Proc. of the 6th Intl. Symposium on Reliability Engineering and Risk Management (6ISRERM)
31 May – 1 June 2018, Singapore
Editor(s) Xudong Qian, Sze Dai Pang, Ghim Ping Raymond Ong, Kok-Kwang Phoon

LCC ANALYSIS BASED ON PERFORMANCE DEGRADATION OF BRIDGE CONSIDERING SITE ENVIRONMENTS

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This study presents the future life cycle cost (LCC) evaluation method considering site environments of highway bridge. The future performance degradation models are adopted to estimate the maintenance cost and the expected loss of bridge safety. A procedure to adjust the future performance degradation model is proposed based on the bridge inspection results. The effect of inspection results is examined in the study. The expected loss in LCC is estimated through the reliability evaluation based on the performance-based resistance deterioration model considering site environments and future performance degradation model. The traffic characteristics and the corrosion environments are considered as the site environments. The case study has been performed with a PSC girder highway bridge.

Keywords: Life cycle cost, highway bridge, Performance degradation, Reliability evaluation.

1 Introduction

The reasonable maintenance schedule is very important due to the increasing number of aged highway bridges. Since the maintenance budget is limited, it must be appropriately allocated in consideration of the required performance of the bridge. This study focuses on the providing LCC analytical results for determining the reasonable maintenance plan of the bridge. The LCC is analyzed by the performance-based resistance deterioration model based on the site environments and the previous inspection results. Traffic characteristics and corrosion environments are considered as important factors in various site environments of the bridge.

2 Traffic Load Model on Bridges

The probabilistic traffic load characteristics acting on the bridge during the service time may play an important role on the performance reliability level of the bridge, such as daily traffic volume, heavy vehicle proportion, heavy vehicle weight model, heavy vehicle consecutive travelling mode, etc. The consecutive travelling characteristics of heavy vehicles are widely understood to cause the unintentional high load effects, especially on medium span bridges. The

Markov transition probability matrix models are developed based on the local traffic load survey data to include the consecutive travelling effects in the estimation of maximum traffic load effects in the intended service period. Table 1 shows some transition probability matrix models for various heavy vehicle proportions.

Table 1. Transition probability matrix models.

(a) Heavy vehicle proportion: 15%

Type*	Consecutive traveling coefficient (Consecutive traveling probability: %)					Simple vehicle proportion (%)	
	P	B	T	TT	ST		
P	1.03 (83.68)	0.95 (3.23)	0.89 (6.64)	0.86 (4.88)	0.88 (1.58)	81.6	
B	0.95 (77.74)	2.29 (7.80)	0.88 (6.62)	1.09 (6.23)	0.89 (1.61)	3.4	
T	0.88 (71.87)	1.00 (3.39)	1.92 (14.42)	1.40 (7.96)	1.31 (2.37)	7.5	15.0
TT	0.87 (70.88)	0.93 (3.17)	1.36 (10.22)	2.28 (13.00)	1.51 (2.72)	5.7	
ST	0.85 (69.27)	1.03 (3.51)	1.42 (10.67)	1.67 (9.50)	3.92 (7.05)	1.8	

*P, B, T, TT, and ST representing a mobile car, bus, small-sized truck, mid-sized truck, and heavy truck, respectively.

(b) Heavy vehicle proportion: 35%

Type*	Consecutive traveling coefficient (Consecutive traveling probability: %)					Simple vehicle proportion (%)	
	P	B	T	TT	ST		
P	1.11 (69.10)	1.01 (2.62)	0.83 (14.58)	0.77 (10.28)	0.82 (3.43)	62.4	
B	1.01 (63.31)	2.38 (6.20)	0.81 (14.19)	0.97 (12.88)	0.81 (3.42)	2.6	
T	0.82 (51.02)	0.90 (2.34)	1.53 (26.79)	1.17 (15.53)	1.03 (4.31)	17.5	35.0
TT	0.81 (50.29)	0.84 (2.18)	1.08 (18.98)	1.76 (23.47)	1.21 (5.08)	13.3	
ST	0.77 (48.06)	0.93 (2.41)	1.12 (19.62)	1.28 (16.98)	3.08 (12.94)	4.2	

*P, B, T, TT, and ST representing a mobile car, bus, small-sized truck, mid-sized truck, and heavy truck, respectively.

3 Performance-based reliability analysis considering site environments

The future performance degradation is to be estimated calibrating systematically the standard degradation model based on the previous inspection results on the bridge (Figure 1). Table 3 shows the inspection results of the bridge members. One example is the case, in which the periodic regular inspections have been performed. Another example is an unusual situation, in which no previous inspection report is available.

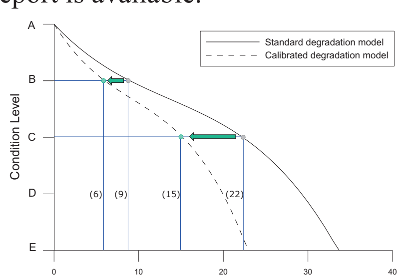


Figure 1. Calibration of performance degradation model.

Table 3. Inspection results of the bridge members.

Bridge member		Year of condition inspection								
		2	4	6	8	10	11	13	15	16
RC slab	With previous inspection	A	A	B	B	B	B	C	C	C
	Without previous inspection	-	-	-	-	-	-	-	-	C
PSC-I girder	With previous inspection	A	A	B	B	B	B	B	C	C
	Without previous inspection	-	-	-	-	-	-	-	-	C

The existing concrete cracks should be considered when evaluating the deterioration of resistance capacity due to the corrosion environments. The corrosion environments of bridges are classified as mild, normal, and severe. Figure 2 shows the cross-sectional profiles of the example bridge at mid span. The performance-based resistance deterioration model is developed by combining a resistance deterioration model and calibrated performance degradation model

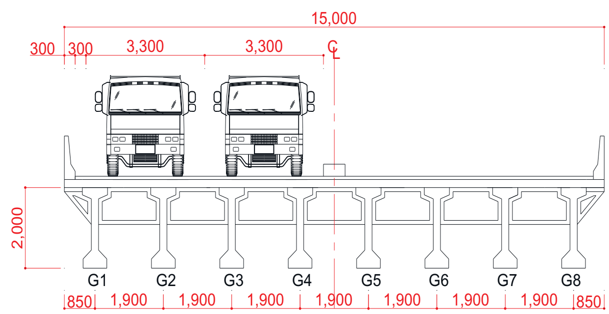
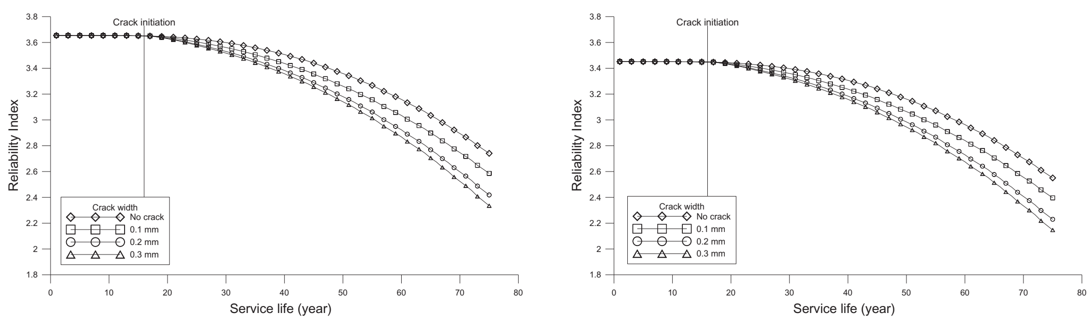


Figure 2. Cross-section of the PSC-I girder bridge.

The expected performance degradation is evaluated quantitatively in terms of the reliability index as shown in Figure 3, in which the probabilistic models of the bridge resistances and loadings are included. The traffic load effects are estimated through the Monte Carlo simulation procedure considering the various probabilistic characteristics in the traffic loads. It is assumed that the cracks of the developed model appeared 16 years after the completion of construction.



(a) Light traffic characteristics (b) Heavy traffic characteristics

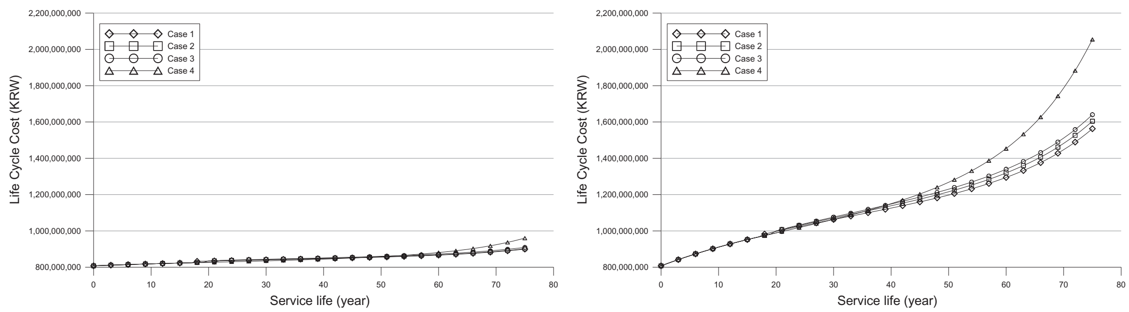
Figure 3. Reliability evaluation under normal corrosion environment.

4 LCC Analysis Based on Performance Degradation of Bridge

The LCC of the example bridge is estimated based on various maintenance cases of the developed model. Maintenance cases for crack damage are assumed to be repaired after one year, three years later, and five years later. Table 4 shows the maintenance alternative cases regarding the damage to the bridge members. Figure. 4 presents the expected LCC analysis results considering each maintenance case.

Table 4. Maintenance alternative cases.

	Case 1	Case 2	Case 3	Case 4
Timing of maintenance	1 year after crack initiation	3 years after crack initiation	5 years after crack initiation	No maintenance



(a) Light traffic characteristics (b) Heavy traffic characteristics

Figure 4. LCC considering maintenance cases.

5 Conclusion

The proper performance-based and reliability-based maintenance plan may be scheduled to achieve an optimum maintenance budget allocation. In this study, the LCC of the example bridge is estimated based on various maintenance alternatives of the developed performance-based resistance deterioration model considering that the site environments, bridge inspection results, and the timing of maintenance are different. It is found that the timing of maintenance and the developed model based on the site environments as well as previous bridge inspection results should be taken into consideration in order to establish an optimal maintenance schedule of the bridge.

Acknowledgments

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea (No. 20174030201480).
This research was supported by Basic Science Re-search Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2017R1D1A1B03028262).

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