ENHANCED FUNCTIONALITY
FOR AN EXISTING BRIDGE MANAGEMENT SYSTEM

Masato MIYATA, Takuto SHIRAISHI, Takashi NISHIOKA, Seigo NASU
Kochi University of Technology

***ABSTRACT*:** In the high economic growth period 1955-1974 in Japan, there were substantial new infrastructure needs, so reinforced concrete structures were built. Now Japan continues to use the same structures, but after the high economic growth period, chloride attack and other deterioration have been detected. In fact reinforced concrete is not permanent without maintenance. Now reinforced concrete structures built in the high economic growth period are approximately 30 to 50 years old and some of them are already deteriorated.

In addition, the national and local governments' financial conditions are tight, so existing operation and haphazard maintenance may not be sufficient for future substantial bridge deterioration. In such a situation, renewed maintenance by the bridge asset management system (BMS) is needed. BMS is expected to include deciding investment timing of maintenance, calculating and minimizing life cycle cost (LCC), and calculating and suggesting maximum maintenance effect. In fact BMS can anticipate decision support systems for consistent bridge safety and quality. In addition, BMS is found to be useful for meeting accountability requirements. In 2007, national and local governments started operation of BMS. However, BMSs are now developing and their functional capabilities are not enough for bridge management, so in Japan BMS is not popular.

In Kochi Prefecture there are 2 BMSs, one for a prefectural bridge and another for a national road bridge. However, there is no substantial functional BMS in operation. Therefore this research will clarify the reasons for the smooth operation of the 2 BMS and suggest an improvement element. To improve BMS, it is suggested to use a physical deterioration model with deductive deterioration stage, maintenance methods for relevant stages, renewal periods for each stage and calculation of minimum LCC with maintenance plan for in-service period. For one bridge, implementing a minimum LCC maintenance plan to the limit of the renewal period is best; however, for substantial bridges this is not implemented because there are budget constraints for maintenance. In that situation, it is essential to consider a minimum LCC maintenance plan and renewal period on all stages, setting maintenance priorities and suggesting a total minimum cost for bridges. This research implements 5 bridge priorities under budget constraint.

KEYWORDS: Bridge Management System (BMS), life cycle cost, maintenance priority

1. Introduction

1.1 Background

In the high economic growth period 1955-1974 in Japan, there were substantial new infrastructure needs, so reinforced concrete structures were built, and Japan still continues to use the same structures. However, the deterioration mechanism including chloride attack, which was not fully understood at the construction, has been gradually clarified in recent years, and it has been found that reinforced concrete structures are not always permanent without maintenance. In addition, the reinforced concrete structures built in the high economic growth period are approximately 30 to 50 years old and some of them are already deteriorated. As stated in the proposal [1] in the advisory committee concerning ideal ways of future management and renewal of the road structure in 2003, there is a concern that the social influence of the increase of the costs required for repair and maintenance of aging road structures and the influence of the regulation of traffic etc. accompanying such repair or maintenance is getting more and more serious, along with the advancement of the aging of road structure.

In addition, the national and local governments' financial conditions are tight, so existing operation and haphazard maintenance may not be sufficient for future deterioration. In such a situation, a new maintenance and management measure using Bridge Management System (BMS) has been getting attention. In Kochi prefecture, there are two types of BMS'; one is Kochi version BMS owned by Kochi prefecture and the other is a document creation tool for bridge repair budget owned by Tosa National Road Administration office of Shikoku Area Maintenance Bureau of Ministry of Land, Infrastructure and Transport (BMS of MLIT). However, neither simulation nor maintenance based on the result of simulation is carried out, and current simulation results are not taken into account for the repair. In other words, BMS is not utilized enough to meet expectations.

1.2 Objectives

The objectives of this study are to demonstrate the problems and reasons that the existing two BMS' in Kochi prefecture are not utilized enough, and to propose a system of operating level, improving basic function of the BMS in order to find out the reasons and to overcome the problems.

2. Deterioration state of bridges and the necessity of bridge asset management

2.1 Necessity of bridge asset management

If we take it into account that the national road network including as major routes has been completed to a certain degree, and consider that many of the bridges in-service are becoming deteriorated all together, how we should maintain and manage them is a more important problem than to construct new bridges. However, as for the bridge maintenance, the national and local governments have conducted the maintenance of the bridges that were judged to be deteriorated or not good enough to be in-service, according to the risk rating based on inspection results. In addition, their financial conditions are tight and existing operation and haphazard maintenance may not be sufficient. In order to predict the future maintenance cost, it is possible to analyze the budget in macro-level and predict how much is required in the future by estimating the maintenance cost based on the maintenance rate as Takahashi et al. [2] did. However, even if the entire budge is calculated or predicted, this is not enough to decide when and what order the maintenance should be conducted based on the prediction. One of the effective ways is to include bridges into the target of asset management. Asset management system (BMS), represented by PONTIS BMS[3], developed by the Federal Highway Administration (FHWA) and American Association of State Highway and Transportation Officials (AASHTO) in 1991, attracted attention as a new measure of bridge maintenance and management. Asset management is an idea of asset management to maximize asset value by appropriately operating property in consideration of risk and profitability, etc. [4] Furthermore, in the light of the idea of asset management for public structures, especially the one that specializes in bridges, BMS is expected to compute the lifecycle cost (hereinafter LCC), propose the minimum LCC, and decide investment timing of maintenance based on the long term prediction of deterioration, aiming at making bridges last long. In addition, because BMS is an effective tool in order to fulfill the accountability and can be a decision making system to realize the stable supply of infrastructure service, especially of bridges, it can be assumed that it is extremely effective to meet the system such as expense support system for maintenance project for long lasting life plan. [5]

3. Problems of BMS and proposal for function improvement

3.1 Proposal for function improvement

Since the BMS of MLIT focuses on the function to compute the cost for next maintenance, this study attempts to propose the improvement of functions focusing on the prefectural BMS. Firstly, we will predict the deterioration of bridges and find out the deterioration state. Then, we will make scenarios for maintenance and management of the bridges by combining several or similar methods that are suitable for the deterioration state. Currently, the prefectural BMS has no scenarios and just chooses only one method for preventive maintenance and breakdown maintenance, respectively. Therefore, the same method has to be repeatedly used while bridges are in-service. We will also predict the deterioration of bridges according to the existing researches and some assumptions, focusing on how chloride attack progresses based on our scenarios. Using different scenarios, it can be expected that there may be differences in the deterioration state. At the same time, we will conduct lifecycle cost analysis (hereafter, LCCA), and try to judge which scenario during in-service will lead to the minimum LCC. Moreover, repairing several bridges at the same period is impossible when there is a budget constraint. Therefore, it is necessary to decide the priority level for repair. Assuming all the bridges as one bridge group, it is possible to establish the priority level by finding the minimum LCC of the group based on the minimum LCC of each bridge under the condition that the maintenance management is carried out while all bridges can keep being in-service.

3.2 Target bridges

In this study, we will choose five bridges (Ananai, Aki 2nd, Awanoura, Enokawa, and Sukawa), which are RC-T girder bridges along the coast and likely to have chloride attack, and conduct chloride attack simulation and LCCA targeting them.

3. Maintenance method, and setting the extent of repairs and amount of deterioration

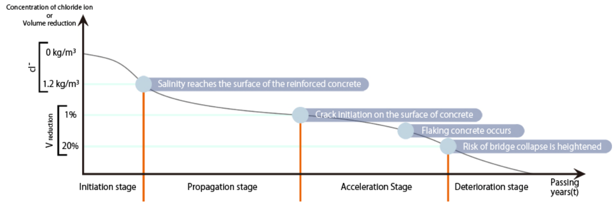

Fig. 1 Definition of progressive deterioration stages

4.1.1 Initiation stage

According to the Standard Specification for Concrete Structures: Guidelines for Application by Civil Engineering, initiation stage is defined as a period until the concentration of chloride ion at the position of protective covering of steel lumber reaches the critical concentration of corrosion generation. [7] Each stage described later is also based on the definition stipulated in the Standard Specification for Concrete Structures. In order to express the phenomenon of the infiltration and diffusion of chloride ion into concrete, in general, the second law of Fick is used, and therefore, it is also used in this study.

$$C(x,t) = C_0\left(1 - erf\,\frac{x}{2\sqrt{D \cdot t}}\right) + C(x,0) \tag{1}$$

$C(x,t)$: depth x (cm),

Concentration of chloride ion in time t (year): (kg/m^3)

C_0 : Concentration of chloride ion on the surface (kg/m^3)

D : Diffusion coefficient of appearance of chloride ion (cm^3/year)

erf : Error function

$C(x,0)$: Concentration of initial chloride ion content (kg/m^3)

Table 1 Value of C_0 vs distance from coast

Distance from coast	C_0 (kg/m^3)
shore line (0)	9
0<distance<0.1km	4.5
0.1<distance<0.25km	3
0.25<distance<0.5km	2
0.5<distance<1.0km	1
1.0km<distance	0

Initial chloride ion content is assumed to be 0.3 based on the Standard Specification for Concrete Structures. In general, the diffusion coefficient of ordinary Portland cement is used for prediction of regular chloride ion. Blast furnace slag cement is used for mending, and it is assumed to use the diffusion coefficient for blast furnace slag cement.

In the case of ordinary Portland cement:

$$\log D = \left(19.5(W/C)^2 + 0.14(W/C) - 8.47\right) + \log\left(3.15 \cdot 10^7\right) \quad (2)$$

In the case of blast furnace slag cement:

$$\log D = \left(19.5(W/C)^2 + 13.8(W/C) - 5.74\right) + \log\left(3.15 \cdot 10^7\right) \quad (3)$$

4.1.2 Propagation stage

According to the Standard Specification for Concrete Structures by Civil Engineering, propagation stage is defined as a period from the beginning of the steel ber corrosion to the occurrence of the corrosion crack. [5] The concentration of the chloride ion at the propagation stage is assumed to be between 1.2 and 2.0 kg/m^3.

4.1.3 Acceleration Stage

Acceleration stage is defined as a period when the corrosion speed increases due to the occurrence of corrosion crack. With regard to the correlation between the concentration of the chloride ion and the steel bar, the rehabilitation study group of concrete structures of Japan Concrete Institute attempted to calculate the reduction in area of the steel bar under the assumption that corrosion progresses thoroughly on the surface of the steel bar. [13] On the other hand, Kodama et al. [6] assume and use various coefficients. In this study, we use the assumption of Kodama et al.

$$V_{reduction} = \frac{4ac}{\phi \gamma_{Fe}} \cdot e^{\frac{\alpha}{a} t} \quad (4)$$

$V_{reduction}$: Volume reduction

a : Coefficient that correlates the amount of corrosion to crack width = 1500 (mg/cm^3)

c : Initial crack width due to corrosion = 0.005 (cm)

ϕ : Steel bar diameter =1.3 (cm)

γ_{Fe} : Mass per unit volume of steel bar = 7850 (mg/cm^3)

α : Relational coefficient of corrosion speed and width of crack = 220 (mg/cm^3/year)

t : Time (year)

Kodama et al. assumes the acceleration stage starts when volume reduction reaches 1%, and ends when it reaches 20%. In this study, we use this assumption.

4.1.4 Deterioration stage

Deterioration stage is defined as a period when the decrease of withstand load is remarkable because of an increase in the amount of corrosion. Kodama et al. defines it as deterioration stage when volume reduction exceeds 20%. Therefore, it is reasonable to assume that collapse of the bridge which entered the deterioration stage would occur in near future. The BMS of MLIT assumes that bridges at the deterioration stage should be updated; namely, a new construction is necessary. However, unlike a pier that shows deterioration evenly, it is necessary to conduct some assumption for the prediction of the deterioration of a bridge if it is near the coastline.

4.2 Calculation of restoration cost

The cost of restoration was calculated based on the interview with Mr. Sakamoto, SHO-BOND Corporation, and information proposed by the New Technology Information System (NETIS) [7] of Ministry of Land, Infrastructure and Transport.

4.2.1 All patch repair method (PR)

$$CS_{Cost} = AU \times MG \times 150000 \quad (5)$$

CS_{Cost} : Cost of all patch repair method

AU : Area of base of main girder

MG : Number of main girders

4.2.2 Partial patch repair method (PR)

Partial patch repair method is a construction work that restores part of main girders. In this study, provisionally assuming that section restoration is applied to 20% of the area of all types of girders, we calculate the costs.

$$SCS_{Cost} = CS_{Cost} \times 0.2 \quad (6)$$

SCS_{Cost} : Cost of partial section restoration

4.2.3 Surface coating method (SC)

$$SPC = AU \times AS \times MG \times 20000 \quad (7)$$

SPC : Cost of surface coating method

AU : Area of base of main girder

AS : Area of both side faces of main girder

MG : Number of main girders

4.2.4 Cathodic Protection Method (CP)

$$iEC = AU \times 80000 \quad (8)$$

$$rEC = AU \times 25 \quad (9)$$

$$eEC = AU \times 7000 \quad (10)$$

iEC : Initial cost of Cathodic Protection Method (only the first year)

rEC : Electricity a year (every year from the second year)

eEC : Power supply exchange cost (once in 20 years)

5. Deterioration prediction of bridges

5.1 Assumption in deterioration prediction

In this study, the ratio of the concentration of the chloride ion (concentration of partial chloride ion), which will be computed in the deterioration predictions later on, is assumed to be 80% of the entire main girders. It is assumed that the remaining 20% is the value immediately before the passive state is destroyed by the chloride ion, that is, the last value of the propagation stage, and the weighted average efficiency is the concentration of the chloride ion (whole chloride ion concentration).

5.2 Deterioration prediction of bridges

Here we will attempt to predict the deterioration of the main girders of five bridges. Since the distance from the coast is known, it is possible to know the value of C_0. The figure below shows the deterioration prediction of the concentration of the chloride ion for 50 years after the installation. As for the values for the stages after the acceleration stage, we use volume reduction. However, we use the concentration of chloride ion for the periods, such as the acceleration and deterioration stages.

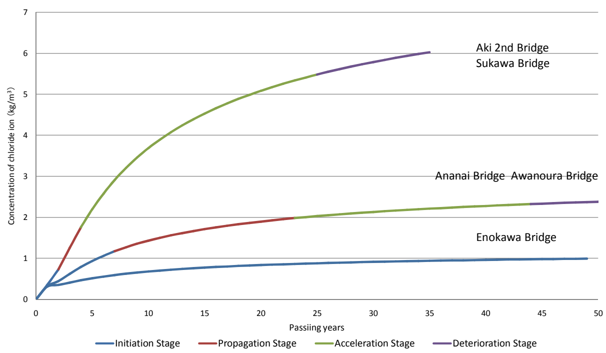

Fig. 2 Prediction of the concentration of chloride ion

As shown in Figure 2, setting the installation year as zeroth year, we can know the present (2007) concentration of chloride ion. However, the concentration of the chloride ion that the result shows is that of the partial chloride ion. Then, it is necessary to calculate the concentration of the entire chloride ion. Firstly, we assume that the proportion of the concentration of the partial chloride ion to the main girders is 80%, and the chloride ion concentration of the remaining 20% is that of the stage just before the accelerate stage. By the weighted average of these chloride ion concentrations, the concentration of the entire chloride ion can be obtained. After obtaining the concentration of the entire chloride ion, it will be possible to estimate the deterioration progress period to which the bridge belongs now. Table 2 shows how many years it will take each bridge to progress from the present stage to the next deterioration stage. In this study, we assumed that Enokawa bridge will not enter the deterioration stage while it is in-service.

Table 2 Deterioration progress stage and number of years each bridge takes before entering the deterioration stage

Bridge name	Deterioration progress period	Number of years before entering the deterioration stage
Aki 2nd	Acceleration	2
Ananai	Acceleration	9
Awanoura	Acceleration	9
Enokawa	Initiation	-
Sukawa	Acceleration	2

6. Establishment of maintenance management scenario and analysis of lifecycle cost

6.1 Calculation of minimum LCC of individual bridge

As for Enokawa bridge, if it is likely to enter the propagation stage, we should assume it to be a target of preventive maintenance, but it should remain in-service while it is at the initiation stage Therefore, it is assumed not to conduct mending on Enokawa bridge while in-service. Because breakdown maintenance can be applied to other bridges, it is necessary to obtain minimum LCC after examining all the applicable mending methods.

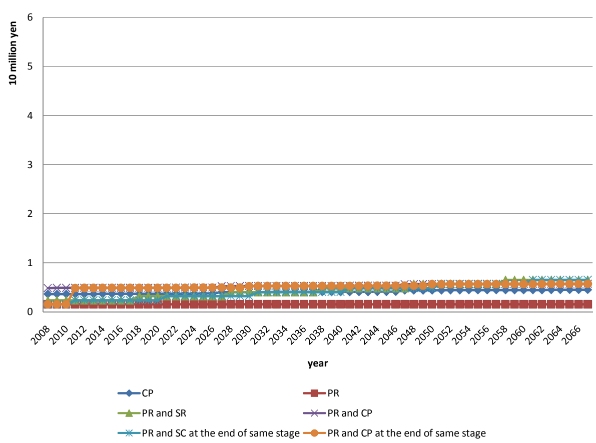

Fig. 3 LCC for mending maintenance applicable to Aki 2nd Bridge

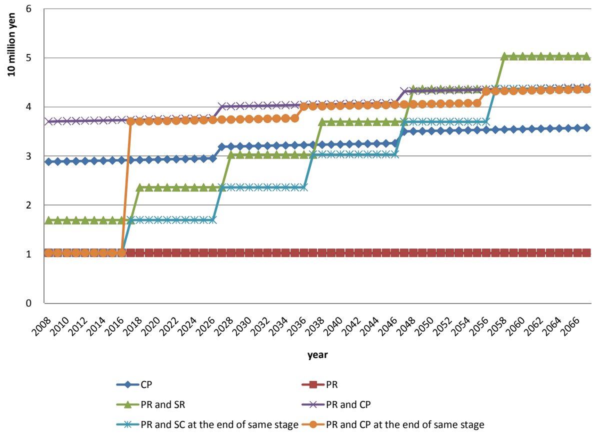

Fig. 4 LCC for maintenance method applicable to Ananai Bridge

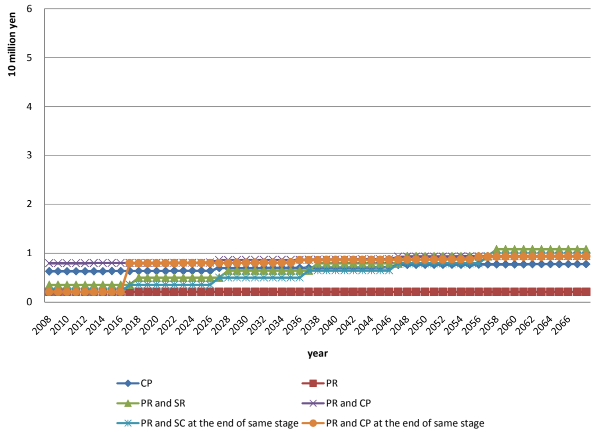

Fig. 5 LCC for maintenance method applicable to Awanoura Bridge

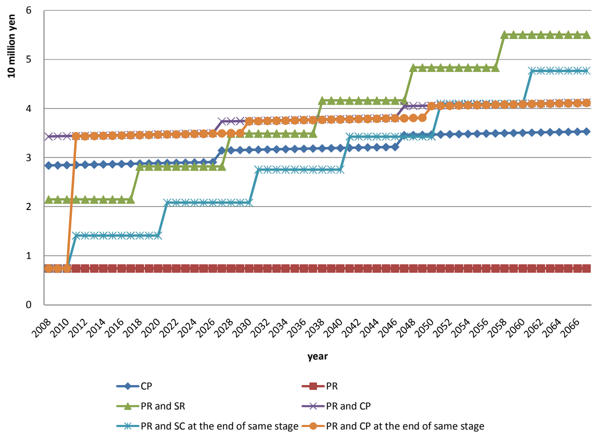

Fig. 6 LCC for maintenance method applicable to Sukawa Bridge

6. Decision of priority level based on analysis of lifecycle cost

6.1 Maintenance and maintenance plan of minimum LCC as bridge group

In Chapter 6, the maintenance plan of the minimum LCC for each bridge was computed from an individual bridge. Moreover, the renewal period is calculated by presuming the deterioration stage, and the maintenance cost of each bridge required after the renewal period, namely at the next stage, can be estimated. With our estimation, the total cost of the maintenance at the present stage is 79.15 million yen. The cost at the next stage is 100.33 million yen, which shows that it is the most appropriate to conduct the repair at the present stage. Because the bridge targeted this time has been in-service for 60 years and it has to continued being in-service, the cost at the next stage was estimated to be higher. However, in the case of the bridges whose in-service years is short (e.g. 10 years), there is a possibility that the estimated maintenance cost at the next stage and after the next is lower, and in that case it is possible to leave it as it is at the present stage.

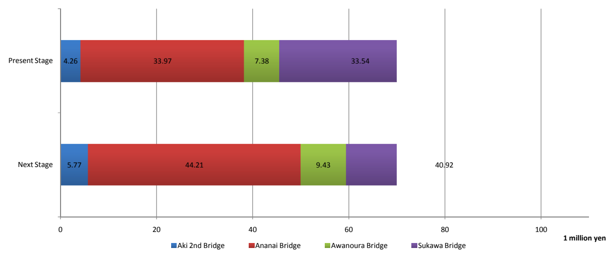

Fig. 7 Maintenance costs at the present stage and the next

6.2 Priority level of maintenance under budget constraint

Because maintenance and management budgets have a limitation, to execute all the maintenance at the same time can be impossible. Therefore, it is necessary to take it into account that there is a case where no bridge is required to be repaired at the present renewal stage, and, at the same time, it is necessary to set up the priority level by investigating which bridge should be repaired at the renewal stage and which should be at the next stage. As for a deciding factor of the priority level, under the budget constraint, it will be possible to determine which bridge should be repaired at the present stage and which ones should be at the next stage if we find out the priority level with which the total cost required for maintenance and mending of five bridges. Under the budget constraint, if the higher the budget allocated for each year, the higher the possibility of conducting maintenance at the present stage becomes, but if the lower the budget allocated for each year, the higher the possibility of conducting maintenance at the next stage becomes. In this study, we will make combination of maintenance methods using the results of the LCCA of each bridge under a specific budget constraint. In this calculation, changes of LCC accompanied by the transition of each deterioration progress stage are taken into account.

$$\sum_{i=1}^{4} L_j^i \qquad (11)$$

L_j^i :Maintenance plan to minimize LCC at the stage j in i bridge

j : Each deterioration stage (Initiation, Propagation, Acceleration, Deterioration)

In this simulation, it is assumed that the maintenance and repair budget for five bridges is 10 million yen in one year and that reserving fund is possible. There are 24 combinations of the maintenance order of four bridges. It is apparent that among the 24 combinations, only a limited number of combinations makes it possible to conduct the maintenance within the present renewal stage and within the budget. It is also clear that to conduct the mending of all the four bridges at the present stage is impossible with the budge of 10,000,000 yen. The priority level that minimizes the total cost has six types as follows:

- Aki 2nd → Ananai → Awanoura → Sukawa
- Aki 2nd → Ananai → Sukawa → Awanoura
- Ananai → Aki 2nd →Awanoura → Sukawa
- Ananai → Aki 2nd → Sukawa → Awanoura
- Awanoura → Aki 2nd →Ananai→ Sukawa
- Awanoura → Aki 2nd → Sukawa → Ananai,

where the total cost becomes 86,533,614 yen. When everything can be executed at the present stage, the investment of 7,379,730 yen is required.

7. Conclusion

We conducted predictions of physical deterioration by chloride attack on the RC bridges, and showed the deterioration state of the existing bridges. Furthermore, we conducted LCCA, which was not included in the existing BMS' of MLIT and Kochi version, and were able to calculate the minimum LCC for each bridge by setting the durable periods and deterioration process after the mending by maintenance methods. In addition, it became possible to show the priority of the maintenance which makes the total costs minimized under the budget constraint.

REFERENCES

1) http://www.mlit.go.jp/road/current/kouzou/index.html
2) Hironao TAKAHASHI and Hiroshi YOKOTA: Development of the estimation model for maintenance and mending cost for port facilities and measurement of future trend, Japan Society of Civil Engineers, Collected Papers, No.679 6-51, pp.135-140, 2001.
3) U.S. Department of Transportation : Asset Management Primer, 1999
4) Shin HARADA, Asset Management for Bridges, Public Works Management Journal, pp12-15, 2006.9
5) Japan Society of Civil Engineers, Standard

Specification for Concrete Structures: Guidelines for Maintenance and Management, 2001.
6) Japan Concrete Institute, Study group of rehabilitation of concrete structure, 1998.
7) http://www.kangi.ktr.mlit.go.jp/EvalNetis/