DEVELOPMENT OF BRIDGE MANAGEMENT SYSTEM FOR EXPRESSWAY BRIDGES IN JAPAN

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Abstract

The Japan Highway Public Corporation (JH) needs to work actively to further reduce the maintenance costs and is making efforts to computerize all maintenance work. JH is proposing early development of a system for supporting planned maintenance by determining bridge soundness and predicting deterioration, and selecting optimal timing and method for repair and/or reinforcement. JH is now conducting studies for building JH's version of BMS (JH-BMS). This paper discusses study themes for building JH-BMS, such as bridge soundness evaluation and deterioration prediction based on the inspection results, repair or reinforcement scenarios for life-cycle cost optimization and future directions or areas of research.

1. Introduction

At present, more than 13000 bridges are under the control of the Japan Highway Public Corporation (JH). They have been in service for 18 years on average and many of them have been deteriorated due to heavy traffic and severe conditions and require repair or reinforcement. As an example of structural deterioration due to external forces including traffic loading, the fatigue of reinforced concrete slabs subject to direct load is outstanding on bridges. Fatigue cracking sometimes occurs on steel bridges or steel bridge piers. An increasing number of cases of salt damage have also been reported. Steel members are corroded and swell as chlorides infiltrate reinforced concrete structures due to the attachment of salts or the application of salts for ice control, resulting in concrete cracking. Investigations and diagnoses are currently being made individually for deteriorated bridges, and various repair or reinforcement methods are being implemented.

2. Outline and main features of JH-BMS

The variations of BMS applied in other countries have the following characteristics.
(1) The system is in place for qualifying inspection engineers.
(2) The soundness of bridge elements is evaluated using deterioration models focusing on transitional probability.
(3) State governments use BMS as a tool for obtaining funds from federal government.
(4) The main goal is to maintain groups of bridges rather than to evaluate the soundness or predict the deterioration of individual bridges.

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In view of the characteristics of BMS in other countries described above, JH-BMS is built not only as a tool for securing budget allocation but also for effective use of BMS in bridge maintenance in the field. The basic approach of JH-BMS is to calibrate the existing deterioration prediction formulas that have been developed in Japan, based on the field inspection data, while considering the mechanism of deterioration due to such factors as chloride attack and fatigue expected under the environmental conditions of the bridge.

JH-BMS evaluates bridges with respect to individual elements/components. The soundness of individual bridge elements is evaluated and their deterioration is predicted at the time of inspection based on the inspection data, the environmental condition and traffic prediction corresponding to the deterioration mechanism. JH-BMS is a bridge repair or reinforcement planning support system that uses a bridge maintenance database integrating the bridge specifications and inspection data to evaluate the soundness of bridge elements, predict deterioration, select optimal timing and method of repair or reinforcement and calculate repair or reinforcement cost (Figure 1).

JH-BMS offers the following features.

(1) Soundness evaluation

The soundness of elements is determined at the time of inspection based on the inspection data, element specifications and environmental data.

(2) Deterioration predictionThe deterioration of elements expected at a given point in the future is predicted based on their soundness, conceivable deterioration mechanism, and environmental and element data at the time of inspection.

(3) Selection of repair or reinforcement method

The effect and unit cost of the repair or reinforcement method are determined for each deterioration mechanism. The timing and method of repair or reinforcement are selected to optimize the maintenance costs.

(4) Calculation of repair or reinforcement cost

The maintenance cost required throughout the design service life is calculated for each bridge. Calculating sub-total costs for respective routes, areas under jurisdiction or other classifications is made possible. Thus, the future maintenance costs are estimated.

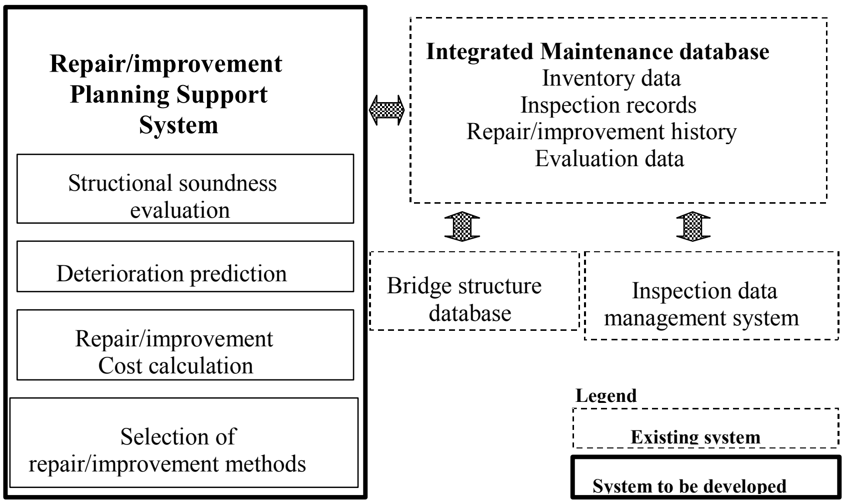

Figure 1. Components of JH-BMS

3. Soundness evaluation and deterioration prediction

Deformation grades are defined to evaluate element soundness (Table 1). The soundness of an element at a given point in time is determined using inspection data. Deterioration prediction based on the result of calculation when the deterioration prediction formula is combined with the inspection data wherever required (Figure 2). For example, if chloride attack causes deterioration, the amount of chloride at the position of reinforcement, area of corroded reinforcement and cracking data are collected through inspection, and used for evaluating element soundness. If insufficient data are available, the soundness of the element is evaluated against chloride attack also based on deterioration prediction made from the calculation employing the environmental conditions. Future deterioration is predicted based on the calculation results according to the deterioration mechanism or actual progress of deterioration identified using accumulated inspection data. The present inspection methods cannot provide sufficient data for evaluating element soundness. In the future, inspection items and methods need to be improved with a view to providing data required for soundness evaluation and deterioration prediction.

Table 1. Deformation grade and remedial measure

Grade	Progress of deterioration	Performance of structure (e.g. load bearing capacity)	Management range	Type of remedial measure	Deterioration phase (refer to specifications*)
I	No problematic deterioration	No progress of deteriotration	Standard control range	No remedial measures are taken.	incubation
II	Minor deterioration	Deterioration progresses but no reduction in load bearing capacity		Preventive maintenance	
III	Deterioration occurs.	Deterioration progresses considerably, and reduction in load bearing capacity demands monitoring.	Control range	Repair or retrofit	propagation and acceleration
IV	Large deterioration	Load bearing capacity decreases and required limit is likely to be reached.	Management limit	Retrofit	Critical state of deterioration
V	Critical deterioration	Load bearing capacity decreases to a serious level and there may arise safety concerns in the short run.	Management limit is exceeded.	Large-scale remedial measures	

※ JSCE:Standard Specifications for Design and Construction of Concrete Structures -Maintenance

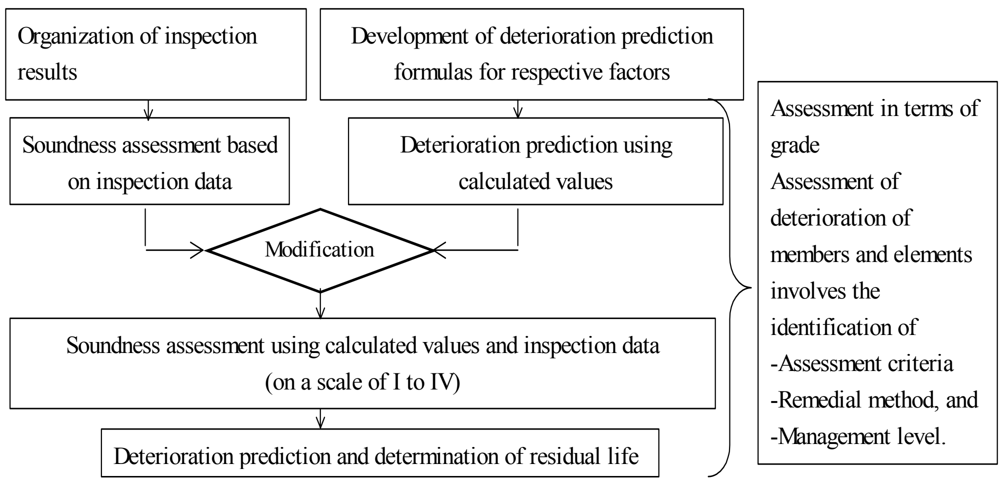

Figure 2. Deterioration prediction based on the result of calculation and inspection data

The deterioration mechanisms and prediction formulas for respective bridge elements are listed in Table 2. For carbonation and chloride attack, the depth of carbonation and chloride ion concentration calculated using the Japan Society of Civil Engineers (JSCE) formulas (1) are compared with the inspection results, and the formulas are calibrated. For the fatigue of reinforced concrete slabs, the soundness calculated using Matsui's formula (2) is related to the fatigue based on free lime. Deterioration prediction formulas will be established for frost damage, chemical attack and ASR (Alkali-Silica-Reaction). For the time being, detailed inspections will be conducted regularly once deformation becomes apparent.
Deterioration prediction curves are calibrated according to the results of mostly visual inspections and of detailed inspections (of carbonation depth, chloride amount, etc.) (Figure 3).

Table 2. Deterioration mechanisms and prediction formulas

Deterioration mechanism	Deterioration prediction formula	Remarks
Carbonation	Carbonated thickness (formula of Japan Society of Civil Engineers), corrosion of steel member	Interpolated from the results of detailed inspections
Chloride attack	Chloride ion concentration (formula of Japan Society of Civil Engineers), corrosion of steel members	〃
Fatigue (reinforced concrete slab)	Degree of fatigue damage (Matsui's formula)	Related to free lime content inspection
Frost damage	If deformation becomes apparent, detailed inspections are conducted regularly.	Deterioration prediction formula will be established.
Chemical erosion	〃	〃
Alkali-silica reaction(ASR)	〃	〃
Fatigue (main members of a steel bridge)	Fatigue assessment formula (Japan Road Association)	

The bridge elements should be repaired or reinforced to keep the management level above the designated level throughout the planned service life. The repair or reinforcement method should be determined for each deterioration mechanism according to the soundness of the element. Where multiple causes of deterioration are conceivable for an element, the grade of soundness against the type of deterioration that progresses most rapidly should be regarded as the soundness of the element. A repair or reinforcement scenario should be prepared for the deterioration mechanism. The effect should be represented by the period over which the post-improvement condition remains free from additional deterioration (additional residual life) (Figure 4).
The bridges under the control of JH have been maintained based on engineers' judgment. Engineers' judgment has been developed based on the technical strength of JH composed of diverse and high-level technical factors. Engineers' know-how should be considered as an important factor even if JH-BMS is operated in the future. JH-BMS is designed to enable engineers to calibrate system output based on their judgment. A flow of major decision making steps of engineers is shown in Figure 5.

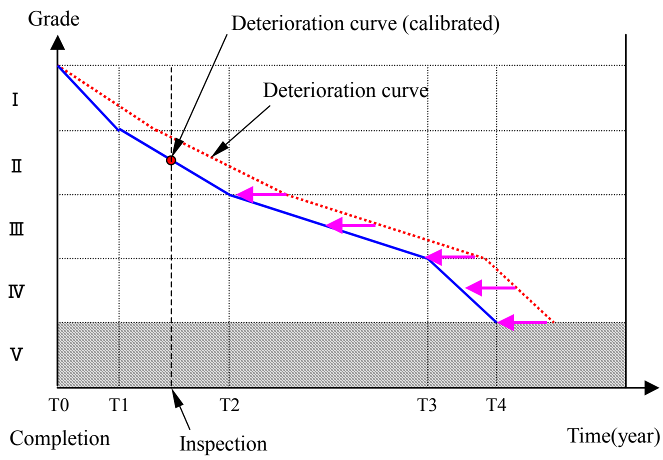

Figure 3. Calibration of deterioration curve

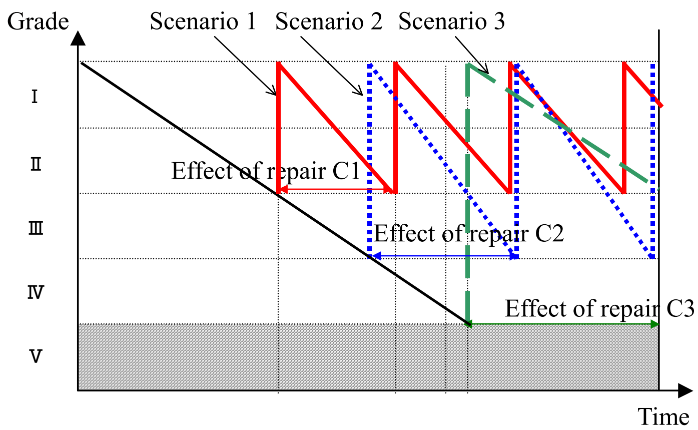

Figure 4. Repair or reinforcement scenario

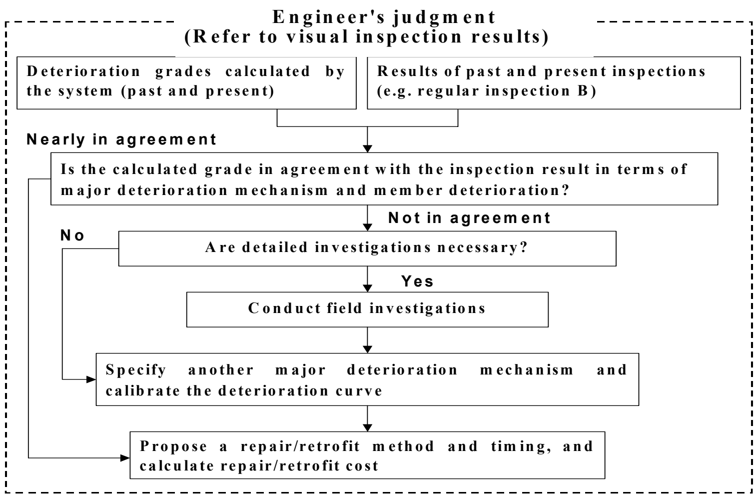

Figure 5. Engineers' judgment

4. Conclusion

JH-BMS is a bridge repair or reinforcement planning support system that uses a bridge maintenance database integrating the bridge specifications and inspection data to evaluate the soundness of bridge elements, predict deterioration, select optimal timing and method of repair or reinforcement and calculate repair or reinforcement cost. Deterioration prediction curves are calibrated according to the results of mostly visual inspections and of detailed inspections. The system is also a tool for objectively verifying the validity of conventional bridge maintenance based on engineers' judgment. It is hoped that technological developments will be made for bridge maintenance with a view towards enhancing JH-BMS.

References

(1) JSCE: "Standard Specifications for Concrete Structures - Maintenance", 2001.

(2) Yukio MAEDA, Shigeyuki MATSUI: "Punching Shear Load Equation of Reinforced Concrete Slabs", Proceeding of JSCE, No.348, V-1, pp.133-141, 1984.