Study on Prediction Method for Group of Bridges Using Markov Chain Method

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Abstract: Japan's infrastructures were intensively developed during high economic growth. Concerns are that the number of deteriorated infrastructures will increase rapidly, and some countermeasures will be needed. Therefore, there is an urgent need to establish a highly accurate prediction method for deteriorating infrastructures. Traditional methods have several problems and are imprecise. Thus, this research aims to utilize bridge inspection data and diagnosis data managed by the national, prefectural, and municipal governments to develop a deterioration prediction method using a Markov chain model. The current issue is how to reflect variations in the progress of deterioration for individual bridges using the calculated transition probabilities. We proposed a deterioration prediction method using a Markov chain model to suggest a more accurate method. In the deterioration prediction method, a method of predicting the deterioration curve of individual bridges from the prediction result of a group of bridges due to the Markov chain model was examined. It is possible to make highly accurate future predictions using the accumulated inspection data.

Keywords: Maintenance, Prediction method, Markov analysis, Inspection data

1. Introduction:

Many infrastructures were developed in the 1950s and 1960s in Japan, and the maintenance cost of deteriorated infrastructures is feared to increase rapidly. In the current Japanese financial climate, local governments have limited budgets for the maintenance and repair of facilities. It is necessary to level and reduce costs through strategic maintenance. In most economically developed countries, concrete bridge structures are at various stages of deterioration progression and require significant maintenance (Setunge, S., & Hasan, M. S. 2011). To use many bridges for a long time, efficient maintenance management is more important than new construction (Seto, D., Ohga, M., & Chun, P. J. 2012). Therefore, it is necessary to accurately predict the deterioration progress of structures, and it is important to make a maintenance plan based on its prediction results.

2. Target area of investigation:

In this study, the target area of investigation is Kirishima City in Kagoshima Prefecture. The first and second periodic inspections of all road bridges were completed from 2016 to 2022. As a result, it was possible to understand the actual state of deterioration of the bridges to be managed in detail. It was necessary to develop a prediction method that can be easily used for the future maintenance of the bridge group to optimize regional asset management using this data. First, we organized and analyzed the inspection data and grasped the current state of the bridges to be managed. After that, the inspection data was rearranged according to the aging of the structures. Then, utilizing the Markov analysis process, this paper describes developing a new prediction method using a database of several bridges in the target area.

3. Prediction method of deterioration of group of bridges using Markov Chain Method

3.1. Method of Markov chain analysis: First, we extracted the year of construction, year of inspection, and judgment category from the bridge inspection results. Then, we calculated the proportion of deterioration in each evaluated category every ten years. Considering the estimated proportion of it and the number of bridge constructions, those that have been in service for 60 years or more were deleted from the analysis data. After that, we calculated the transition probability of Markov Chain Analysis (MCA) using the least squares approximation method between actual data and estimated data. A deterioration progression model can be created by graphing the predicted bridge ratio.

3.2. Methods of individual bridge deterioration prediction curve from MCA result: **Figure 1** shows the changes in distribution in the soundness of the bridge group over time obtained through the analysis. Here, when considering the progress of deterioration of structures, the soundness level should progress sequentially from I to IV. Therefore, line a in **Figure 1** can be viewed as a deterioration curve (time change in health level) of a certain structure. Using this assumption, we estimated the deterioration curves of individual bridges. In the analysis, the results of the first and second periodic inspection data are used to identify the range of soundness of each bridge over its years of service at the time of inspection (① and ② in **Figure 1**). Since this inspection result was for the same bridge, it is estimated that the bridge's deterioration curve lies in the range where ① and ② overlap. It is necessary to estimate one line within this range, but this can be set according to the road administrator's maintenance management policy. In this study, 75% was used as the safe judgment.

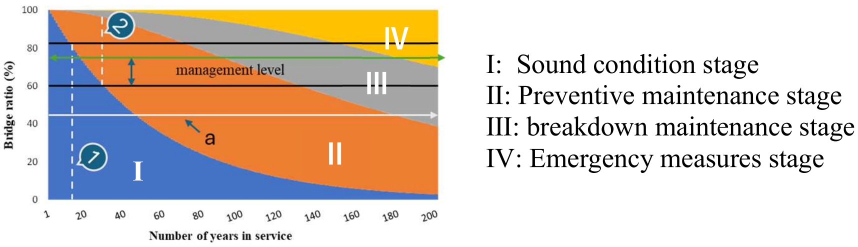

Fig. 1. Changes in soundness level over time.

4. Results and Discussions:

Figure 2 shows the graph of the percentage of bridges for original data, which Kirishima City manages. The proportion of deteriorated bridges tends to increase with service period increases. This time, we will show the results of the RC and PC beam deterioration curves using Markov analysis. **Figure 3** shows that the beams of PC bridges are in better condition than those of RC bridges.

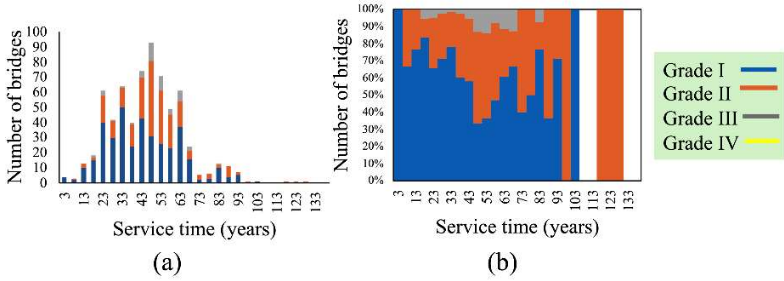

Fig. 2. Inspection result of Kirishima city. (a) number distribution (b) Percentage distribution

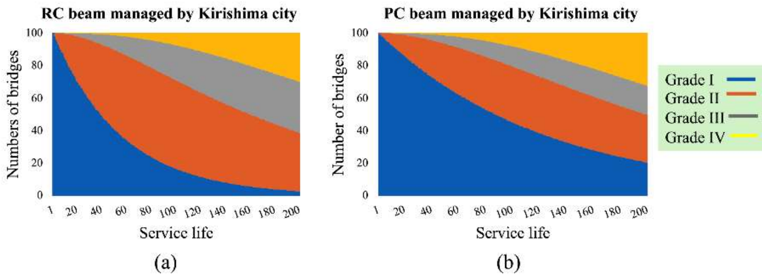

Fig. 3. Markov chain analysis result. (a) RC beam, (b) PC beam

Regarding the prediction of deterioration of individual bridges, **Figure 4** shows the deterioration curve of the T bridge, for which the inspection results shown in **Table 1** were obtained.

The bridge's soundness levels remained the same in the first and second rounds, and the deterioration curve (Fig. 4) captured the inspection results. The right-side figure (**Fig. 4. (b)**) predicts that the bridge will continue at the same soundness level 2 until 2054.

Table. 1 Inspection result of T bridge

	1st round			2nd round		
Year of construction	Inspection year	Judgment category	Service period	Inspection year	Judgment category	Years in service
1960	2016	**II**	56	2021	**II**	61

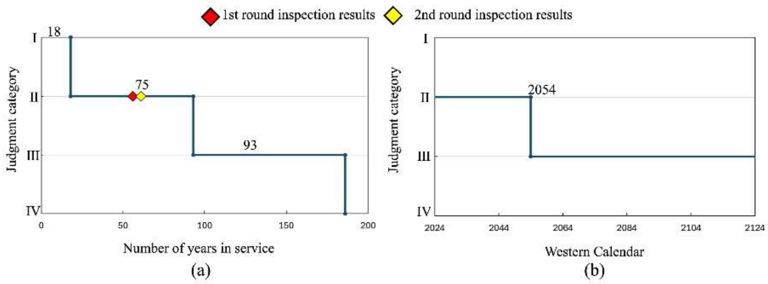

Fig. 4. Deterioration curve of T bridges. (a) Deterioration curve, (b) Future prediction

As another example, **Figure 5** shows the deterioration curves of the K and U bridges, for which the inspection results shown in **Table 2** were obtained. The bridge has different health levels in the first and second rounds and each deterioration curve captures the inspection results. In addition, the inspection results of K bridge indicate that it remained at a soundness level I for about 50 years after it was in service, suggesting that it remained sound for an extended period. In the future, it can be predicted that the soundness level will continue to be II until 100 years from now.

The U bridge has been in service for 60 years. It already has a soundness level of III that requires early repair, so if the maintenance classification is preventive maintenance, early repair is needed. However, it is predicted that the repair period will be until about 70 years in managing at soundness level III as breakdown maintenance. Based on the above, through this process, it is considered possible to predict the deterioration of individual bridges. Therefore, by implementing deterioration prediction technology due to this method for individual bridges, it is possible to make an efficient maintenance plan for bridge groups.

Table. 2 Inspection result of K and U bridge

	Bridge name	K bridge	U bridge
	Year of construction	1965	1954
1st round	Inspection year	2016	2016
	soundness	I	II
2nd round	Inspection year	2021	2021
	soundness	II	III

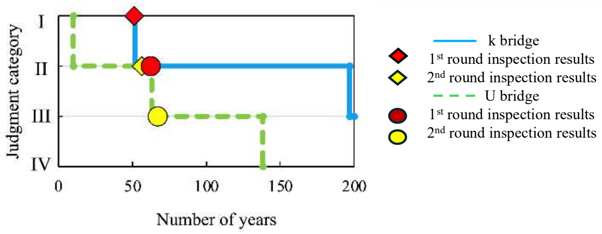

Fig. 5. Deterioration curve of K and U bridge.

5. Conclusion: We were able to derive deterioration curves for individual bridges using the deterioration prediction method for bridge groups using Markov chains. By implementing this method, we can develop maintenance plans for individual bridges or bridge groups. It is thought that more accurate predictions will become possible by continuing regular inspections and accumulating data.

References: Seto, D., Ohga, M., & Chun, P. J. (2012). Deterioration prediction of the bridge by Markov chain model and Bayesian theory.

Setunge, S., & Hasan, M. S. (2011). Concrete bridge deterioration prediction using the Markov chain approach.