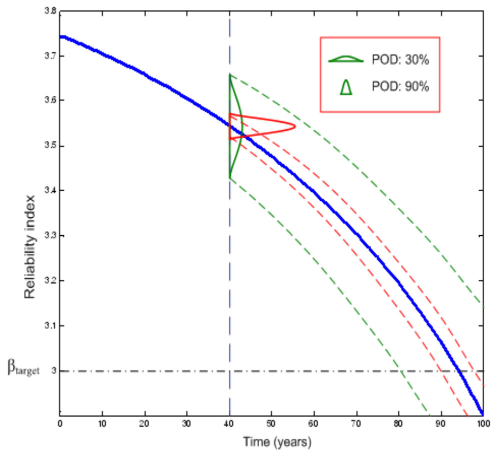

Fig. 2a

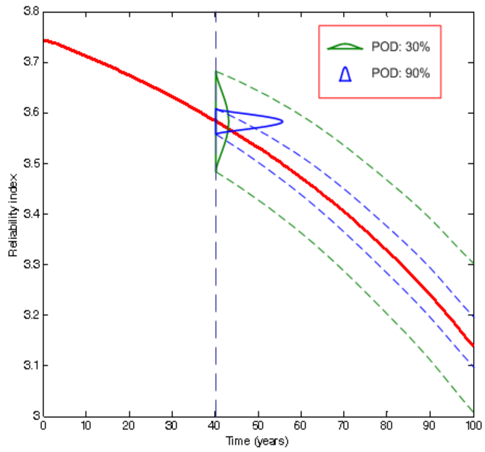

Fig. 2b

4. Conclusions

This study focused on the pitting corrosion phenomena which occurred commonly in the PC structure during the service lifetime of structure. Moreover, the sources of chloride, which can originate from an insufficient quantity of grout, the grouting process itself, the anchorage corrosion, the concrete crack, the sheath problem and other causes, were investigated. The pitting corrosion phenomena is applied and formulated to perform the deterioration of structure which considered the inspection cost and failure cost.

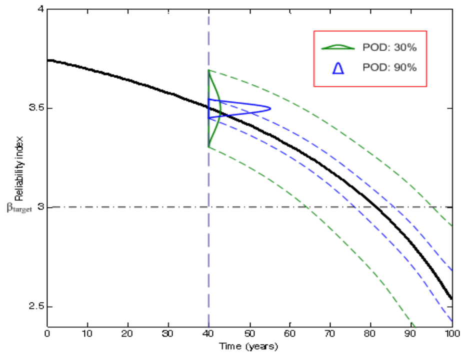

Fig. 2c

Numerical analysis is performed for an existing PC box girder bridge subjected to the pitting corrosion attack. At the same point time, the inspection method can allow to predict the structural behaviors under environmental agents, which induce the resistance of structure. The reliability index was obtained for different pre-defined level of accuracy of inspection methods basing on the model of reliability analysis and Bayesian updating process. The results can indicate the benefit of inspections during the lifetime of structures to predict the remaining time of the structure as well as perform some extend actions such as maintenance, repairing and replacing .

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