Development of Practical Bridge Management System for Prestressed Concrete Bridges

Ayaho Miyamoto*, Tatsuro Katsushima*, and Hiroyoshi Asano*

*Graduate School of Science & Engineering, Yamaguchi University, Ube, Japan

ABSTRACT: This paper introduces a newly developed bridge management system for the prestressed concrete (PC) bridges (J-BMS PC version) which integrated with the PC bridge rating expert system (PC-BREX). The proposed system is able to predict the deterioration process of the existing PC bridge superstructure components as well as assess a broad array of optional corrective strategies. The system also has the capability to search and retrieve from a J-BMS database system(J-BMS DB), the necessary information, carry out suitable analyses to arrive at some recommendations that would help users to optimize their decisions based on engineering aspects, cost and economic issues and bridge management policies. A comparison of the results of applying the system to some actual in-service PC bridges with a special designed survey form to experts shows that optimal maintenance planning as well as bridge rating can be predicted accurately by using the system.

Keywords : Lifetime management system , prestressed concrete bridge , J-BMS DB , Bridge rating expert system (BREX) , practical application

1 INTRODUCTION

In Japan, because there are a huge number of civil infrastructure systems, it has become important to develop an integrated lifetime management system for such infrastructures. They include urban expressway/railway networks and other social infrastructure systems, and such structures as bridges, dams, and tunnels. It will therefore be necessary to maintain the service life of social infrastructure stocks as long as possible and to take appropriate measures as society ages, in harmony with the natural environment (Bien et al.2007). Especially in existing bridges, it is required to put into practical use the Bridge Management System (BMS) for effective and efficient bridge management. BMS provides support to bridge administrators in all types of actions for bridges from planning to design, construction, inspection, deterioration diagnosis, repair, retrofit and replacement from a viewpoint of quality, economy, safety and functionality.

The authors have been developing a practical Bridge Management System that is referred to as the Japanese Bridge Management System (J-BMS) (Miyamoto (2000) & Kawamura et al.(2003)) integrated with the Concrete Bridge Rating Expert System (BREX) that can be used to evaluate the serviceability of existing concrete bridges. J-BMS is composed of three subsystems, namely, J-BMS Data Base System (J-BMS DB) (Konno et al.(2003)), Bridge Rating Expert System (BREX) (Kawamura et al.(2003) and Maintenance Plan Optimization System (MPOS). The J-BMS uses multi-layered neural networks to predict deterioration processes in existing concrete bridges, construct an optimal maintenance plan for repair and/or strengthening measures based on minimizing life-cycle cost and maximizing quality, and also estimate the maintenance cost. In this system, the Genetic Algorithm (GA) technique was used to search for an approximation of the optimal maintenance plan.

For example, it will be focusing on prestressed concrete (PC) structures including PC bridges, PC structures are more effective than reinforced concrete (RC) structures because prestressing the cross section of a member eliminates an unfavorable stress condition that is created by external forces and thus enables an effective use of the total cross section. If the tensile stress in any given cross section of a concrete member is controlled so as not to cause surface cracking under any combination of predictable external forces (as concrete is generally weak in tension stress), it is possible to construct a structure that requires minimum maintenance in the future. Then, it is generally say that cracking or other types of damage to concrete surface of a PC structure designed based on the above assumption therefore implies that the durability of the member has already been lost. To introduce of prestressing in all parts of a PC structure is, however, actually impossible. Especially, prestressing is often difficult at joints in cast-in-place backfill, in the longitudinal direction of a bridge slab, or at the anchorage of prestressing steel, then, reinforced concrete (RC) is used in some parts.

The J-BMS subsystems were developed at different points in time and no compatibility had been established. In order to solve the problem, the J-BMS subsystems were integrated and a version of J-BMS for prestressed concrete bridges (J-BMS PC version) was developed in this study. Verifications from diverse viewpoints are, however, required before practical system implementation. Numerous data obtained in the inspections of an actual bridge were input to PC-BREX and the diagnostic results were closely verified. For consideration, variances were identified according to the structural type, input method and inspector, and points to be improved and problems were organized.

2 OUTLINE OF J-BMS

The configuration of J-BMS is shown in Figure 1. The figure shows J-BMS functions corresponding to the steps of the bridge management flow. As the steps of the flow, (i) bridge specification data such as the age and grade of the bridge and inspection data on cracks and other parameters are extracted (J-BMS DB), (ii) performance and soundness of the bridge are assessed based on the extracted data (BREX), (iii) deterioration of the bridge is predicted using deterioration curves based on the diagnostic results (MPOS), (iv) cost and effect of corrective measures are verified based on the results of deterioration prediction (MPOS), and (v) optimum timing and cost of corrective measures are proposed based on the verification results and an optimum management plan is developed (MPOS). The J-BMS functions (subsystems) are described in detail and their characteristics and problems are organized below.

(1) J-BMS Data Base System (J-BMS DB)

J-BMS DB is composed of the “bridge specification DB”, “ordinary inspection DB” and “repair and retrofit DB”. The subsystem was developed to efficiently accumulate all types of data on bridges such as bridge specification data, inspection data that is collected in ordinary and detailed inspections and data on the history of repair and retrofit.

(2) Bridge Rating Expert System (BREX)

BREX assesses the present bridge performance (e.g. load bearing capacity and durability of main girders and slabs) based on the bridge specification data and various inspection data

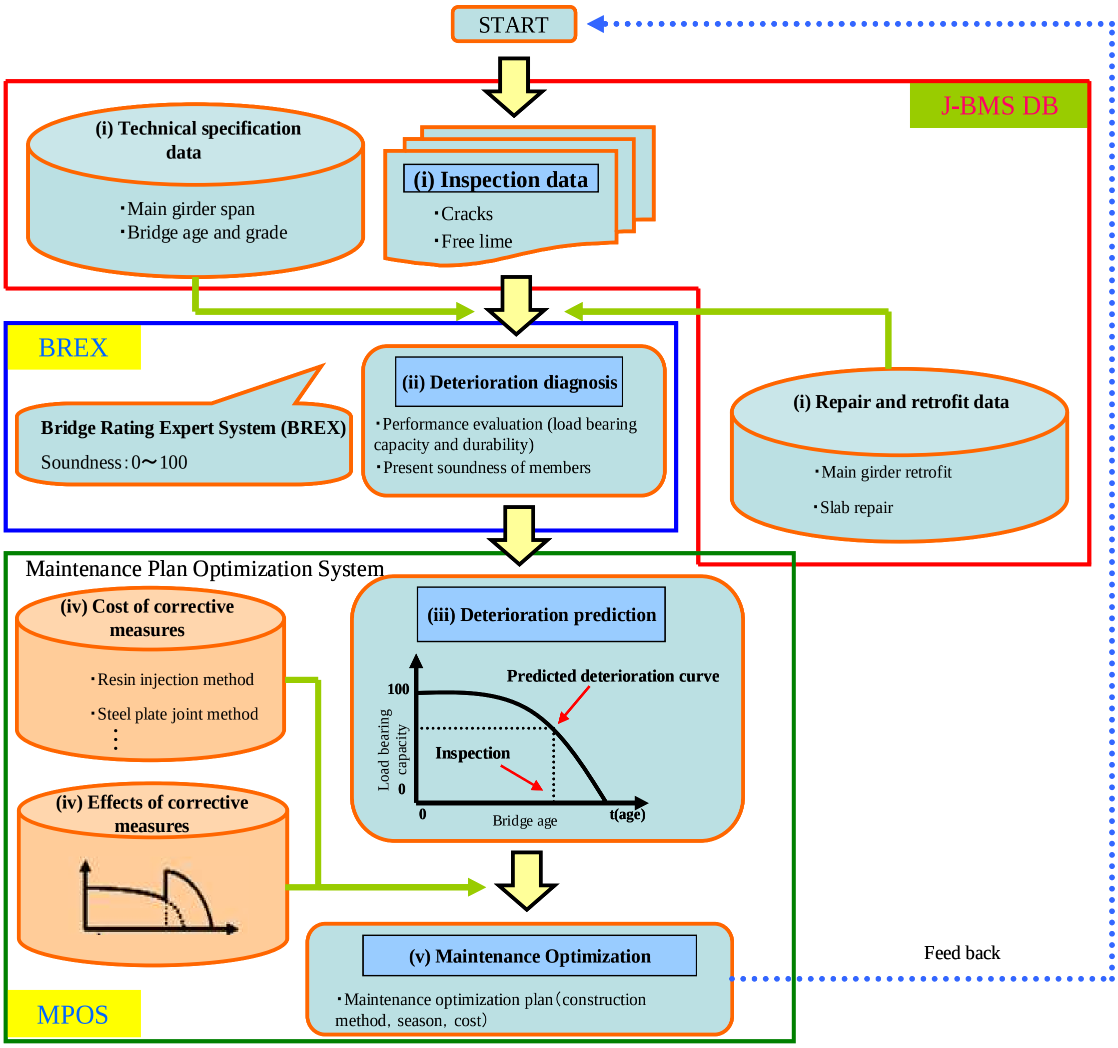

Figure 1. Configuration of J-BMS

provided by J-BMS DB, using neural networks and fuzzy theory. BREX is composed of RC-BREX for reinforced concrete bridges and PC-BREX for prestressed concrete bridges.

(3) Maintenance Plan Optimization System (MPOS)

MPOS helps develop optimum maintenance plans for efficiently managing bridges by inputting the bridge specification data and ordinary inspection data (soundness determined by BREX) output by J-BMS DB and having users set “deterioration prediction equations”, “cost of maintenance and renovation”, “period of applying corrective measures” and “renovation budget”.

3 DEVELOPMENT OF J-BMS PC VERSION

(1) Re-building of PC-BREX

PC-BREX was re-built because (i) no compatibility was provided with Microsoft Windows Vista or later versions of OS, (ii) no explanation functions were available and (iii) bugs occurred in the case where a specified folder contained no data. PC-BREX evaluates the overall durability of main members (main girders and slabs). Overall durability means comprehensive performance of members identified through composite evaluation of load bearing capacity and durability.

This chapter describes the evaluation process and evaluation function of newly built PC-BREX.

a) Evaluation process

The evaluation process is the key component of PC-BREX. The hierarchical process shows the steps of evaluation leading to the evaluation of overall durability of main girders and slabs conducted by domain experts (bridge administrators with expertise and the people with adequate basic knowledge and experience concerning bridges in Yamaguchi Prefecture) (Kawamura et al.(2003)). The evaluation process enables the evaluation of overall durability at the highest level by transferring evaluation results from lower to higher levels. Figure 2 shows part of a process of evaluating the overall durability of main girders.

b) Evaluation function

Evaluation function aims at evaluating various types of performance of main members (main girders and slabs). PC-BREX users can obtain the results of performance evaluation by inputting required data on the specific bridge. PC-BREX outputs evaluation results based on the conditions of cracking and free lime in various positions, which are typical of prestressed concrete bridges. Figure 3 shows a sample screen presenting the results of evaluation of main girders produced by PC-BREX. Users can visually confirm on the evaluation result screen the ratings on the overall durability of main members with respect to the load bearing capacity and durability, and design, general damage, construction and damage at specific positions.

(2) Development of J-BMS PC version

The subsystems of J-BMS were developed at different points in time. Development environments and programming technology therefore varied and no adequate compatibility was established among the subsystems. This chapter discusses the development of J-BMS PC version for the purpose of integrating J-BMS subsystems and effectively managing prestressed

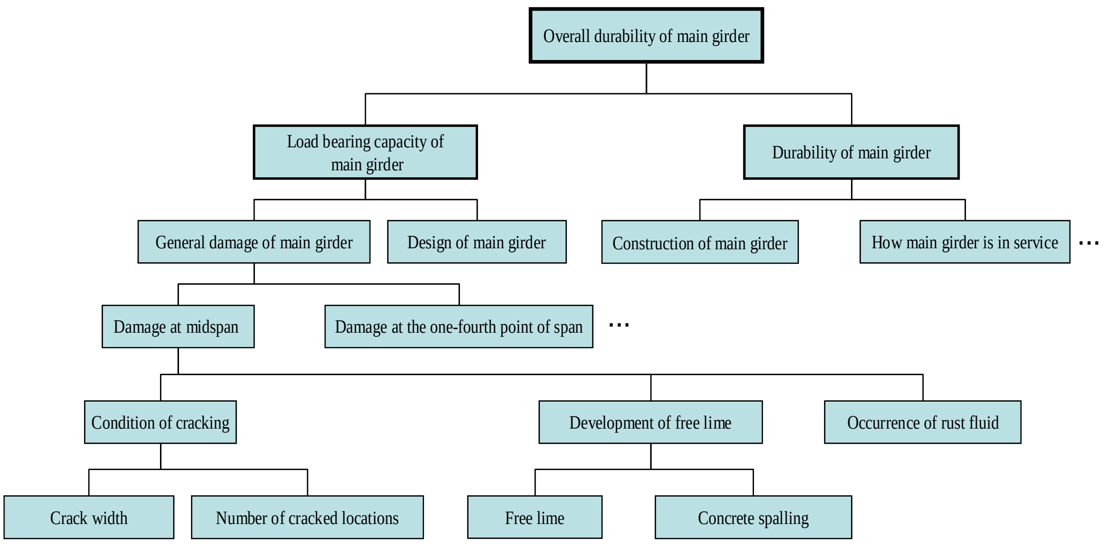

Figure 2. Part of the process of evaluating overall durability of main girder

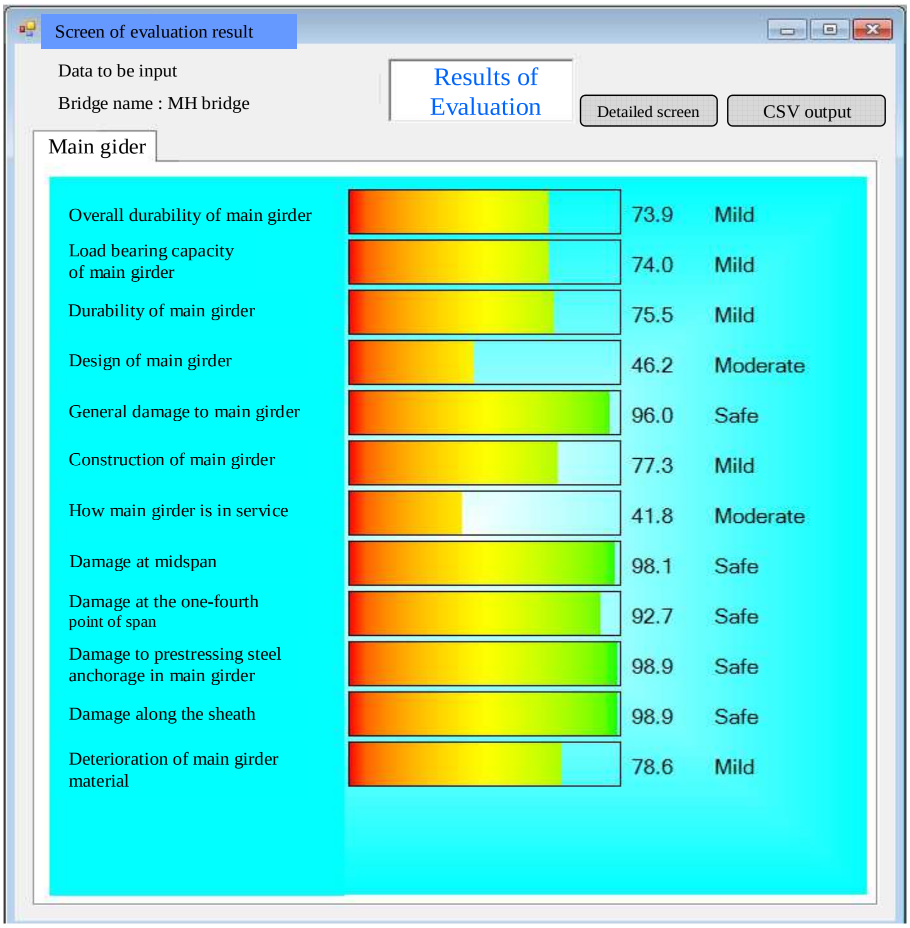

Figure 3. Sample screen showing evaluation results for parameters of main girder

concrete bridges. A general view of J-BMS PC version is given in Figure 4.

The processes of system integration conducted in this study are described below:

(i) J-BMS DB was integrated with PC-BREX by downloading BREX data from J-BMS DB, outputting the results of evaluation by PC-BREX as CSV files and uploading the CSV files to J-BMS DB. BREX data includes an inspection report, input file (brx. file) and explanation file containing compressed data, which can separately be downloaded.

(ii) J-BMS DB was integrated with MPOS by using bridge specification and inspection data stored in J-BMS DB. Corrective measures are stored in J-BMS DB in three levels. Soundness is evaluated on a scale from 0 to 100 by diagnosis using PC-BREX and is input to MPOS.

4 SYSTEM VERIFICATION

This chapter presents the results of application of re-built PC-BREX to an actual prestressed concrete bridge in Yamaguchi Prefecture and an optimum maintenance plan that was developed using developed J-BMS PC version, and verifies the systems.

(1) Results of application of PC-BREX to an actual bridge

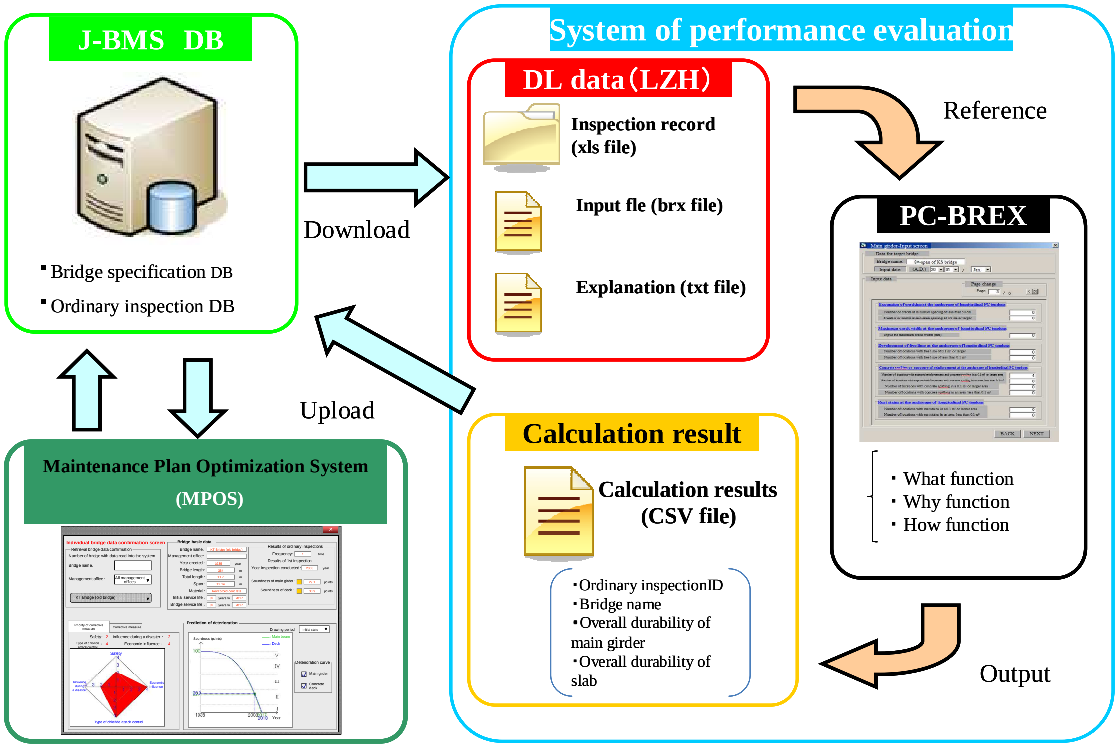

Figure 4. General view of J-BMS PC version

The MH Bridge (Mine City) was inspected on-site through the cooperation of four experts who work in consulting firms and have adequate knowledge about bridges. Table 1 lists the results of evaluation of specific parameters obtained by inputting the inspection data collected by domain experts to PC-BREX and standard deviations. The table indicates that ratings are low for “design” and “serviceability” either for main girders or for slabs. This may be because the MH Bridge has been in service for 42 years and because out-of-date specifications were applied at the time of design and the bridge was designed under smaller design loads than at present. General evaluation results show that the rating of overall durability by BREX is approximately 70 on a 100-point scale. It is therefore evident that the MH Bridge needs no urgent repair.

A comparison of results of evaluation by four inspectors shows great variations in “construction” either for main girders or slabs. Figure 5 shows a hierarchical structure of “main girder construction”. “Slab construction” is of a similar structure. As is obvious from Figure 5, construction is evaluated in terms of two parameters, “discoloring and deterioration” and “occurrence of honeycombing”. The ratings in these terms seem to greatly govern the final scores. The options concerning the “discoloring and deterioration” and “occurrence of honeycombing” are shown in Figures 6 and 7, respectively. The options are similar for slabs. Specific figures are input concerning the “occurrence of honeycombing” (Figure 7). Slight difference in number of locations of occurrence therefore has no impact on evaluation results. Figure 6 shows that a checkbox is used for inputting subjective decisions. Small difference in the determination of damage by inspectors greatly affects evaluation results.

The evaluation results obtained through comprehensive review may be used effectively if the difference in inspection is adjusted in prior interviews.

Table 1. Results of evaluation of the MH Bridge

	Rating parameter \ Inspector	Expert A	Expert B	Expert C	Expert D	Standard deviation
Main girder	**Overall durability of main girder**	63.6	63.8	79.7	70.8	6.58
	Load bearing capacity of main girder	73.2	73.4	73.6	73.9	0.26
	Durability of main girder	65.2	65.3	81.6	72.8	6.74
	Design of main girder	46.2	46.2	46.2	46.2	0.00
	General damage to main girder	91.0	91.7	93.0	95.3	1.64
	Construction of main girder	52.8	52.8	98.3	73.8	18.7
	How main girder is in service	41.8	41.8	41.8	41.8	0.00
	Damage at midspan	93.2	80.4	82.7	92.6	5.74
	Damage at the one-fourth point of span	81.9	98.9	98.9	93.3	6.94
	Damage to prestressing steel anchorage in main girder	98.9	98.9	98.9	98.9	0.00
	Damage along the sheath	98.9	82.0	82.6	98.9	8.30
	Deterioration of main girder material	69.4	76.8	78.4	77.3	3.55
Slab	**Overall durability of slab**	64.1	71.1	57.3	79.1	8.10
	Load bearing capacity of slab	66.6	70.7	58.0	68.4	4.80
	Durability of slab	73.0	76.2	69.5	91.5	8.40
	Design of slab	48.6	52.2	26.7	53.4	10.8
	General damage to slab	79.0	83.7	80.7	80.6	1.70
	Construction of slab	73.8	74.5	28.3	99.0	25.5
	How slab is in service	70.1	70.2	82.5	82.5	6.18
	Damage at the center	72.3	93.2	75.5	74.3	8.38
	Damage at the point of filling	37.2	81.2	60.9	48.0	16.4
	Damage in other areas than at the point of filling	98.9	98.9	94.2	98.9	2.04
	Damage to slab overhangs	98.9	79.7	95.6	98.9	7.95
	Damage to the anchorage of perpendicular prestressing steel	98.6	99.0	99.0	99.0	0.17
	Deterioration of slab material	48.8	61.3	49.7	58.1	5.36
	Surface condition	78.1	78.4	78.4	78.3	0.12

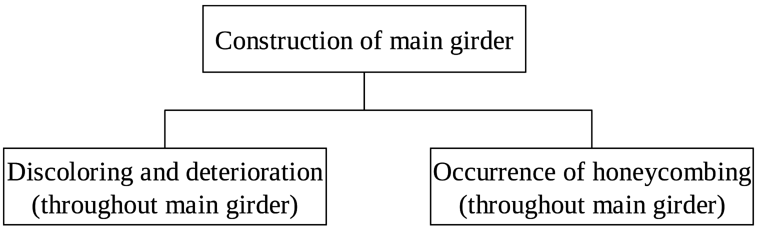

Figure 5. Hierarchical structure for evaluating main girder construction

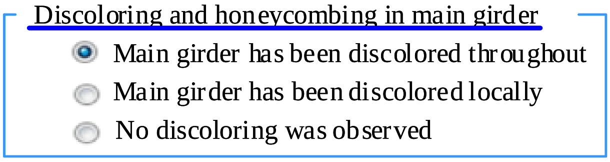

Figure 6. Options for determining the discoloring and honeycombing of main girder

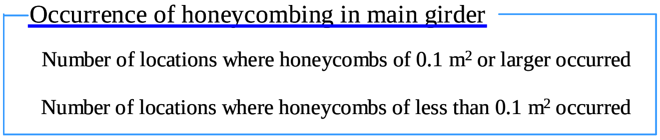

Figure 7. Options concerning the occurrence of honeycombing

(2) Development of an optimum maintenance plan

An optimum maintenance plan was developed using J-BMS PC version based on the inspection data on the YN Bridge in Ube City stored in J-BMS DB. A sample screen is shown in Figure 8 of the optimum maintenance plan output by MPOS after the input of conditions for developing the optimum maintenance plan. Not only deterioration curves before and after repair or retrofit and predicted remaining service life but also optimum timing of repair or retrofit may be output for the bridge under study.

In the future, it is necessary to review the integration of subsystems for reinforcing final evaluation results.

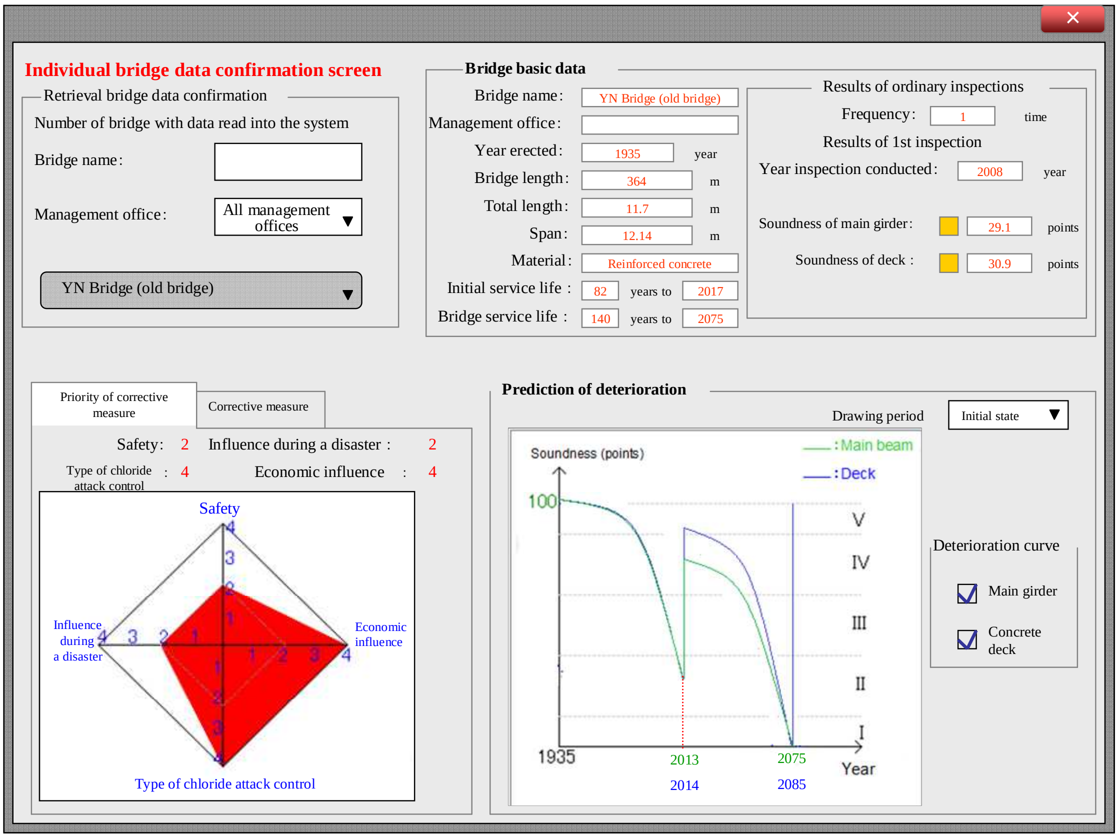

Figure 8. Sample screen of an optimum maintenance plan for YN Bridge

5 CONCLUSIONS

The authors have been developing PC-BREX as a bridge rating expert system for prestressed concrete bridges. J-BMS DB and MPOS, subsystems of J-BMS that is capable of effectively maintaining prestressed concrete bridges, were developed and implemented separately and coordination between the subsystems required various improvements. In order to meet the requirement, PC-BREX was re-built and J-BMS subsystems that had been developed separately were integrated. For putting J-BMS into practical use, data obtained in inspections of an actual bridge was input to PC-BREX and the results of diagnosis were verified. As a result, J-BMS PC version was completed that enables comprehensive bridge management by J-BMS.

The results of this study are described below:

1) Combining J-BMS DB and PC-BREX enabled direct downloading of compressed BREX data (brx. file) and ensured the flow from the reading of inspection data into PC-BREX to performance evaluation.

2) It was made possible to output deterioration curves and develop an optimum maintenance plan by MPOS based on the bridge specification data and inspection data stored in J-BMS DB; and on the overall durability of main girders and slabs obtained by PC-BREX.

3) Subsystems of J-BMS were integrated based on the results in (i) and (ii). Then, it became possible to develop J-BMS PC version, a variation of J-BMS for prestressed concrete bridges and to increase the efficiency of maintenance work for prestressed concrete bridges.

4) It was revealed that the results of evaluation varied with respect to some parameters even among domain experts. For most of the parameters for which variations occurred, lower level evaluation depended on a checkbox. For solving the problem, using three-dimensional bridge models, using a diagram showing damaged positions for on-site inspections and other means are considered to enable the sharing of recognition of damage. Reinforcing the explanation function built in the system for supporting users to add detailed explanations about the damage is expected to reduce the variations of inspection results from inspector to inspector.

REFERENCES

Bien, J., Elfgren, L and Olofsson, J.(Ed), 2007. *Sustainable Bridges -Assessment for Future Traffic Demands and Longer Lives-*, Wroclaw, Poland, Dolnoslaskie Wydawnictwo Edukacyjne.

Kawamura, K. and Miyamoto, A., 2003. Condition State Evaluation of Existing Reinforced Concrete Bridges using Neuro-Fuzzy Hybrid System, *Computers & Structures*, Civil Comp Ltd. and Elsevier Ltd., 81(18-19): 1931-1940.

Kawamura, K., Miyamoto, A., Frangopol, D.M. and Kimura, R., 2003. Performance Evaluation of Concrete Slabs of Existing Bridges using Neural Networks, *Engineering Structures*, Elsevier Science Direct, 25(12), 1455-1477.

Konno, M., Kawamura, K., Miyamoto, A. and Nakamura, H., 2003. Practical Application of Database System for Bridge Maintenance Management, *Journal of Applied Computing in Civil Engineering*, Committee on Civil Engineering Information Processing, JSCE, 12, 179-186.

Miyamoto, A., 2000. Development of a Bridge Management System (J-BMS) in Japan, *Proceeding of the 1st US-Japan Workshop on Life-Cycle Cost Analysis and Design of Civil Infrastructure Systems*, ASCE, 179-221.