Analysis Examples of Periodic Inspection Results of National Highway Bridges in Japan -Application of degree of damage for element level-

Fumihiko Nomura[1], Masanori Okubo[2], Takashi Tamakoshi[3]

Abstract

In order to have enormous highway bridge stocks in Japan already, it is important to save safe and smooth traffic networks and to have them maintained both economically and rationally. Thus, it is a matter of urgent business to grasp and evaluate their states appropriately, and to develop well-planned maintenance methods.

National Institute for Land and Infrastructure Management (NILIM) conducts feature arrangements and analyses of damage by statistical processing of national highway bridges periodic inspection data, and provides the insights into the further rationalization and standardization of their periodic inspection.

In this paper, the features of generation and progress of damage on bridges are reported based on analysis examples of element periodic inspection results, and the direction of the goal of bridge maintenance in Japan is explained.

Introduction

Periodic inspection of national highway bridges in Japan based on ‘Bridge Inspection Manual’ (Public Works Research Institute Document No.2651, July 1988) had been conducted every 10 years, and that based on ‘Bridge Periodic Inspection Manual’ (National Highway and Risk Management Division, March 2004) (hereinafter referred to as ‘Periodic Inspection Manual’) has been being conducted within two years for initial inspection, and every five years after that since 2004.

Data as objective facts for damage and deterioration obtained from inspections is made use of future projections and trend analyses by grasping continuously as well as be indispensable for cause estimation and evaluation of current performances. In order to be used for statistical processing and quantitative projection, it is important that the data is the objective one based on a uniform standard possible to be used for relative comparison over time.

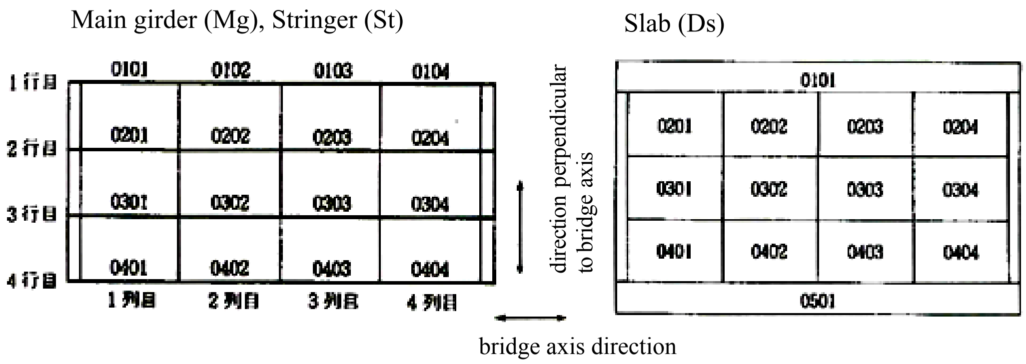
On the other hand, for road administrators who do not always have the knowledge enough to judge effects on bridge performance, primary diagnosis as evaluation of functional states of bridges is essential to take action to make appropriate decisions for taking measures to traffic regulations, and repairs and retrofits. In other words, except the facts as individual kinds of damage and damage progression, it is possible for road administrators to make responses to conduct the further surveys right after obtaining measures for effects of damage on functional states of bridges. So, in case primary diagnosis has no troubles, it is so difficult for them to have suspicions about the results.

[1] Researcher, Bridge and Structural Division, Road Department, NILIM
[2] Senior Researcher, Bridge and Structural Division, Road Department, NILIM
[3] Head, Bridge and Structural Division, Road Department, NILIM

Thus, the revision of 2004 regulates that objective facts as size of the damage are recorded as 'evaluation of degree of damage', at the same time, primary diagnosis for functional states of bridges by appropriate engineers is evaluated as 'judgment of measure classification'. Moreover, the evaluation system is set to taking saving the continuity with the existing inspection data into consideration. In this way, for national highway bridges, data for the new manual converting into inspection data based on manual of 1988, and data based on the new inspection manual operating from 2004 are gradually saved.

As for periodic inspection, damage states for element levels and every kinds of damage are surveyed. Figure 1[1)] shows examples of element numbers of a main steel girder and a concrete slab. For the main girder and concrete slab, one element is defined as the element enclosed by the main girder and a cross frame, indicating the main girder divided by 16 elements and the concrete slab by 14 elements per a span. 'Evaluation of Damage States' is judged and recorded based on 'Evaluative Standard of Damage States'. The evaluative standard of damage states is set to be 5 stages (from 'a' to 'e') by every sorts of damage. 'a' means to be sound, while 'e' to be the most severe damage of all five stages. As shown in Table 1-1, sorts of damage are set for every regions and members. On the other hand, judgment of measure classification is conducted by appropriate engineers as primary checks for functional states of bridges.

Thus, periodic inspection of national highway bridges in Japan is the most fundamental action to grasp the bridge states comprehensively, and at the same time, it plays an important role in obtaining the fundamental information for well-planned and effective maintenance.



(a) Steel main girder (b) concrete slab

Figure 1 Examples of element number

Features of damage occurrence for each member & region

Since element level inspection results are gradually saved, and it is possible to grasp damage occurrences for each member and region, the damage occurrences for each were analyzed. The number of the parameters was 21,636 bridges, and objective bridges of them were extracted.

In this case, corrosion of steel members, cracks, cracks at concrete girders, and cracks at reinforced-concrete (RC) slabs of steel bridges with the significant features of damage for each member and region are shown as the analysis examples.

(1) Corrosion of steel girder bridges

For corrosion of main girder in the steel plate girder bridge, Figure 2 shows the degree of corrosion at the end and middle of the same girder. The degree of the corrosion at the end of the main girder has a tendency to be worse than that at the middle.

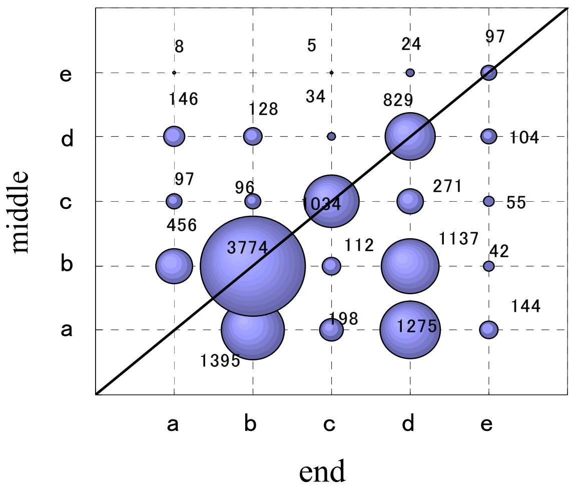


Figure 2 Corrosion, Steel plate girder bridge, main girder, Degree of damage for each region

For corrosion of main girder at the middle in the steel plate girder bridge, Figure 3 shows the degree of corrosion at the outside and inside of the same span. The degree of the corrosion at the outside of the main girder has a tendency to be a bit worse than that at the inside.

In this way, it was indicated that there was a difference of the degree of corrosion between the end and the middle of the girder, and the outside and the inside girder. That means there is a possibility of taking measures of bridge maintenance economically and rationally for corrosion at the end girders by partial coating. Moreover, there is a possibility of making inspections effectively by restricting the inspection region.

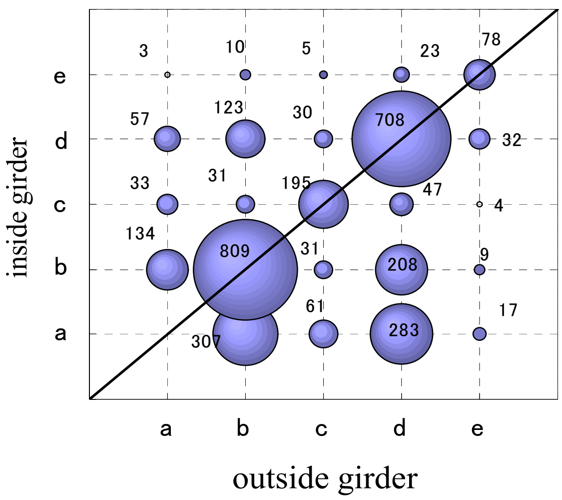


Figure 3 Corrosion, Steel plate girder bridge, main girder at the middle, Degree of damage for each region

(2) Cracks of steel plate girder bridge

For cracks of steel plate girder bridge, Figure 4 shows the degree of cracks at the end and middle of the same girder. The degree of the cracks at the end of the main girder has a tendency to be worse than that at the middle.

For cracks of main girder in the steel plate girder bridge, Figure 5 shows the degree of cracks at the outside and inside of the same span. Since there are some cracks at any objective region such as outside, inside, and all span of the girder.

In this way, it is considered that there is a possibility of reducing a risk of missing at the inspection time due to incorporating into specific inspection of fatigue, which the government is planning.

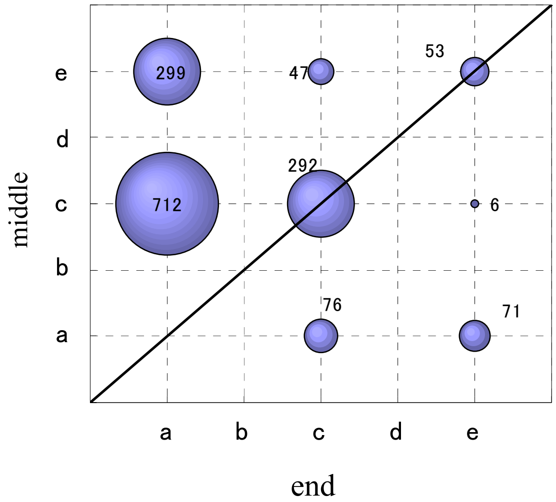


Figure 4 Crack, Steel plate girder bridge, main girder, Degree of damage for each region

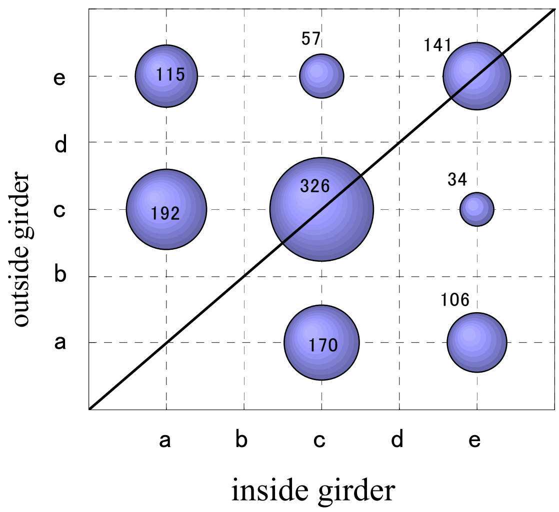


Figure 5 Cracks, Steel plate girder bridge, main girder, Degree of damage for each region

(3) Cracks of concrete bridges

For cracks of concrete bridges, Figure 6 shows the degree of cracks at the end and middle of the T-girder bridges with pre-tensioning system, Figure 7 shows those with post tensioning system, and Figure 8 shows those of RC-T-girder bridges. Most of the T-girder bridges with pre-tensioning and post tensioning system have cracks only at the end or the middle of the main girders. The degree of the cracks at the end of the main girder has a tendency to be worse than that at the middle. On the other hand, RC-T-girder bridges have a tendency to have cracks at all of the main girders.

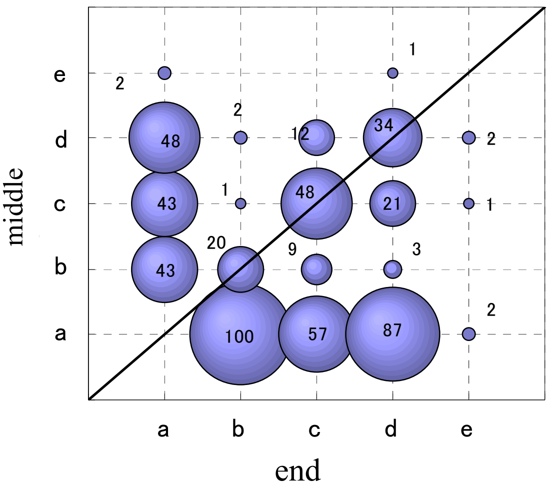


Figure 6 Cracks, T-girder bridges with pre-tensioning system, main girder, Degree of damage for each region

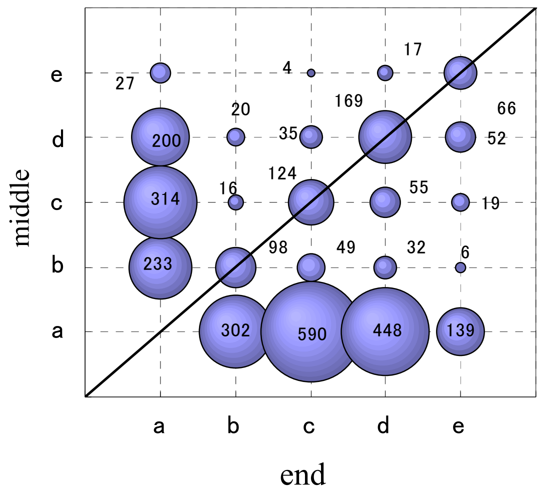


Figure 7 Cracks, T-girder bridges with post tensioning system, main girder, Degree of damage for each region

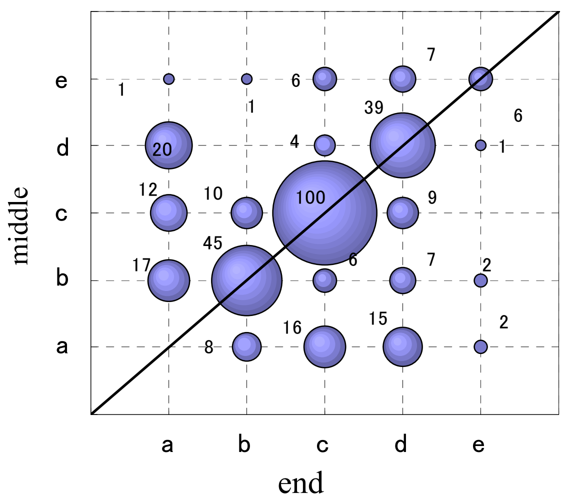


Figure 8 Cracks, RC-T-girder bridges, main girder, Degree of damage for each region

For cracks of concrete bridges, Figure 9 shows the degree of cracks at the outside and inside of the T-girder bridges with pre-tensioning system, Figure 10 shows those with post tensioning system, and Figure 11 shows those of RC-T-girder bridges. Most of the T-girder bridges with pre-tensioning and post tensioning system have cracks only at the outside or inside of the main girders. The degree of the cracks at the end of the main girder has a tendency to be worse than that at the middle. On the other hand, RC-T-girder bridges have a tendency to have cracks at all of the main girders

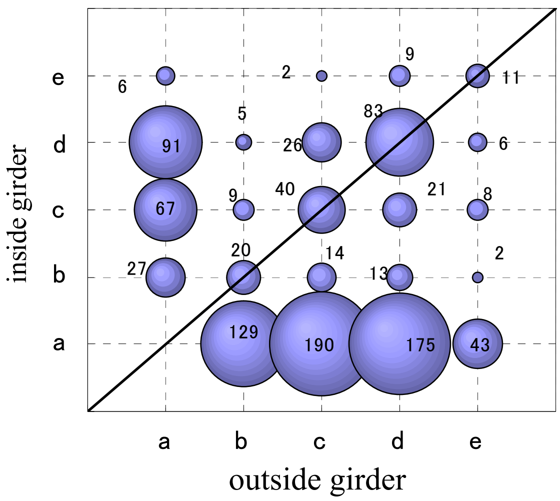


Figure 9 Cracks, T-girder bridges with pre-tensioning system, main girder, Degree of damage for each region

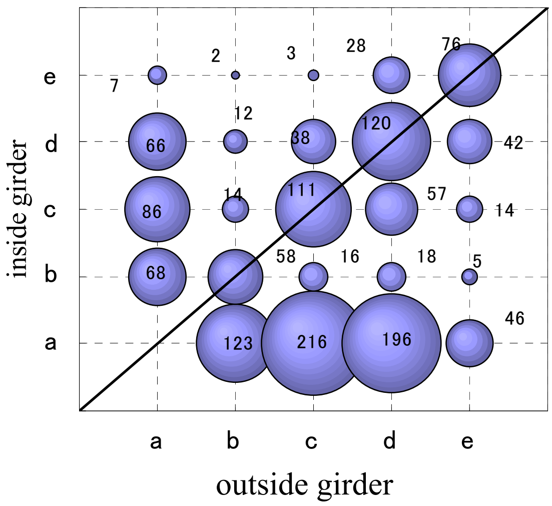


Figure 10 Cracks, T-girder bridges with post tensioning system, main girder, Degree of damage for each region

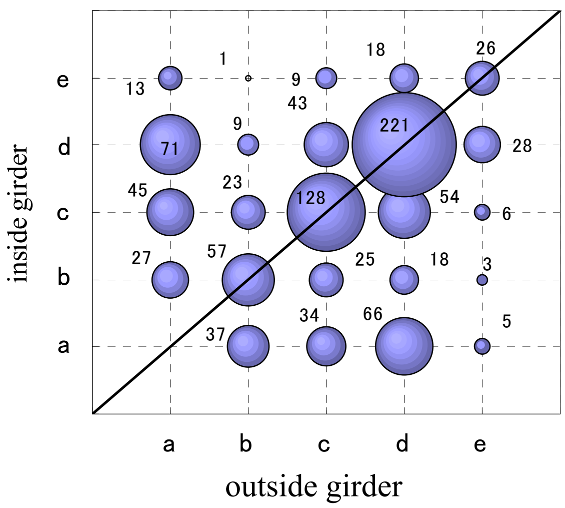


Figure 11 Cracks, RC-T-girder bridges, main girder, Degree of damage for each region

For cracks, adding to recording the degree of damage at the element level, typical crack types are divided into 20 patterns and the pattern number is recorded.

For concrete T-girder bridges, Figure 12 shows the number of members with crack for each pattern for T-girder bridges with pre-tensioning system, Figure 13 shows that with post tensioning system, and Figure 14 shows that for RC-T-girder bridges. The number of members with ‘pattern□’(vertical cracks at the girders on the bearings) for pre-tensioning system, ‘pattern□’(vertical cracks at the bottom/side of the girders of the center of the span) for post-tensioning system, and ‘pattern□’(longitudinal cracks at the bottom of the girders of the center of the span) for RC-T-girder bridges were the largest.

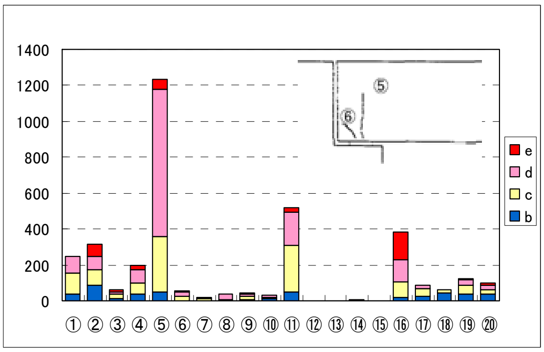


Figure 12 Cracks, T-girder bridges with pre-tensioning system, The number of members with crack for each pattern

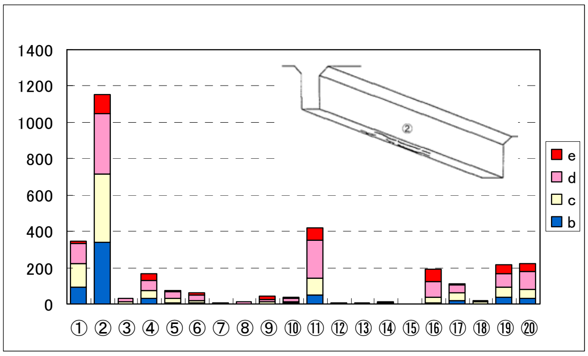


Figure 13 Cracks, T-girder bridges with post tensioning system, The number of members with crack for each pattern

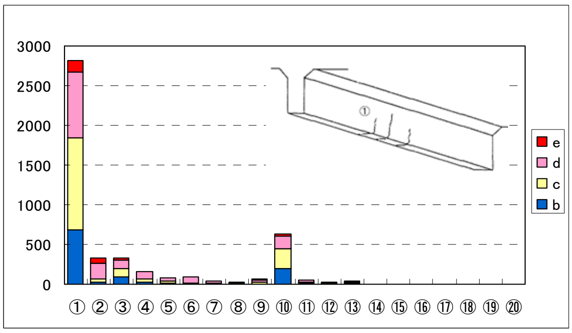


Figure 14 Cracks, RC-T-girder bridges, The number of members with crack for each pattern

For concrete cracks, it was indicated that there was a difference of the degree of cracks depending on types (pre-tensioning system, post-tensioning system, and RC-T-girder) and girder regions (end and middle, and outer and inside girder). In this way, since the features of cracks by bridge types can be grasped, it is possible to implement crack control measures at the design-time, and to improve the initial material qualities. Moreover, there is a possibility of making inspections effectively by restricting the inspection region.

(4) Cracks of RC slabs of steel bridges

For cracks of slabs of steel plate girder bridges, Figure 15 shows the relationship between passed years and degree of damage for cracks of slabs at each general and cantilever parts. Degree of damage for cracks of slabs at the general parts has a tendency to be worse over years, while that at the cantilever parts does not.

In this way, for the cracks at the RC slab, there was a difference of the degree of cracks depending on slab types (general and cantilever parts). In this way, it was indicated that there is a possibility of improving the initial material qualities economically and rationally especially for the cantilever parts by taking measures at the initial design-time.

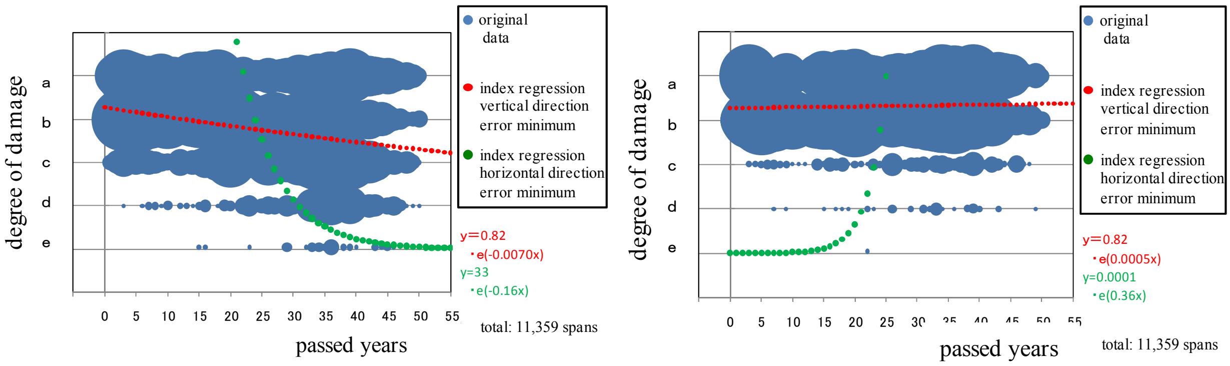


Figure 15 Relationship between passed years and degree of damage at general and cantilever parts

(Cracks of slabs, Steel plate girder bridges, RC slabs)

DAMAGE PROGRESSION

A tendency of damage progression was analyzed by calculating transition probability of degree of damage (from ‘a’ to ‘e’) for each member and region in order to grasp how the degree of damage will progress within 5 years by using two periodic inspection results (hereinafter called ‘the new inspection’ for the most recent inspection, and ‘the old inspection’ below) conducted to the same bridge in the different time.

A group of data consisting of the most recent periodic inspection results based on the manual and the results based on the manual of 1988, and a group of two data of bridges conducting two periodic inspection based on the manual are used for the analyses.

For the verification of the old and new inspection results, the results which satisfy the following extracted conditions were regarded as the effective data.

i) Inspection interval is within five years.
ii) The old and new inspection data for the same elements exist.
iii) No repairs were done between the old inspection and the new inspection.
iv) Degree of damage for the new inspection is the same or the worse as compared to that for the old.

The total is 5,109 bridges, and the objective bridges were extracted for each analysis.

In this chapter, analysis examples of steel corrosion and crack of slab remarkable for features of damage for each member and region in the previous chapter were indicated. The analysis contents are a transition probability made up the degree of damage for the new inspection to the old one, Markov chain based on that, an expected value for Markov chains every five years weighting each degree of damage (‘a=1.00’, ‘b=0.75’, ‘c=0.50’, ‘d=0.25’, and ‘e=0.00’), and standard deviation in some of these graph.

(1) Corrosion of steel plate girder bridges

For corrosion of main girder of steel plate girder bridges in a A & B type of painting, Figure 16 shows transition probability, Markov chain, and expected values for whole members (from the left to the right), Figure 17 for the end of the girders, Figure 18 for the middle, Figure 19 for the outside girders, and Figure 20 for the inside girder.

For the transition probability of the left figure, for example, 80% of the degree of damage ‘a’ (no corrosion) for the old inspection keeps the same state, while most of the rest of 20% progress the degree of damage ‘b’, others progress ‘c’, ‘d’, and/or ‘e’. Thus, the damage progression depends on the bridges, and so it has a tendency to vary to some extent.

In this way, features shown in the damage progression states were also shown in the damage occurrence states.

Moreover, the deterioration prediction distribution varies, however, the accuracy improvement of the deterioration curve by each region in Figure 17 & 18 more than that by the whole members in Figure 16 is expected.

For Markov chain (the middle figure) and the expected values (the right figure) obtained from the transition probability (the left figure), the degree of damage at the end of the girders has a tendency to be worse than the middle of the girders, as seen in Figure 2. Also, the degree of damage at the outside girders has a tendency to be a bit worse than the inside girders, as seen in Figure 3.

Also, Markov chain shows the probability of occurrence of the degree of damage after some years. However, it is common to use the expected values for the application of future prospects of the individual bridges instead of Markov chain. In this case, since the expected values are the uniform ones, the values have a possibility to be confused with the fixed ones. In order to prevent this confusion, standard deviation of the expected values were shown to the right figure. Future prospects should be used with the recognition that it just shows the probability with variation.

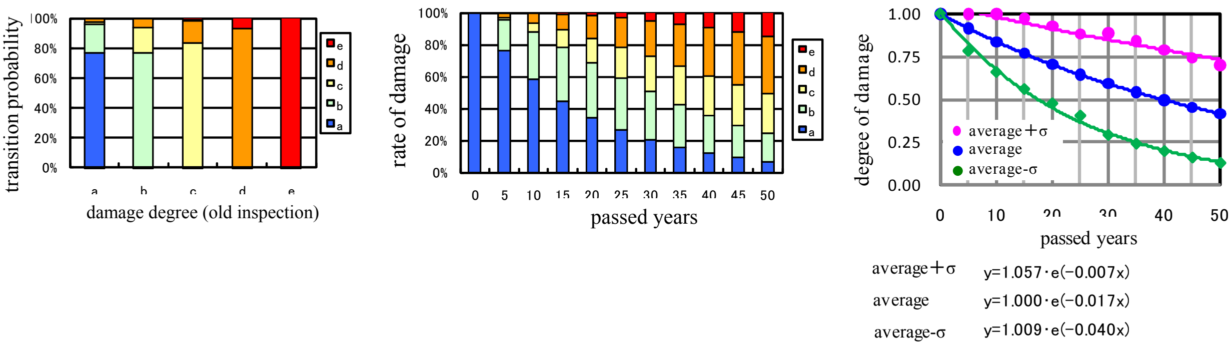


Fig. 16 steel plate, main girder, corrosion, A & B type of painting, whole member

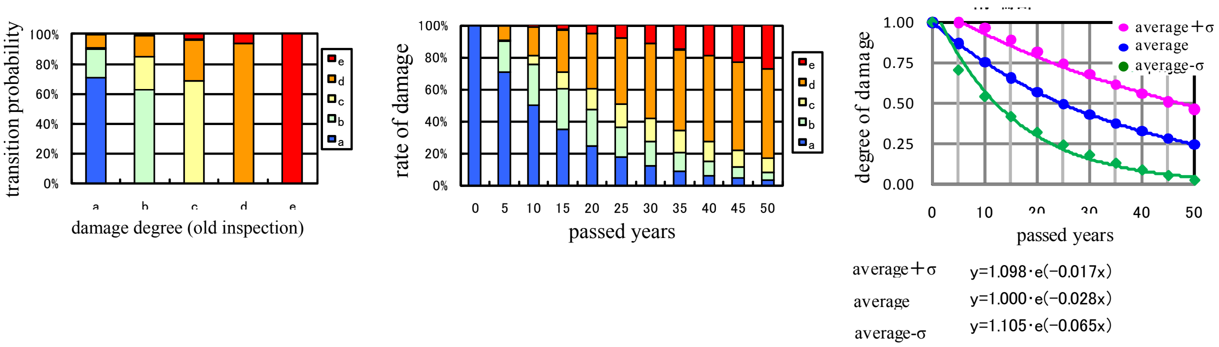


Fig. 17 steel plate, main girder, corrosion, A & B type of painting, end of girder

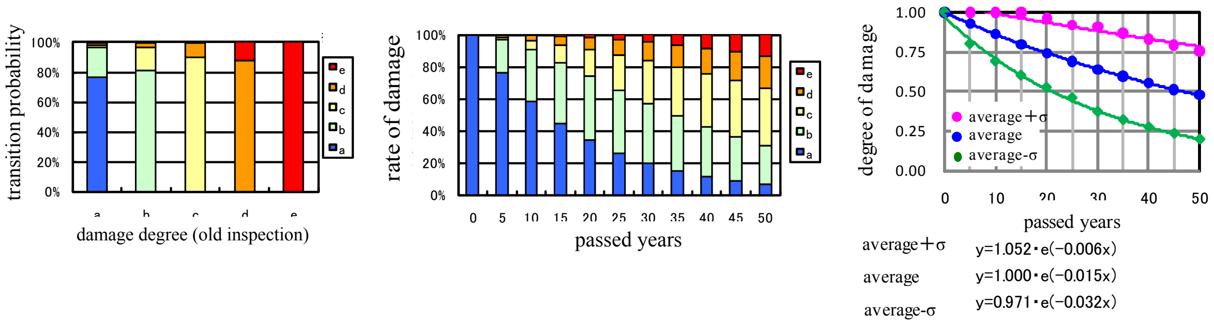


Fig. 18 steel plate, main girder, corrosion, A & B type of painting, middle of girder

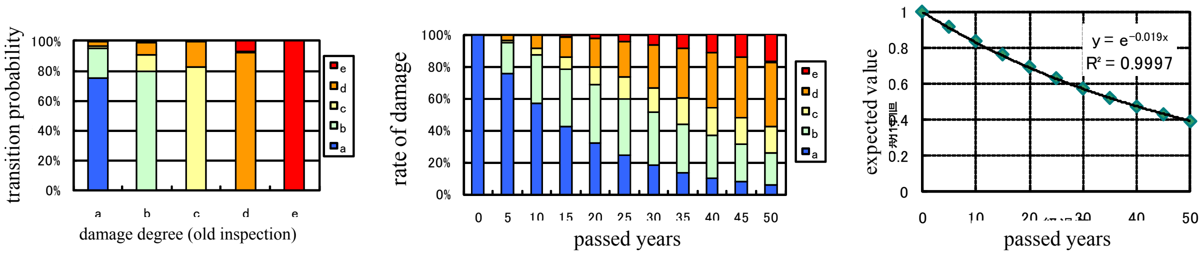


Fig. 19 steel plate, main girder, corrosion, A & B type of painting, outside girder

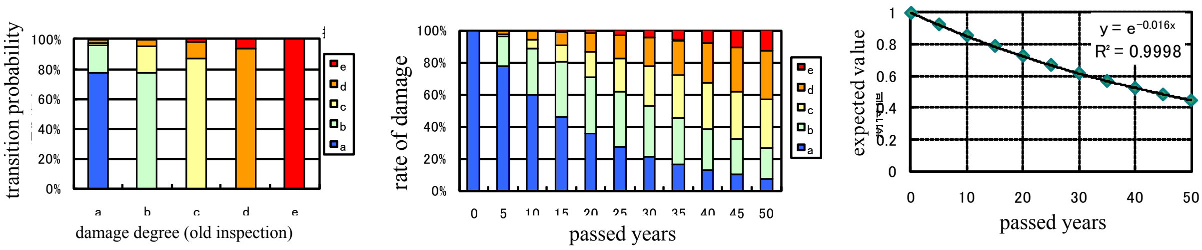


Fig. 20 steel plate, main girder, corrosion, A & B type of painting, inside girder

(2) RC slab of steel bridges

For crack of RC slab of steel plate girder bridges, Figure 21 shows transition probability, Markov chain, and the expected values (from the left to the right) for the cantilever parts, Figure 22 for the general parts. The degree of damage for crack of the slabs for the cantilever parts progresses up to ‘b’, as seen in Figure 15. In this way, features shown in the damage progression states were also shown in the damage occurrence states. Results obtained from the deterioration prediction were already shown in the above (1).

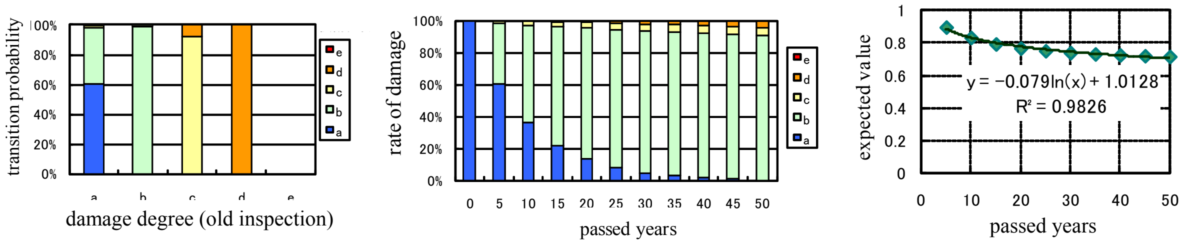


Fig. 21 steel plate, RC slab, crack of slab, cantilever part

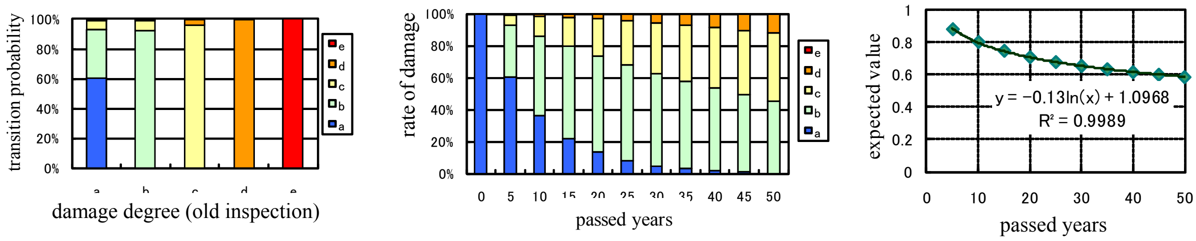


Fig. 22 steel plate, RC slab, crack of slab, general part

Summary

Since the periodic inspections in the element level are conducted, it is possible to analyze the degree of damage for each member and region. Thus, differences of the degree of damage and damage progression for each member and region in the same bridge were recognized. Also, transition probability, Markov chain, and the expected values and standard deviation using the probability could be calculated by analyzing the old and new inspection data in the element level.

Based on features of damage occurrence and its progression adding material, bridge types, and environments, improvements of the frequency and the method of the periodic inspection, accuracy improvements for the data analyses, and improvements of the initial design, lead to rationalization of bridge maintenance. Saving the data in the element level, the more detailed survey analyses for identification of damage progression, their correlation, and quantitative evaluation for variation of the degree of damage will be conducted. In the future, the further research plans to be conducted toward the achievement of the smart bridge maintenance system, which the life-cycle costs and the risk among the users can be minimized due to the use of the recent information technologies and the appropriate maintenance for individual bridges.

References

[1] National Highway and Risk Management Division, MLIT: Bridge Periodic Inspection Manual (Draft), March, 2004