Multi-stage Optimization for Flexible Bridge Maintenance and Management Planning against Modification of Deterioration Curve

Hitoshi FURUTA
Professor
Kansai University
Osaka, Japan
furuta@res.kutc.kansai-u.ac.jp

Hiroshi FUJIKAWA
Graduate Student
Kansai University
Osaka, Japan
k218037@kansai-u.ac.jp

Yoshiaki KAGAWA
Graduate Student
Kansai University
Osaka, Japan
k687816@kansai-u.ac.jp

Koichiro NAKATSU
Lecturer, Osaka Jonan
Women's Junior College
Osaka, Japan
k-nakatsu@jonan.ac.jp

Ken ISHIBASHI
Postdoctoral Fellow
Kansai University
Osaka, Japan
r108047@kansai-u.ac.jp

Summary

In this study, an attempt is made to propose a method for flexible bridge maintenance plans against the modification of deterioration curve by using the multi-stage optimization. Both the minimization of cost and the maximization of structural soundness are important for the maintenance planning. Numerical experiments with 10 bridges were presented to demonstrate that solutions obtained by the proposed method were effective against the uncertainties involved in the financial circumstances and the deterioration prediction.

Keywords: bridge maintenance planning; multi-stage optimization; genetic algorithm; uncertainty.

1. Introduction

This proposition attempts to formulate practical maintenance plans by focusing on the flexible periods included in preventive plan as shown in Figure 1. During this period, a maintenance schedule can change the executing year of work without the huge increase of cost. This means that a plan adapts the change due to uncertainties with keeping the assessed budget and the structural soundness. The proposed method makes effective preventive plans by using the two-stage optimization in order to maximize flexible periods.

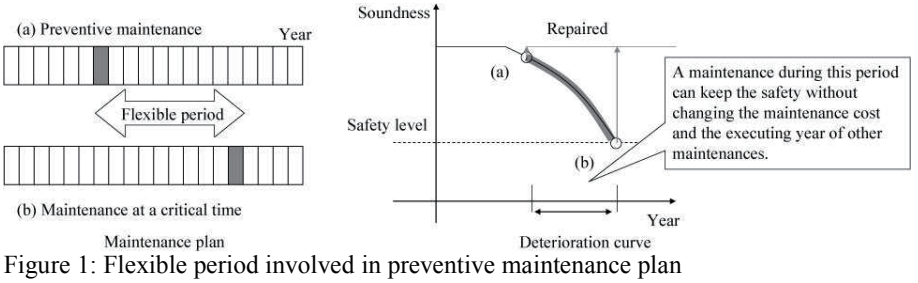

Figure 1: Flexible period involved in preventive maintenance plan

The planning for bridge maintenance requires the minimization of cost and the maximization of safety. However, these are trade-off. Actual budget allocated to the maintenance depends on the financial circumstances. Therefore, the preventive plan is useful for the rational maximization of structural soundness because it can modify the schedule without changes of maintenance method. In addition, the effect of flexible period, proposed in this paper, is improved by the preventive maintenance.

In the proposed optimization, the first stage assesses the maintenance cost required for the keep of safety, and an optimization in the second stage maximizes the structural soundness within the cost constraint calculated in the previous stage. When there is a trade-off between criteria, it is difficult to formulate an integrated objective function. On the other hand, an optimization that gives

importance to one criterion tends to raise the bias of searched solutions. Therefore, by using multiple-stage optimizations, this paper attempts to improve the practicality of maintenance plan in consideration of the maintenance cost and the structural soundness.

2. Numerical experiments

This paper demonstrates the effectiveness of the proposed method through the numerical experiments in the problem of maintenance planning for 10 bridges used in the previous study [1]. Genetic Algorithm (GA) is applied to the optimization for single bridge. Then, a plan to 10 bridges is established through the integration of schedules for each bridge. The deterioration speed is determined based on the prediction. In the experiments, a plan made based on the mean value of deterioration speed (Pattern 1) is compared with a plan based on the early speed of deterioration. (Pattern 2). Furthermore, this paper sets the importance to each bridge randomly; 4 bridges are given high importance, 3 bridges are given middle importance and 3 bridges are given low importance. Then, by making schedules of high important bridges based on the early speed of deterioration, maintenance plan of each bridge are integrated (Pattern 3). Obtained results of these patterns are shown in Table 1. Here, values of Table 1 calculated through 1,000 times simulations under uncertain situation, which included the random change of deterioration speed.

In Table 1, the pattern 4 represents the result obtained by the previous method that optimized the preventive plan through the single optimization. In contrast to the pattern 4, solutions obtained by the proposed method could improve the expected structural soundness. In addition, patterns 1 and 4 could reduce equivalent maintenance cost. A maintenance plan can enhance the robustness by assuming the early speed of deterioration like the pattern 2. However, this assumption raises the increase of maintenance cost. The pattern 3 could enhance the structural soundness with reducing the increase of cost by improving the robustness for important bridges. This result indicates that a schedule based on a scenario appropriate for each bridge can improve the flexibility of maintenance plan against the modification of deterioration curve. Therefore, it is expected that the proposed method is effective for the improvement of the practicality of optimal maintenance plan.

Table 1: Experimental results

Scenario pattern	Pattern 1	Pattern2	Pattern 3	Pattern 4
Maintenance cost (million yen)	1920	2576	2187	1874
Estimated soundness	0.977	0.996	0.986	0943
Maximum soundness	0.985	0.996	0.992	0953
Minimum soundness	0.967	0.995	0.978	0932
Standard deviation of soundness	2.593E-03	2.395E-04	2.027E-03	3.379E-03

3. Conclusions

In this study, an attempt was made to propose a method for flexible bridge maintenance plans against the modification of deterioration curve by using the multi-stage optimization. Numerical experiments with 10 bridges were presented to demonstrate that solutions obtained by the proposed method were effective against the uncertainties involved in the financial circumstances and the deterioration prediction. The proposed method can make schedule for single bridge based on various scenarios. Therefore, by generating various candidates of schedule for each bridge, it is expected that the combination of them can improve the practicality of maintenance plan.

References

[1] H. Furuta, K. Takahashi, K. Nakatsu, K. Ishibashi and M. Aira, “Robust Maintenance Planning with Flexible Periods against Uncertainty of Deterioration Prediction”, *Safety, Reliability, Risk and Life-Cycle Performance of Structures & Infrastructures, Proceedings of International Conference on Structural Safety & Reliability* (*ICOSSAR 2013*), New York, NY, USA, 2013, p.381.