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Remaining Life Prediction and Verification of an Aged Bridge based on Field Inspections

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ABSTRACT

This paper describes methods for physically checking and predicting the remaining life of an aged RC-T girder bridge and for verification based on field tests using either visual inspection data or concrete core test results. The authors have been developing a Bridge Management System (J-BMS) that is able to predict the deterioration process of existing bridge members. The remaining life of the aged RC-T girder bridge (KT bridge) can be quantitatively estimated by applying the bridge rating expert (BREX) system, which is a sub-system of the J-BMS with field inspection data. In this study, it was found that both the main girder and concrete deck had a remaining life not exceeding a decade by using the BREX system. Additionally, the influence of the health score (safety indices) was shown by selecting the learning (supervised) data. The remaining life prediction was also verified using the concrete core specimen test.

Keywords. Aged RC-T Girder Bridge, Field Inspections, Concrete Core Specimen Tests, J-BMS, Remaining Life

RESEARCH SIGNIFICANCE

A considerably large-scale bridge, the "KT bridge (aged bridge)" (Ube Native, 1975), was constructed when National Highway Route No. 190 crossed a first-grade river. This RC-T girder bridge was constructed in 1935 under the jurisdiction of the Ministry of Land, Infrastructure and Transport (Yamaguchi River National Highway Office). The bridge length is 364 m, the span is 28 m, and the total width is 11.7 m. At the time of the construction, the road bridge had only two lanes. In 1959, an independent pedestrian bridge was constructed on the upstream and downstream sides of the road bridge. After that, several construction repairs were performed, and in 1998, the "KT bridge" was dismantled and removed due to the deteriorating bridge conditions. A new six-lane KT bridge was completed in its place.

Visual inspection of the bridge (Miyamoto, 2011) was performed by professional engineers four times between 2003 and 2009. The visual inspection data is useful for making a framework to manage the reliability of existing bridges, establishing a method of inspection, developing a method of repair or reinforcement, and making a management database system for the Ministry of Land, Infrastructure and Transport or the local government. In addition, the use of visual inspection has attracted significant attention particularly in Europe and America, where the maintenance of civil infrastructures as well as the development of a practical system that can support the maintenance duties are considered priorities. It is expected that this will be a significant topic of concern in the near future.

This study presents the results of the checks performed during the bridge dismantling and removal by the "bridge management system (J-BMS)" (Miyamoto, 1997; 1998; 1999), which the authors originally developed. The J-BMS calculates the remaining life prediction using the visual inspection data provided by specialists (6 to 8 persons) for eight spans (two spans each time) in accordance with the inspection manual.

A material examination of the main beam and slab deck was performed using a concrete core piece in order to objectively verify the physical results (for the durability and trafficability of the main beams and slab decks) using J-BMS. Thus, it is thought that objective grounds can be given for a physical check result with a score of 100 points (perfect) to input the inspection data mentioned into J-BMS.

Figure 1 shows the flow of the management and maintenance plan including the remaining life prediction process from visual inspection. As the diagram indicates, the data from the visual inspection is input into the bridge rating expert (BREX) system (Emoto, 2010). After that, the BREX system gives points (health value) representing the durability and trafficability. Furthermore, the BREX system evaluates the remaining life based on the expected deterioration curve.

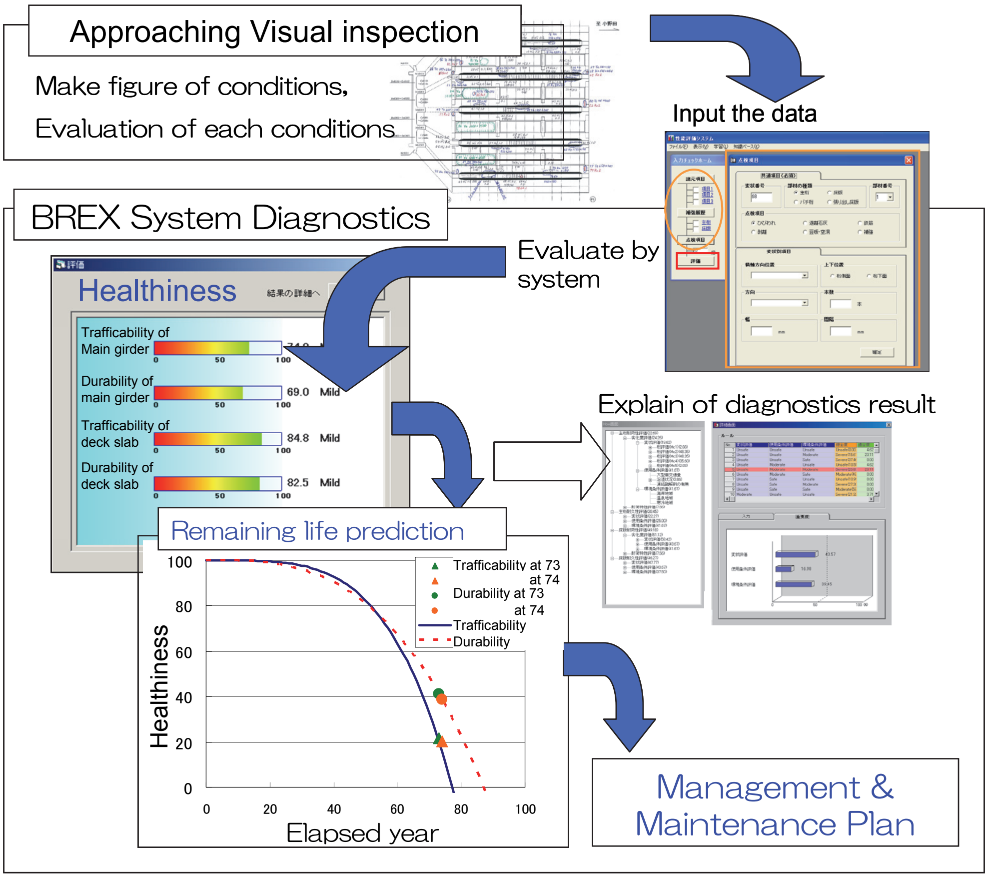

Figure 1. Outline of the remaining life prediction process

SYSTEM EVALUATION METHOD

Outline of System Evaluation Method. The BREX system supports the diagnosis of the bridge deterioration by managing the bridge diagnosis by the specialist. Figure 2 indicates the BREX input procedures for the base specifications (service conditions, environmental conditions, etc.) and inspection data (from visual inspection). The evaluation object is one span, the main beam, and the slab deck. The results obtained using this system are used to evaluate the "trafficability" and "durability" of each of the parts based on the bridge inspector's assessment.

"Trafficability" means the deterioration of a structure with respect to the load capability, and "durability" means the deterioration of the material immediately after construction. Part of the BREX evaluation and learning function (as shown in Figure 2) is a combination of a "neural network" and "fuzzy inference" based on extracting the knowledge of the expert (visual inspection specialist) using a questionnaire. Specifically, this system calculates the weight of the hierarchical structure from the inspection data and learning data, which evaluates the deterioration conditions for the specialist. This evaluation represents the health score with a maximum value of 100.

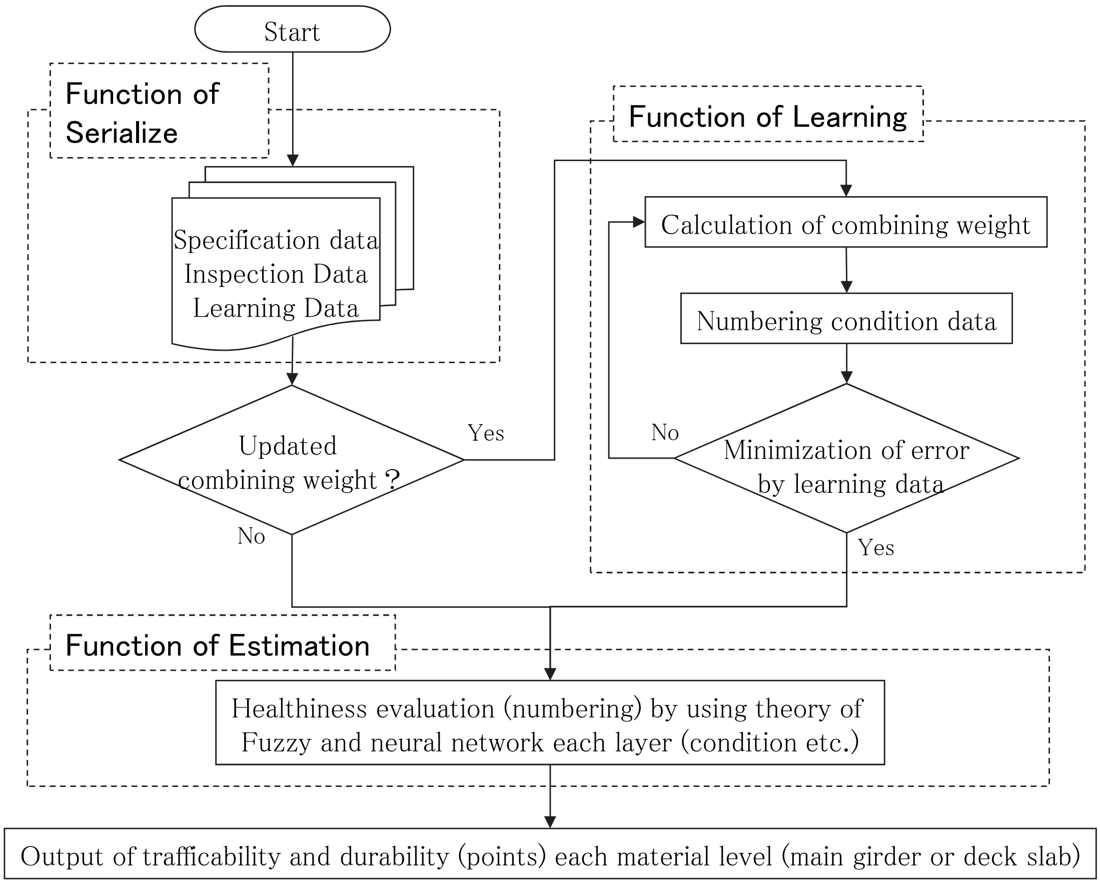

Figure 2. BREX system procedure

Method of Remaining Life Prediction. The procedure for predicting the remaining life of the bridge is shown below. Firstly, the damage condition must be assessed by visual inspection. Next, the health of the bridge must be evaluated at the time of the investigation. Finally, the remaining life is predicted. In order to predict the remaining life of the bridge, it is necessary to use an estimation formula (deterioration curve), which estimates the health from the time of the investigation into the future. Here, Eqs. (1) and (2) are adopted for the deterioration curve (Miyamoto, 1984; Takahashi, 2012). The term “S_L” in Eq. (1) represents the “trafficability,” and “S_D” in Eq. (2) represents the “durability.”

$$S_L = b_L - a_L t^4 \tag{1}$$

$$S_D = b_D - a_D t^3 \tag{2}$$

Here, “b_L” and “b_D” represent the start time of the services, and they are set to 100. The health value becomes “0” when it is at the limit of the bridge management system.

RESULT OF SYSTEM EVALUATION

Variation in Learning Data. Table 1 shows the health score compared with the learning data with respect to the “trafficability” and “durability” during the 2008 (3rd) and 2009 (4th) investigations. Figures 3 and 4 show the probability density of the “trafficability” and “durability,” respectively.

At first, the health score from the differential learning data is considered. The “trafficability” shown in Figure 3 indicates that it is possible to change the health ranking based on the “trafficability” using this method based on 100 total points. On the other hand, the “durability” shown in Figure 4 indicates that although the difference in learning data had an influence on the unevenness of the evaluation to some extent, the difference in the evaluation score was smaller than that for the “trafficability” evaluation. Thus, in order to improve the reliability of the “durability” evaluation, it is necessary to reduce the variation in the inspection data and also to complement the investigation data. For example, it is thought that the effective utilization of actual survey investigations to gather core pieces contributes to the reliability improvement of the “durability” evaluation. Also, learning data A and B are from the same investigator, where learning data A is the ordinary data based on the inspection, and learning data B is special data based on the inspection obtained before the field work using the bridge inspection support system in a virtual reality system. It is shown that the selection of the learning data becomes important for the reliability of the health evaluation since a difference in the learning data influences the health evaluation.

Table 1. Health score of bridge compared with learning data

		Learning Data A		Learning Data B	
		Ave.	3σ	Ave.	3σ
Trafficability	2008(3rd)	30.6	5.09	21.5	4.09
	2009(4th)	29.5	5.71	20.4	3.4
Durability	2008(3rd)	45.6	11.95	41	8.25
	2009(4th)	43.5	10.91	38.7	6.91

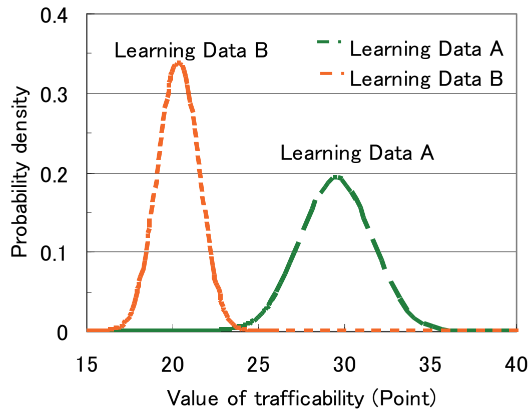

Figure 3. Probability density of trafficability

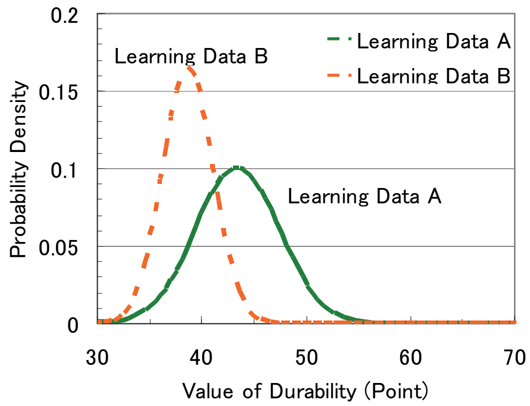

Figure 4. Probability density of durability

Result of Remaining Life Prediction. It is possible to calculate the remaining life with Eqs. (1) and (2) using the health value from the BREX output. Figures 5 and 6 show the health of the main girder based on the "trafficability" and "durability," respectively. Table 2 shows the remaining life of the main girder. For example, with respect to the "trafficability" from the investigation in 2008 (3rd), as shown in Table 2, the average health is 21 points, the age of the bridge is 73 years, and the remaining life is four years according to Eq. (1).

It is clearly seen in Table 2 that the remaining life prediction, which is estimated from the BREX system using the "trafficability" and "durability," tends to be long for the "durability" regardless of the investigation year and span. It is thought that a deterioration curve is the third function that influences the bridge age t and that the evaluation result (score) of the "durability" health from the BREX system tends to increase when it evaluates the estimated remaining life from the durability. Furthermore, the remaining life estimated in Figure 6 from the durability deterioration curve based on the health score (degree) evaluation result is relatively large at 13 to 20 years because the multiplier of the deterioration curve is three. On the other hand, the remaining life from the "trafficability" in Figure 5 based on the health score (degree) evaluation result is relatively small at about five years because the multiplier of the deterioration curve is four. For the reasons mentioned above, it is thought to be possible to improve the accuracy of the remaining life prediction by reforming the evaluation system that selects the learning data for the BREX system, and the evaluation of the standard levels of "trafficability" and "durability" is proposed.

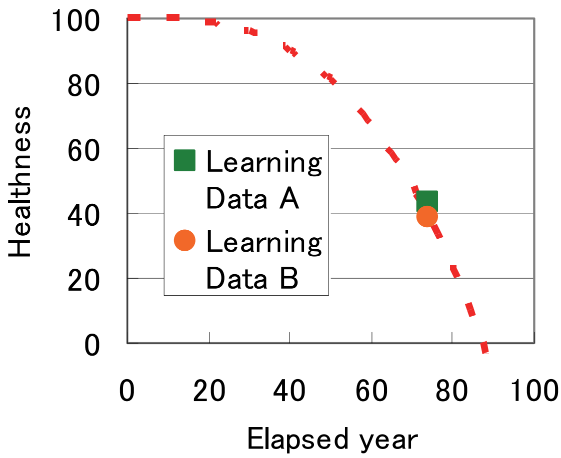

Figure 5. Progress of health for "trafficability" of main girder

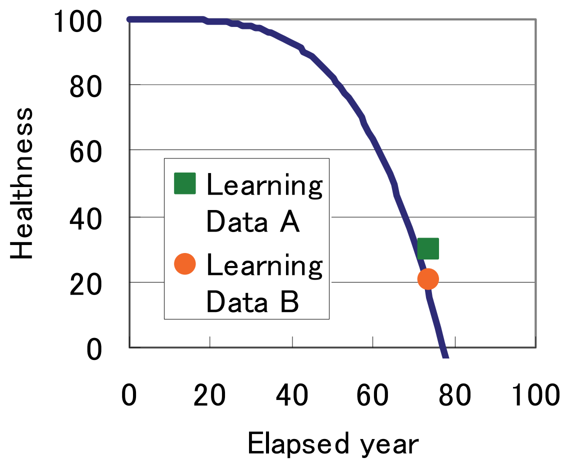

Figure 6. Progress of health for "durability" of main girder

Table 2. Remaining life of main girder

No of Span	Span A				Span B			
Elapsed year	Trafficability (point)	Remaining life (year)	Durability (point)	Remaining life (year)	Trafficability (point)	Remaining life (year)	Durability (point)	Remaining life (year)
68 (2003)	28.7	6	42.9	13	30.3	6	42.9	13
72 (2007)	28.7	6	44.1	15	28.7	6	38.9	12
73 (2008)	21.2	4	40.4	13	21.8	4	41.6	14
74 (2009)	20.3	4	38.6	13	20.4	4	38.7	13

Comparison of core test and BREX system for remaining life prediction. Here, the result of the remaining life prediction based on the chloride ion density of the concrete core pieces and the result of the remaining life prediction using the BREX system are compared, as shown in Table 3. Here, the result of the system evaluation uses the remaining life viewpoint of "durability."

Table 3 indicates the following:

1) The estimated number of years of remaining life for the "durability" from the system (BREX) evaluation is close to that from technique (C). In addition, in technique (B), the estimate is close to the result of the system (BREX) evaluation if it is assumed that the accumulated corrosion quantity for the reinforcing rod is around 75 mg/cm^2.

2) As for the estimated results in 2008, all of the techniques have a smaller remaining life prediction than the system (BREX) evaluation. Because the core investigation method is a "local" evaluation method, it is thought that the results are more critical than for the "general" (average) system evaluation.

3) Because of technique (B), technique (C) can set the evaluation standard, and they can estimate the criterion for the system (BREX). It is thought that for technique (B), around 75 mg/cm^2 of corrosion accumulation in steel (assuming the remaining life using technique (C) is about 3.7%) is obtained for the criterion of the system (BREX) evaluation.

Therefore, the evaluation result and the estimation criterion for the remaining life prediction using the BREX system were able to be verified based on the core piece investigation.

Table 3. Comparison between core test and BREX system for the remaining life prediction

Investigation year	Parts	Remaining life prediction using core peace test (year) each prediction methods				Remaining life prediction using BREX system (year)
		(A)	(B) 50mg/cm^2	(B) 100mg/cm^2	(C)	Durability
2009	Span A	6	4	21	13	13
	Span B	16	9	29	17	13
2008	Span B	-3	-4	11	9	14

CONCLUDING REMARKS

In this study, visual inspections of the "KT bridge," which was removed after 60 years of continuous construction, were performed four times by the same specialist. It was attempted to diagnose the bridge conditions (physical check) and to predict the remaining life at the time of removal. The main conclusions of this paper can be summarized as follows:

1) This paper discussed the evaluation of the bridge condition using the Bridge Rating Expert System (BREX), which is a Bridge Management System (J-BMS). As a result, it was determined that the selection of the training data was important in the BREX system evaluation. In addition, a method for evaluating the bridge conditions and estimating the remaining life using the BREX system was presented, and an example showing how to diagnose the bridge conditions (physical check) at the time of removal was given. The results showed that the remaining life was less than 10 years for both the main beam and slab deck of the KT bridge (old bridge).

2) This study discussed how to prove the evaluation (output) of this BREX system objectively. This time, concrete core pieces were examined from several parts (i.e., the main girder, slab deck, and pier). It was established how to verify the evaluation value given by this system. As for the durability evaluation, the verification of the BREX system's result (evaluation value) was clearly shown.

3) It was found from the result that the bridge maintenance plan (i.e., rebuilding and removal) in a real strategy is the same as in the BREX system strategy. This system accounted for a reduction in the variation of the visual inspection data, bridge condition diagnosis, and remaining life prediction. In the future, the use of a physical check of the infrastructure will be important in the selection of a bridge maintenance strategy.

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