STATE OF BRIDGES AND THEIR MANAGEMENT

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Overview

A large number of bridges were constructed in a short period after the end of World War II in Japan. Because most of these bridges grow older, a heavy burden such as replacement increasing intensively in the same term will arise in the future unless they are given necessary repair works at a proper time.

Therefore we need to establish a rational management method from both micro and macro point of view that includes utilizing data of the existing bridges besides promoting preventive maintenance and extension of bridge lifetime in Japan.

In this report, we introduce the current state of road bridges, approaches to rational management, and research on measures to specific damages.

1. Situation and condition on bridges in Japan

As shown in Figure 1, the number of bridges increased rapidly in Japan during the high economic growth period (1955-1973) and there are nearly 150,000. About 34% of them were constructed in the period. At present, these bridges are about 37 years old on average, and they all will be in old age in the near future. As indicated in Figure 2, bridges over 50 years old currently account for 6%, but they will account for 20% in next 10 years and 47% in next 20 years. As in the human society, aging society is developing in bridges.

It is hard to give a general answer to a bridge lifetime because it depends largely on each individual condition. However, it is important to know what the aging bridge will be in planning future maintenance. The graph in Figure 3 shows the rate of damaged bridges which need repair of main members by age from the result of the major routine inspection to bridges managed by the national government. The progress of bridge deterioration is different to each individual condition, it is clear that the rate of damaged bridges which need repair tends to increase as they grow older. While aging of bridges and decrease of soundness as they grow older is estimated like this and more adequate budget for their maintenance is needed, the national government is in severe financial situation and cannot allocate adequate budget for their maintenance in recent years as shown in Figure 4. In fact, budget for new infrastructures has been considerably reduced, and that for their maintenance that should be added naturally with an increase of stocks

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has been slightly reduced. Taking the above facts into consideration, we need to implement prompt and appropriate measures to the aging of bridges that is growing apparent.

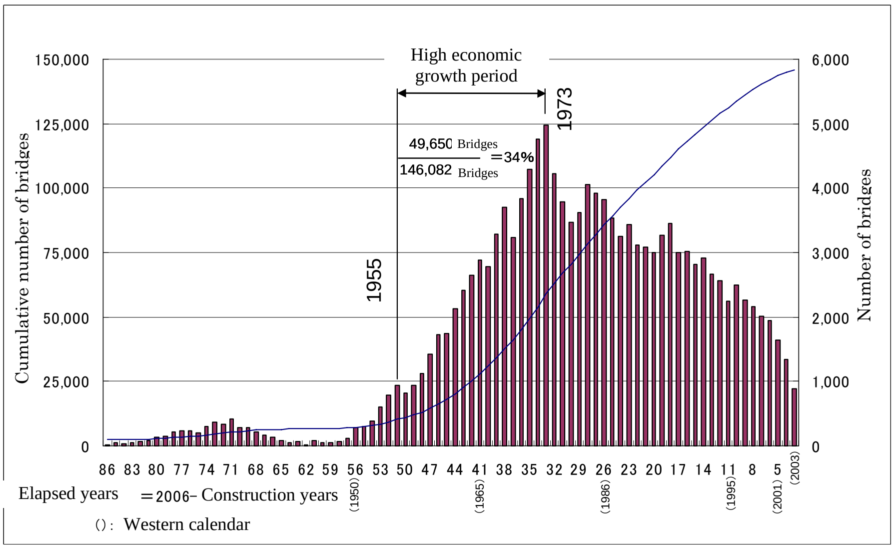


FIGURE 1. DISTRIBUTION OF ELAPSED YEARS OF BRIDGES

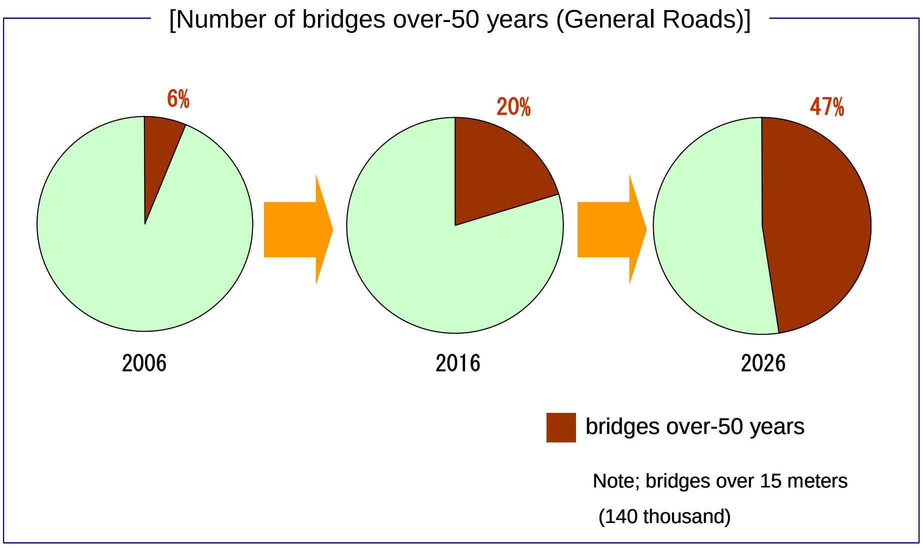


FIGURE 2. NUMBER OF BRIDGES OVER-50 YEARS (GENERAL ROADS)

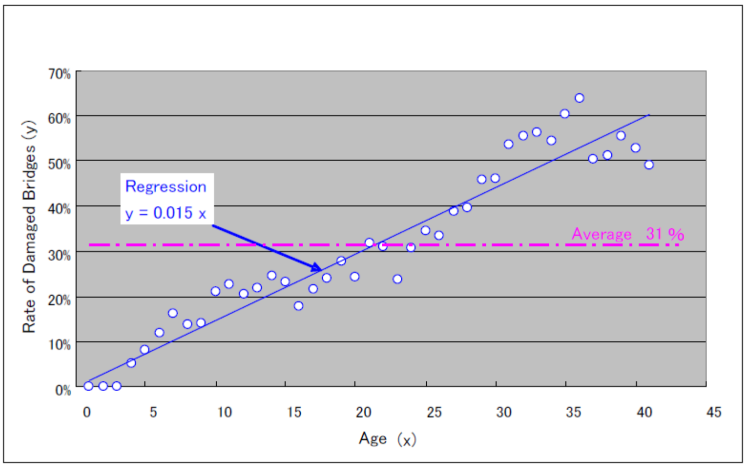


FIGURE 3. RATE OF DAMAGED BRIDGES WHICH NEED REPAIR

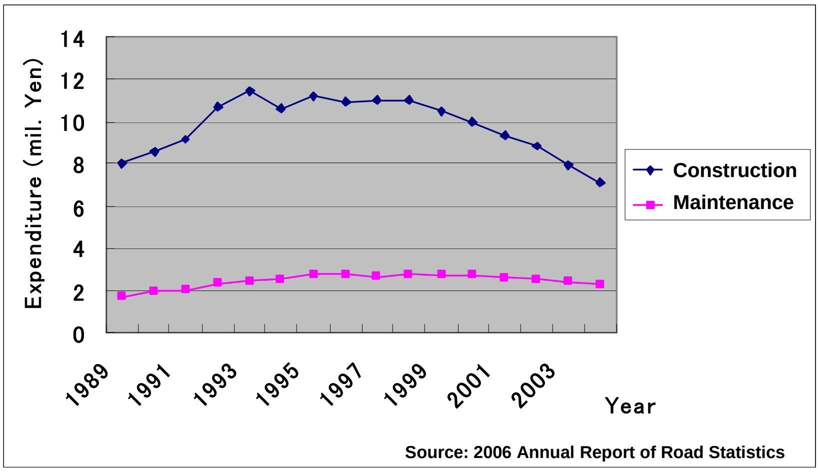


FIGURE 4. INVESTIMENT IN CONSTRUCTION AND THAT IN MAINTAINANCE

2. Reducing LCC and introducing preventive maintenance

For the rational and effective management of huge bridge assets, we need to estimate life cycle cost (LCC) that is the lifetime expenses for a bridge including expenses for repair and renewal besides the construction, and take appropriate method in a proper time. The most effective method to reduce LCC is to convert from the conventional ex post maintenance to preventive maintenance.

For example, Figure 5 shows the LCC of a concrete bridge in an area featured by salt damage. Although it had been given ex post maintenance, it was replaced 34 years after construction. Suppose we set 1 to the cost for 100 years required to give the same maintenance to a bridge after replacement, the cost for the preventive maintenance that prevents salt damage from going inside the concrete in an early stage is estimated to be half.

The case of the steel bridge close to the coastal area, replaced because of salt damage, is shown in Figure 6. If we had given the bridge preventive maintenance that includes heavy-duty painting in the early stage, the cost would have been half that is required for 100 years if we take ex post maintenance. We give the summary of conditions we used for the estimation in Table 1.

Therefore it is possible to decrease LCC by applying preventive maintenance rather than ex post maintenance.

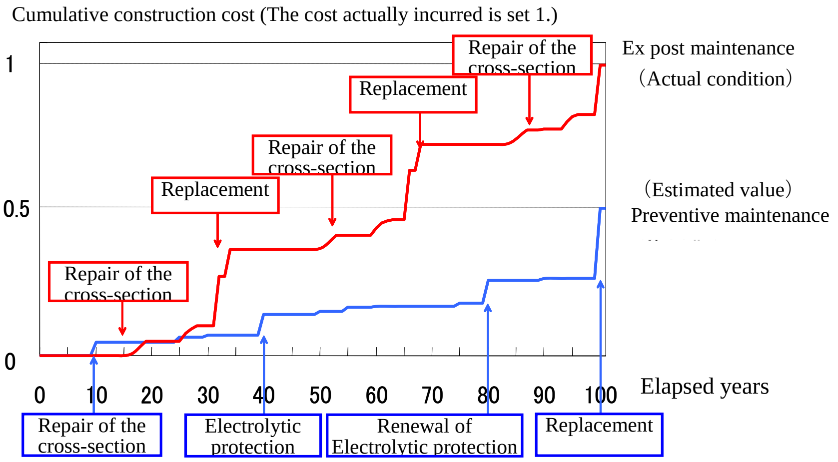


FIGURE 5. ESTIMETE CASE OF CONCRETE BRIDGE IN THE AREA FEATURED SALT DAMAGE

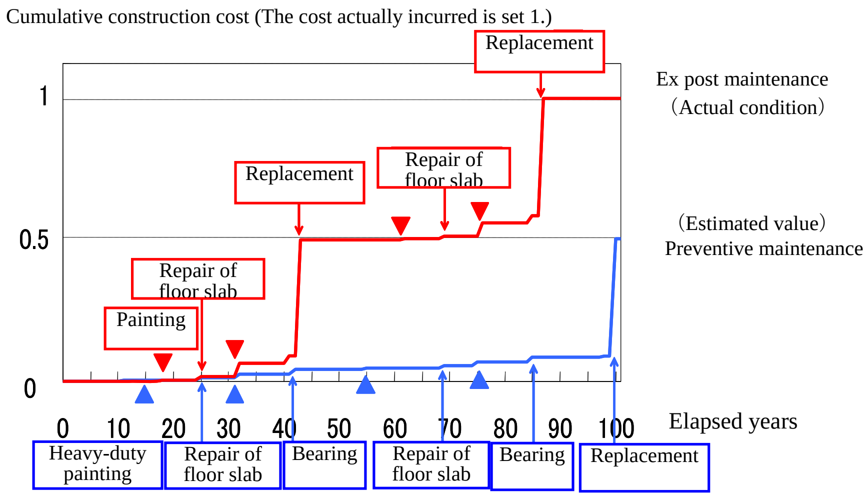


FIGURE 6. ESTIMATE CASE OF STEEL BRIDGE NEAR THE COASTAL AREA

TABLE 1. ESTIMATE CONDITION IN THE CASE GIVEN THE APPROPRIATE MAINTENANCE

Objects	Condition of calculation
Concrete bridge in the area featured by salt damage (Figure 5)	・Girder: Cross section surface is repaired in 10 years, and electrolytic protection is applied in 40 years. ・Substructure: Cross section surface is repaired in 25 years, and electrolytic protection is applied in 55 years. Electrolytic protection of the girder and substructure is renewed in 80 years. ・Reference: Medium-term vision of road improvement published in June 2004 by the Ministry of Land, Infrastructure and Transportation
Steel bridge near the coastal area (Figure 6)	・Repaint in a 10-year interval using B paint (Setup according to the field survey) ・Other conditions are allocated in the same period as they were allocated in the results.

3. Approach to better bridge management

We think that it is necessary to develop and optimize three management factors shown in Figure 7 to realize the rational management that takes the concept of preventive maintenance into consideration. The first is to collect and store large amount of various kinds of data for effective utilization. The second is to establish national macro management that enables the optimization of investment plans for various structures and prediction of the network performance for the optimization. The third is to establish micro management that prevents damage of each individual bridge, optimizes bridge maintenance including repair and reinforcement, and enables implement of maintenance for extending bridge lifetime.

As for the approach to the rationalization of macro management, we are discussing the improvement of the developed bridge management system (BMS) and what the management method as the network should be for the optimization of investment plans and the assistance to predict network performance.

As for BMS, we are developing a system for the progress management such as prediction of deterioration, and time for measures based on the prediction, simulation of construction method and cost, tendency analysis of damage, and extraction of bridges taken no measure, using data of repair history, data of each element (MICHI data), inspection data, and management list of damage.

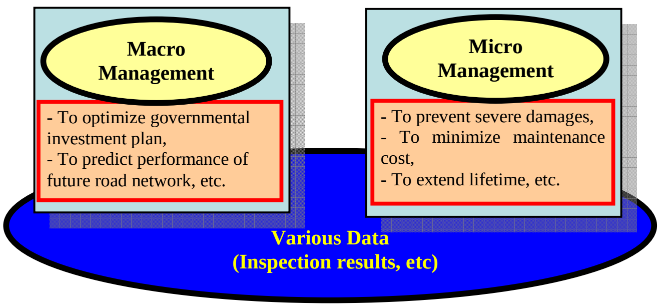


FIGURE 7. FACTORS OF RATIONAL MANAGEMENT OF BRIDGES

For the rational management of each bridge, Japan has so far been devoted to establishing the BMS that could predict deterioration, simulate time for repair and reinforcement and necessary expenses to each bridge. That is, the BMS is expected to perform both macro and micro management function, but failed to have necessary accuracy. We can point out several reasons for the insufficient accuracy. Most damage that affects the performance of a bridge is partial, and what is dominant in the progress of deterioration is the influence of micro environment and structural conditions. In addition, inspection mainly conducted by observation, visual inspection cannot get enough data to know the damage exactly. BMS developed so far is used only for screening of badly deteriorated bridges and schematic macro estimation. Lately, there are serious damage cases of bridges that cause the closure to vehicle traffic in main artery in Japan. Even if BMS is sophisticated and elaborated, it is hard to prevent serious damage and accident cases only by utilizing the BMS.

It is, therefore, necessary to approach comprehensively prevention of specific structure damage, optimization of bridge maintenance including repair and reinforcement, and extension of bridge lifetime, besides approaching the establishment of rational macro management. Besides technological development through research activities, we should continue to bring up professionals who can predict the deterioration of inner part with accuracy using the information obtained through visual inspection and to improve the inspection system that enables the rational management as a part of the approach.

4. Approach to rationalize macro management and micro management

We are developing the following approaches to rationalize macro management and micro management.

(1) Macro management

a) Improving accuracy of deterioration estimate used in the BMS
We are planning to analyse the correlation between the bridge condition, such as environment and traffic of large trucks, and the data of damage using the GIS data. In the future, we will consolidate bridge specifications, such as structure and anticorrosion, with repair history and improve the accuracy of prediction of anticorrosion deterioration, cracking of floor slab, and salt damage.

b) Indicators for evaluation of bridge condition
We propose some indicators for evaluation of bridge condition that focus on the major performances of bridges (Load Resistance, Resistance to disasters, and Safety when driving). In the future, we will estimate and verify the indicators based on results of the major routine inspection by the nation and inspection by municipalities.

c) Evaluation of various structures and networks using the indicators

We discuss the common indicators to evaluate various road facilities, such as tunnel, earth structure, based on the concept described in b) for the rational management of the whole network including the prioritization of maintenance in consideration of the position of routes.

(2) Micro management

To prevent serious damages and implement rational maintenance, we specify and extract the deterioration or the fatal damages that affect the bridge performance. Then, we are reviewing a series of necessary measures such as detection method, method to evaluate influence on performance, and measures (including preventive method), and working on how to reflect the developed approaches in the management system. We are currently working on the following matters:

- Deck-penetrating fatigue crack in steel deck
- Corrosion at edge of steel girder
- Soundness of PC member (insufficient prestress)
- ASR damage of foundation
- Corrosion of embedded part of steel in the concrete

Japan sorts out and manages progresses of researches against deterioration and damage cases that possibly affect the performance of road structures include bridge to review them comprehensively according to the plan.

The following shows researches and approaches on the response to corrosion at edges of steel girders among the above matters.

5. Approach to prevent specific damage - corrosion at edges of steel girders -

5.1 Background

Edges of steel girders often corrode partially because of inferior condition in terms of corrosion, and damaged edges may affect the performance of the whole bridge depending on the part or degree of the corrosion. In the Niigata-Chuetsu Earthquake on October 23, 2004, the main girder of the steel bridge was damaged badly because of serious corrosion on part of edges of steel girders corroded seriously, and girders were worried to collapse. (Figure 8)

Therefore, we are clarifying what influence these kinds of partial corrosions give to the performance of the bridge and examining the measure to prevent partial corrosions from deteriorating the performance of new and existing bridges.

FIGURE 8. RUPTURE OF CORRODED PART OF THE GIRDER EDGE AND BUMP CREATED BY THE FALLEN GIRDER (NIIGATA-CHUETSU EARTHQUAKE)

5.2 Analyzing patterns of partial corrosion

We analysed the corrosion of steel girders statistically using the existing inspection results and clarified the characteristics of the parts of occurrence and the spread of corrosion. And we looked into the corroded conditions on edges of girder whose examples exist a lot and broke them into patterns. We used the method to process the major routine inspection data statistically for the relations between parts and corrosion for the steel I girder and H girder bridges that has the largest number of management cases. Our analysis clarified the following points. (Figure 9)

- The outside girder has higher frequency of corrosion than inside girder. This is possibly because outside girder is more liable to be affected than the inside girder by the external environment.

- Support points have higher frequency than the span center, and the end support points have far higher frequency. Water leakage from drainage equipment and expansion joint is supposed to cause corrosion because space on the support point, especially on the abutment, is generally closed and narrow.

- The bridges that do not have corrosion in the support point of outside girder but have corrosion in the span center account for only 9.5% of all. That is to say, if corrosion occurs in the span center, 90% of them also have corrosion in the support point of outside girder.

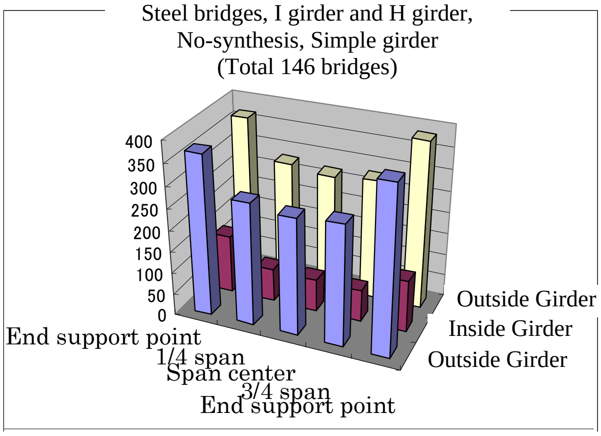


FIGURE 9. OCCURRENCE OF CORROSION BY PART

Next, we collected corrosion cases from the inspection results of bridges and analyzed the tendency of corrosion conditions. We learned that corrosion tends to develop intensively in such extremely limited areas as near the weld line divided by stiffeners and the lower flange or the free edge of the members. This is possible because the structure of connections tend to allow such factors of corrosion as moisture, sand, and dust to accumulate, and the paint quality of the free edge is inferior to that of other standard parts. The three corrosion patterns (Model 1 - 3) in Figure 10 account for about 65% of the corrosion cases.

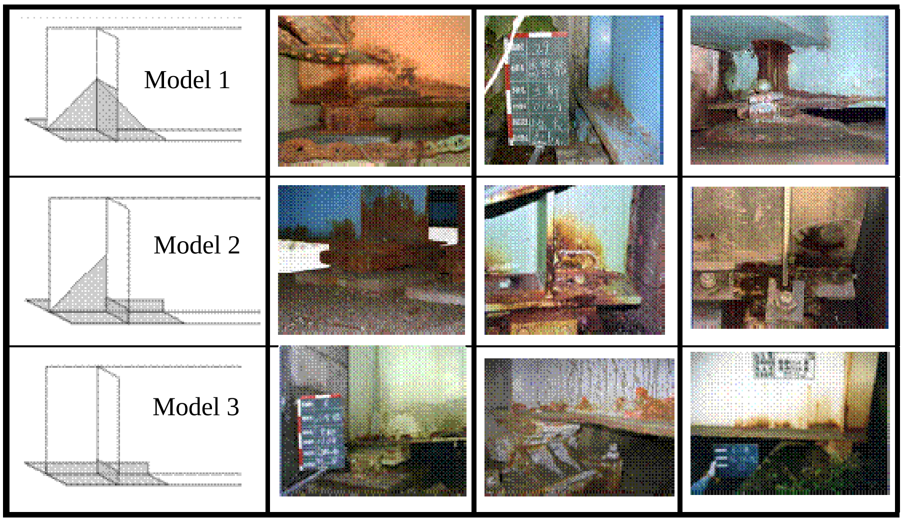


FIGURE 10. REPRESENTATIVE CORROSION CASES IN THE GIRDER EDGE

Based on the analysis of corrosion at edges of girders of existing bridges, the following measures are supposed to be effective for new or existing bridges for the prevention of corrosion.

- If it is clear that water puddles and dusts tend to accumulate at edges of girders of the existing bridge, it is possible to prevent partial corrosion from occurring and developing by devising measures to avoid moisture and dust through the major routine cleaning and improved drainage.

- It is possible to equalize the durability of anticorrosion function of the whole bridge by applying heavier-duty painting to the girder edge which tends to deteriorate faster than other parts. A great effect can be expected by applying heavy-duty painting only to the neighborhood of the support points. In the case of existing bridges, effective and rational measures can be taken by specifying the corrosion trend through the observation.

- If painting quality causes a problem due to insufficient thickness of painting in stiffeners of girder edge and free edge of the lower flange, the improvement and strengthening of anticorrosion performance as the necessity arises is helpful to prevent partial corrosion. As for new bridges, it is important to work out details like chamfering of free edge or curved surface processing so that painting quality can be secured easily to prevent partial corrosion.

5.3 Analyzing consequences of partial corrosion

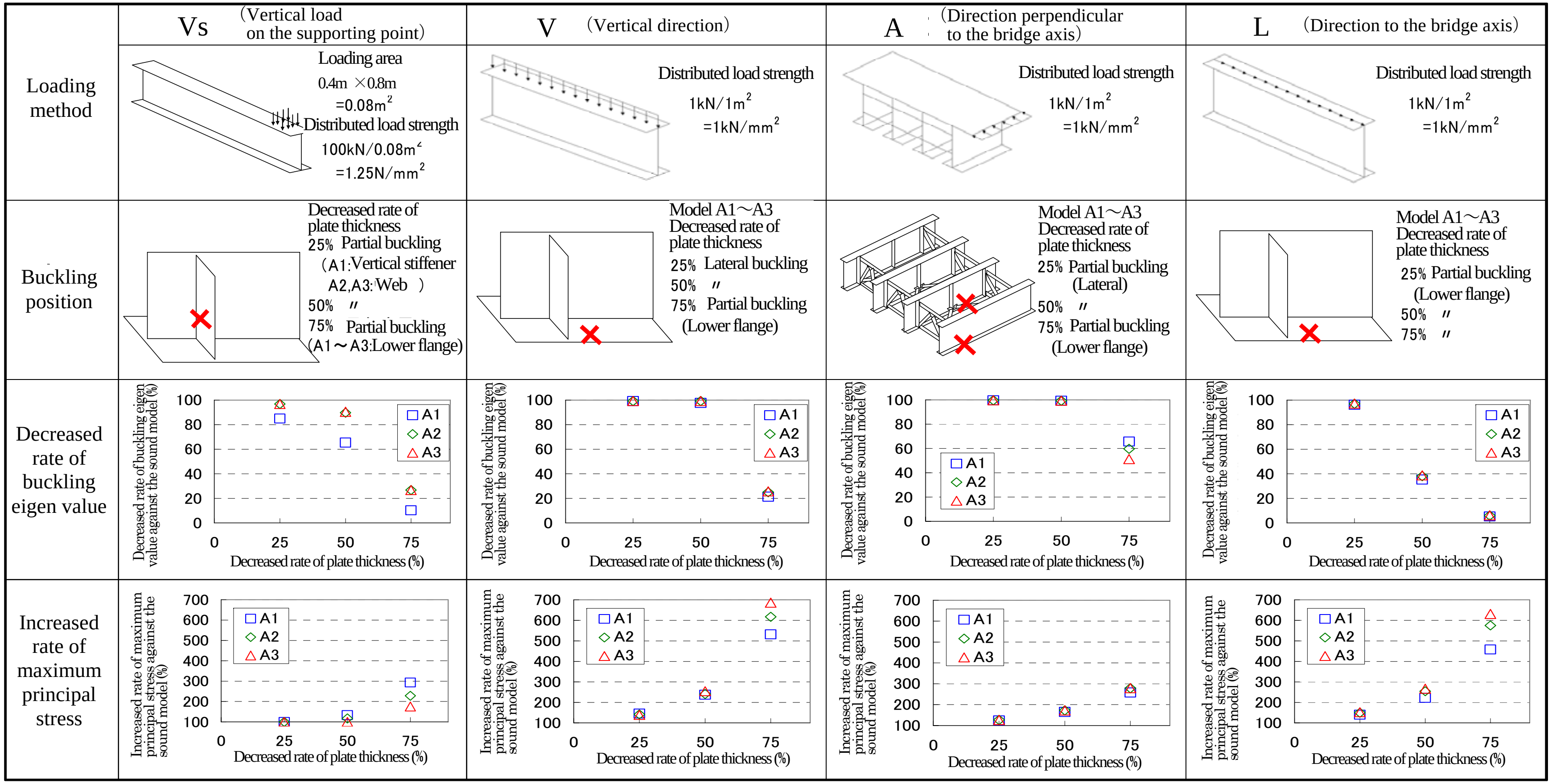
We conducted numerical analysis to see the influence of intensive development of partial corrosion at edges of girders and decreased plate thickness over proof strength. We divided the decreased rates of plate thickness of corroded parts to 25%, 50%, and 75%, and set up model damage according to the corrosion pattern in Figure 10 that has a high corrosion frequency.

Taking into consideration live load and action in earthquake, we analysed buckling eigen values and operating stress using the finite element method (FEM) analysis to the loaded condition in each of the three directions, vertical direction, direction to the bridge axis, and the direction perpendicular to the bridge axis. At the same time, we conducted analysis of the influence that the position of the sole plate and the area of corrosion give to strength.

Figure 11 shows the analysis results of influence due to the difference of decreased rate of plate thickness. It indicates that the case whose decreased rate of plate thickness is 75% increased the decreased rate of buckling eigen value and increased rate of maximum principal stress greater than the cases of 25% and 50%. That is, if the decreased rate of plate thickness exceeds 50%, the proof strength drastically decreased. On the other hand, there was virtually no difference in the influence due to corrosion pattern.

As for the analysis of the influence of sole plate, strength drastically decreased if the area of corrosion exceeds the position of the sole plate. (Figures 12 and 13)

The above analysis teaches us that even if the corroded part is small and partial, load resistance ability is greatly affected if the decreased rate of plate thickness is high and corrosion progressed beyond the sole plate. We need to pay attention to see if the girder edge was corroded considerably and if corrosion progressed beyond the sole plate regardless of the corroded area, though current evaluation stipulated in the major routine inspection guidelines divides the ranks that need attention into the depth and area of damage.



Note: A1: Model 1 of Figure 10, A2: Model 2 of Figure 10, A3: Model 3 of Figure 10

FIGURE 11. ANALYSIS RESULTS OF THE INFLUENCE OF EDGE CORROSION ON THE DECREASE OF PLATE THICKNESS

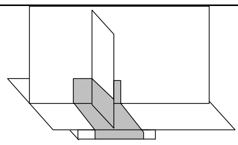
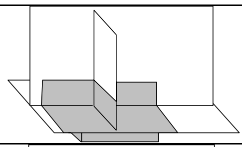
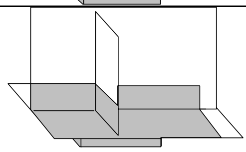
Model of corrosion analysis		Decreased rate of plate thickness	
		50%	75%
Corrosion model 1 : Inside the sole plate (C1)		C1-50	C1-75
Corrosion model 2 : Beyond the sole plate (C2)		C2-50	C2-75
Corrosion model 3 : Widespread (C3)		C3-50	C3-75

FIGURE 12. MODEL OF ANALYSIS OF CORROSION AGAINST SOLE PLATE

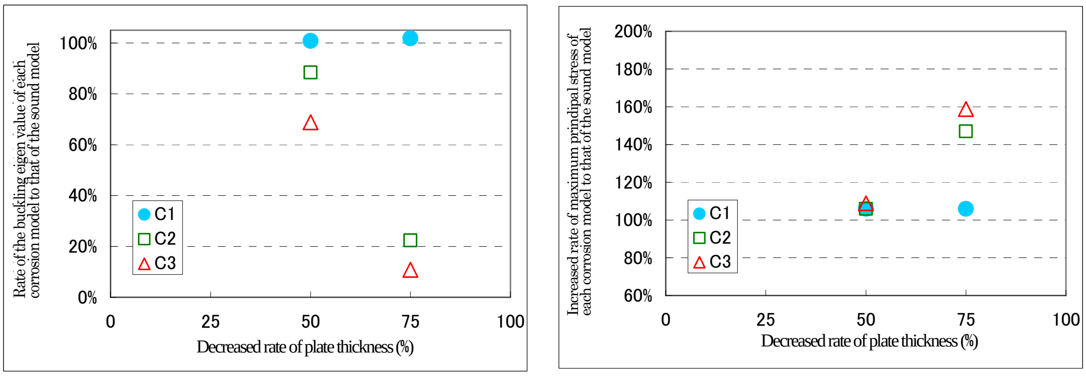


FIGURE 13. ANALYSIS RESULTS OF INFLUENCE OF SOLE PLATE

5.4 Comprehensive approach to prevent partial corrosion at edges of steel girders

Based on the analysis results in 5.3, we implement the following approaches to prevent partial corrosion at edges of girders of new and existing bridges.

(1) Reviewing the descriptions in the manual

We were reviewing the following descriptions of the “Painting Manual of Steel Road Bridges” in the “Manual of Painting and Anticorrosion of Steel Road Bridges” that was revised in December 2005.

- We placed the description of the measure for water paddles of the stiffeners on the supporting point as a point that should be kept in mind in designing construction.

We clarified the points to consider, such as better ventilation at edges of girders and prevention of water leakage from expansion joint.

- In the maintenance chapter, we placed the section for the treatment of water leakage and drainage, and described the concrete measures including installation of drainage slope made of resin besides cleaning and improving the structure.
- We described the target of a painting area in the weathering steel that was placed in the revised manual for the first time.

(2) Reviewing the major routine inspection guidelines

The existing guidelines use the degree and area to evaluate corrosion. We are considering to revise them to make it possible to evaluate corrosion in a rational way from the following points of view.

a) Selection of subjects and parts that satisfy the subject of evaluation
For example, partial decrease of plate thickness at edges of girders
b) Setting up criteria responding to bridges performance required
For example, evaluation of the risk that specific safety cannot be secured in an earthquake

(3) Establishing method for partial repainting

No method has been established for partial repainting against partial corrosion represented by edges of girders, we are trying to establish an approach. We will describe it in detail in 5.5.

5.5 Developing method of partial re-painting

Because there has been no established method of partial repainting against partial corrosion in Japan, problems arose because response varies with managing bodies.

a) Uneconomical and irrational implementation from the viewpoint of LCC to leave the corrosion at edges of girders until the repainting period of the whole bridge.
b) Conduct of partial painting using our own method
c) Insufficient performance such as lack of durability of original methods of partial repainting because of insufficient cleaning or application of tentative repair painting

Therefore we conducted test to verify applicability of heavy duty repainting which is expected to prevent partial corrosion at edges of girders effectively. Test objectives, results and future challenges are shown in Table 2, and Test situation is shown in Figure 14.

We plan to propose a manual for partial repainting and verify it by tests with addressing challenges shown in Table 2.

TABLE 2. SUMMARY OF EXPERIMENT OF REPAINTING OF EDGES OF GIRDERS

Item	Content
Objectives	a) Verification of the applicability of the first class Cleaning (condition for heavy-duty painting) b) Confirmation of the workability in the narrow part
Results	a) It is possible to secure the antirust equivalent to ISO Sa2.5 by combining open blast plus small-sized blast or machine tools. b) Because it is relatively easy to get at the edge in the steel girder structure that we used in this research, it is possible to secure workability.
Challenges	a−1 Durability experiment of repainting of old and new paints a−2 Development of blast technology Operation in a narrow part, low noise, and function to prevent splash b−1 Improvement of parameters in a narrow part The bridge bearing is shorter than 170 mm. b−2 Experiment of application to other types of bridges Box girder (Narrow part is wider.) Truss bridge (Measures to prevent splash of blast)

(Sample) (Adjustment of substrate)

FIGURE 14. EXPERIMENT OF PARTIAL PAINTING AT EDGES OF GIRDERS

6. Future challenges

In this report, we introduced the current state of bridges, approaches to the rational management of bridges, and measures to specific damages in Japan. In the future, we will continue to implement approaches for rational management of various structures systematically and comprehensively as a network, and conduct research on measures to prevent each structure damage and rationalize bridge maintenance including how to reflect the inspection and maintenance system in the technology development while aging society progresses.