Element-level inspection results and accuracy of probabilistic structural condition forecasting for highway bridges

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Abstract

The road network in Japan was developed rapidly during the rapid economic growth of the 1970s, and the number of road bridges has now reached approximately 680,000 (bridge length ≥2 m). If the current situation continues, the number of bridges that have been in use for over 50 years will account for almost half of the total bridges in 15 years. A strategy to lower maintenance costs for each bridge while maintaining adequate maintenance standards is essential.

Effectively reducing maintenance costs through preventative maintenance is important for this strategy. A first-generation bridge management system (BMS) has been used in Japan since 2004. A three-year program for fiscal 2005-2007 was implemented to complete inspections and repairs of damage requiring a rapid response. The second-generation BMS planned to be announced in 2013 will entail evaluations on a unit level. In terms of main girders, the unit level indicates each main girder in the range delimited by cross beams as shown in Fig. 3. (In the United States structural units of slabs, superstructure, substructure, and others (expansion device, bridge shoe, etc.) are used.)

Fig. 1 Examples of damage

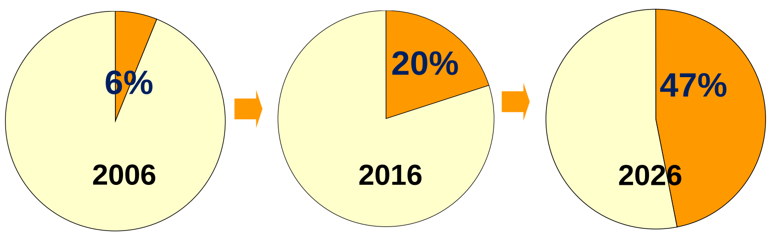

Fig. 2 Percentage of the bridges aged 50 years or older

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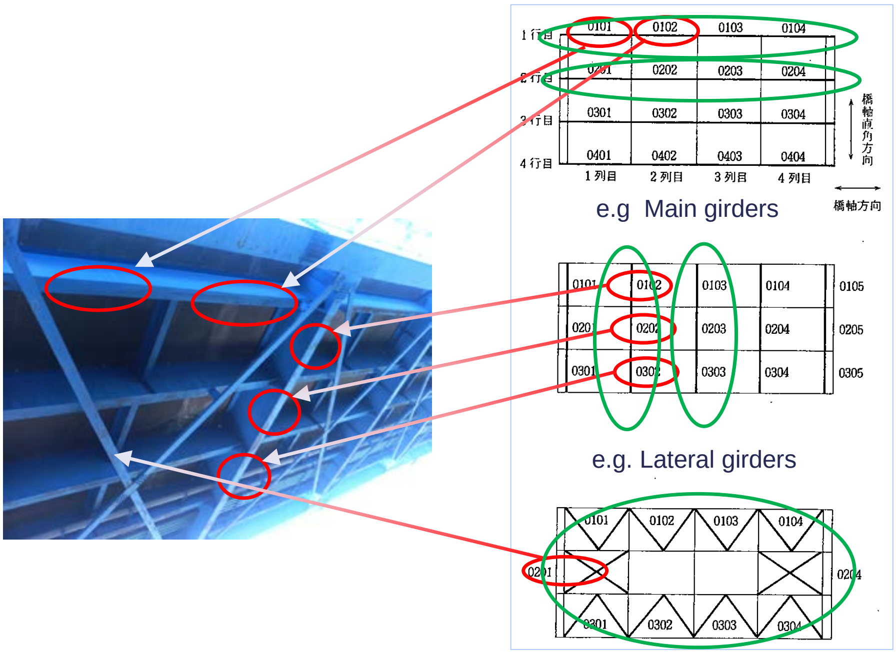

Fig. 3 Concept of unit-level BMS

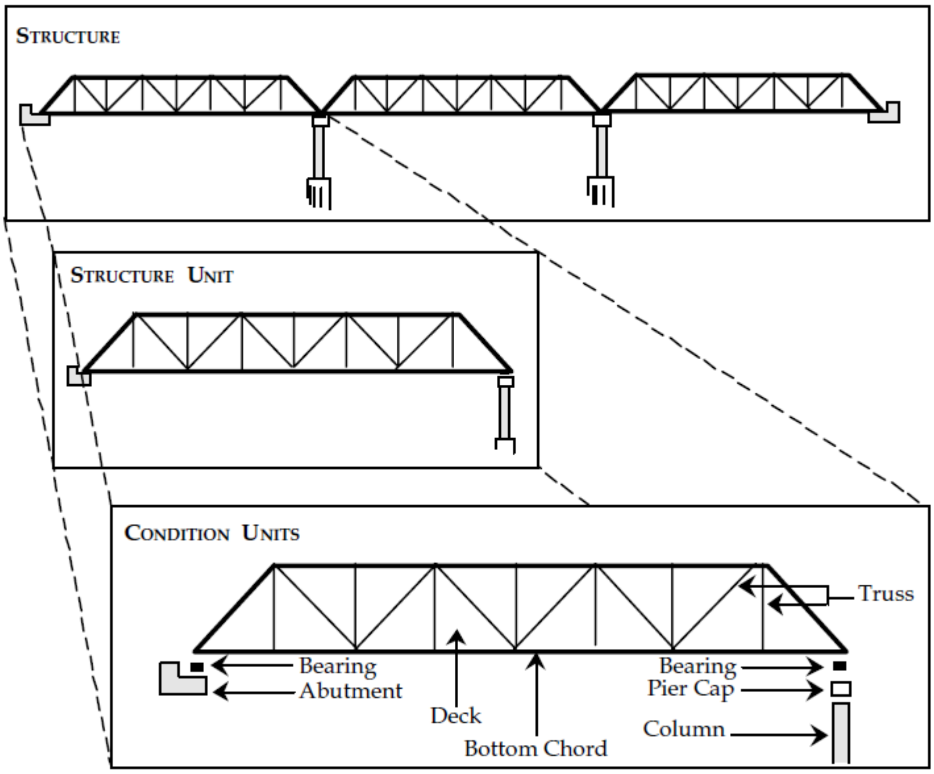

Fig. 4 PONTIS (Element-level BMS)

Comparison of Routine Inspections

	Japan	USA	UK	France
Inspection frequency	Every 5 years	Every 2 years	Every 6 years	Every 3 or 6 years
Inspection method	Direct visual inspection			
Scope of inspection	All parts			
Evaluation of degree of damage	Unit level, 5 classifications for each damage type	Element level, 3 classifications for each damage type; quantitative values (extension, etc.)	Element level, extent (4 levels), seriousness (5 levels), countermeasures (7 classifications), priority (3 classifications) for each damage type	Element level, 5 classifications for each damage type

1. Concept of unit-level BMS and unit-level maintenance

A significant feature of the new BMS is that it establishes various deterioration prediction relations that correspond to various component attributes on the basis of unit level inspection data; in contrast, the first-generation BMS used a deterioration prediction relation for simply a representative deterioration phenomenon, because there were insufficient inspection data accumulated on the unit level. The new BMS is primarily intended for use in simulations to decide maintenance and repair schedules, similarly to the first-generation BMS. For example, deterioration prediction formulas for each section of bridge components can be used to predict cases, such as in Fig. 4, where repainting all components is unnecessary and zone painting is appropriate, with the aim of allocating a limited budget appropriately according to the characteristics of the bridge.

To enable the BMS to decide such maintenance and repair schedules, data relating to the condition of bridges are being collected in bridge inspections in element units even smaller than component units.

In 2004, Japan implemented a policy whereby, out of the 160,000 bridges in the country, the 21,635 bridges under central government management are inspected once every 5 years. In these inspections, the types and units of data collected were determined taking into account application in the BMS.

Fig. 4 Example of unit-level maintenance

2. Background bridge inspection data

The new inspections implemented in 2004 consist of regular patrols for the early detection and early measurement of abnormalities; periodic visual inspections for the detection of damage near each part and determination of the functional status of the bridge; special inspections for the assessment of phenomena such as chloride ingress, for which the extent of damage cannot be determined by a general visual inspection alone; and emergency inspections for the assessment of possible damage caused by an earthquake or typhoon. Through these multiple types of inspections being complimentarily performed on the same bridge, up-to-date and accurate information about the bridge can be obtained.

Among these inspection types, the periodic inspection records all conditions on a micro-component level for all bridges with a length of 2 m or greater once every 5 years, and from a unified perspective, the damage is evaluated according to 5 levels, with the aim of application in the BMS.

Figure 5 shows an example of a periodic inspection record. Two batches of this type of unit data, covering 10 years, have been accumulated for all bridges.

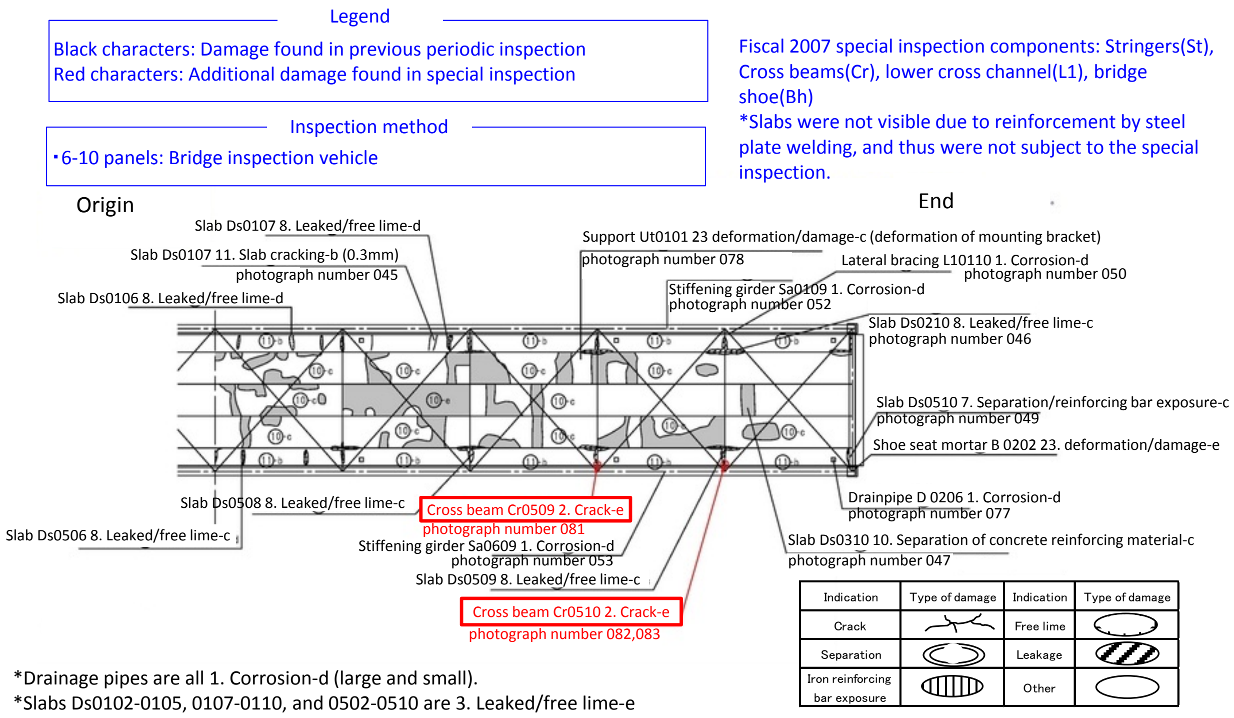

Fig. 5 Example periodic inspection record (sketch of bottom surface of deck)

From these inspection results, taking the corrosion of a steel girder bridge as an example, we can monitor each element given a damage rank of “b” to determine whether the extent of damage has progressed to a rank of “c–e” five years later.

Trends in the location of the damage can also be ascertained. Figure 7 shows an example where the end and outside girders have a greater extent of damage compared with the inner and mid-span girders. In practice, we can determine whether the coating is in a sound condition as a whole, but not overlook cases, such as in Fig. 8, where considerable corrosion has occurred at the end.

Fig. 6 Example of inspection results relating to the corrosion of a steel girder bridge

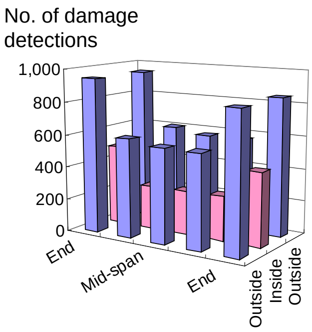

Fig. 7 Inspection results for a steel girder bridge

Fig. 8 An example of a bridge with considerable corrosion at the ends only

3. Constructing deterioration curves and transition probability matrices

The new periodic inspection data made possible the new BMS, in which exclusive deterioration curves can be assigned to each location or zone in the bridge components rather than just deterioration curves in units of components.

For each unit, the new BMS constructs deterioration prediction relations from the Markov transition probability calculated by using inspection data on at least the unit level. In addition, the BMS is designed to enable the incorporation of various deterioration prediction relations, such as regression equations that approximate the relationship between the number of years elapsed and the deterioration relative to the original data, and the durability evaluation formulas used in design for phenomena such as fatigue in steel and slabs. However, taking into account the uncertainty of actual phenomena at the present time, we consider prediction by the Markov transition probability calculated by using inspection data to be the most reliable method.

An example of calculating a deterioration curves is shown in Fig. 9. The results of periodic inspections performed at two different times on the same point of the same bridge found, as a Markov transition, the progression of corrosion of main steel girders that had been coated with ordinary paint. The same diagram shows the average for each year and the approximate curve obtained upon replacing the degrees of damage “none” to "severe” with the numerical values of 1.0 to 0.0, including the standard deviation.

The calculated corrosion deterioration curves are shown in Fig. 10 for the bridge at each bridge component location. From these curves, we can see a difference in the progression of corrosion according to the location.

Figure 11 shows an example of inspection results for a slab. In this case, damage is greater for the slabs closer to the ends than for central inner slabs. Figure 12, in which deterioration curves are plotted by using these inspection results, shows that the trend of the deterioration curves is different between the central sections and ends of the main girder.

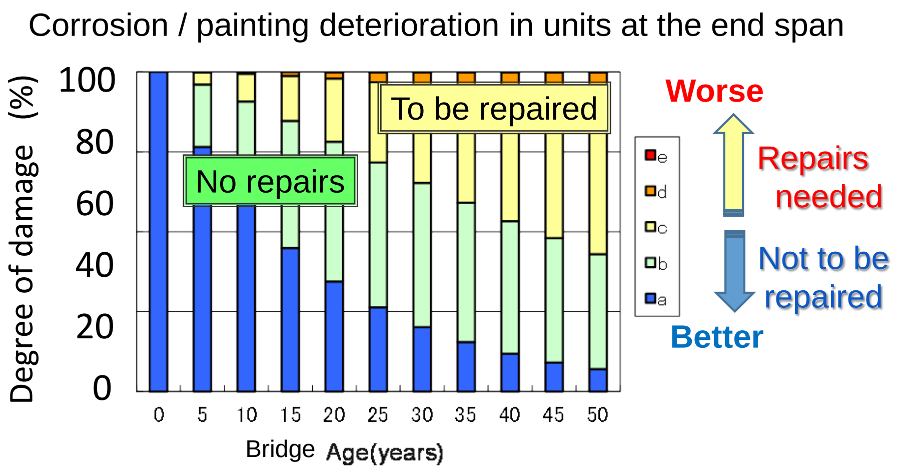

Fig. 9 Example of deterioration curves calculated by using the Markov transition probability

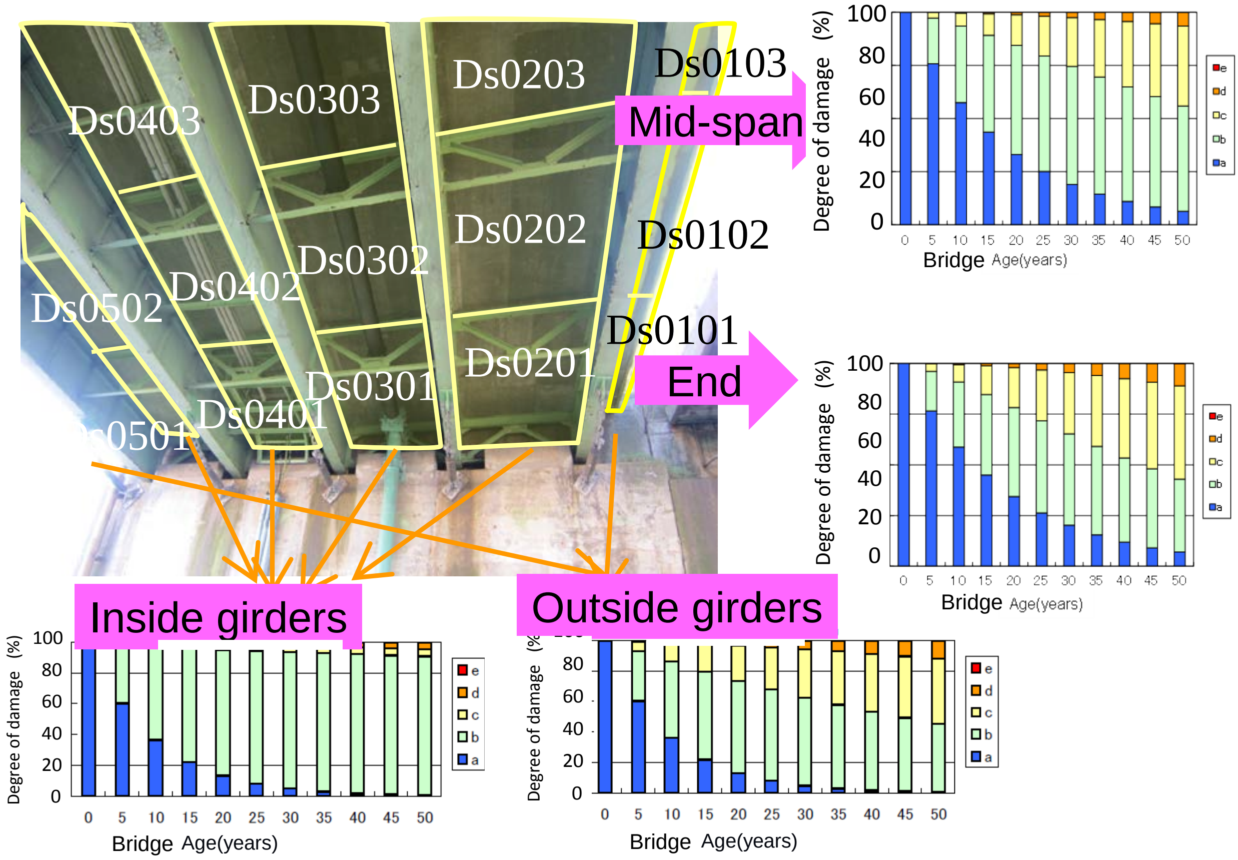

Fig. 10 Creation of deterioration curves for each element

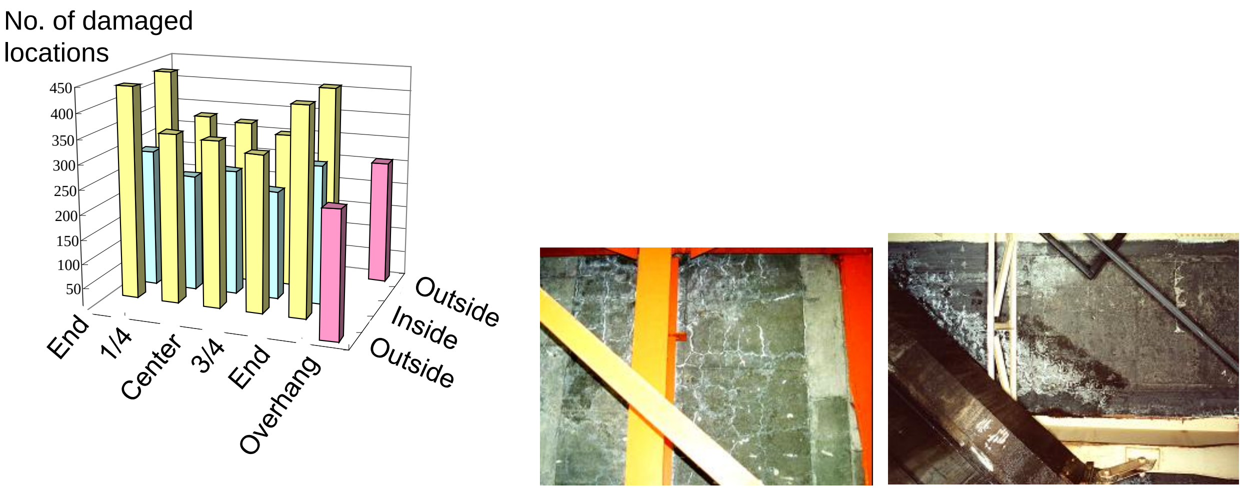

Fig. 11 Example of cracks in the deck of plate girder bridges

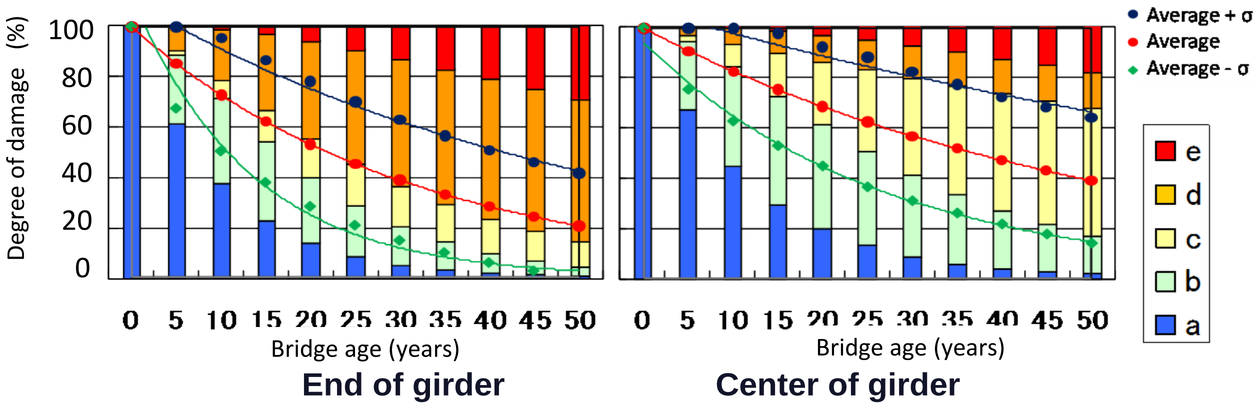

Fig. 12 Expected deterioration curves for the corrosion of steel girders with typical paints

Furthermore, provisionally using the average for the deterioration curve as the method of expression of these graphs for the end parts, for example, results in a prediction of under 0.5 (= “c”) for 25 years in the future. However, this means only that, while reliability is not high, the expected value will be approximately “c,” and will not definitely be “c” for any bridge 25 years in the future. Moreover, bridge environments differ (e.g., whether the bridge is located on the coast or sprayed with antifreeze), and even on the same bridge, the progression of corrosion will differ between parts[5)]. In other words, the actual situation is such that there is an extremely large scatter in the deterioration predictions found from the statistics. One method to express this degree of scatter is the presentation of deterioration curves including standard deviation values.

4. Why BMS cannot be used for individual bridge lifespan predictions

Even if element-level inspections are performed and element-level deterioration predictions are formulated, there is almost no possibility that the BMS will be applicable to individual bridge lifespan predictions. This is because the implementation schedule and details of repairs will change according to various factors that cannot be predicted by the BMS, such as budgetary limitations and other obstacles to construction work in the future repair schedule for the particular bridge. In addition, considering the quality of bridges actually built and the current method of durability design, there is an unavoidably large scatter in the deterioration characteristics of bridges. For this reason, there is a large issue with reliability when using the BMS to predict the deterioration of individual bridges. The principal factors that have an adverse effect on prediction reliability are listed below.

・Differences in environment

The Japanese archipelago has long mountain ranges in the Northeast and central regions, resulting in large differences in climate by region. The photographs in Fig. 13 show different conditions of external forces, such as the bridge environment and automobile load.

Fig. 13 Differences in environment

・Difference in construction period

Design standards have changed in respond to the numerous disasters in Japan as well as to changing social conditions such as increases in traffic levels and vehicle size. The load-bearing capacity and durability of bridges have also changed according to each of these standards.

Figure 14 shows an example method for strengthening bridge supports; this method was adopted following the Great Hanshin Earthquake of 1995. Figure 15 shows an example of experimentally verifying durability improvements due to the changing specifications of concrete slabs.

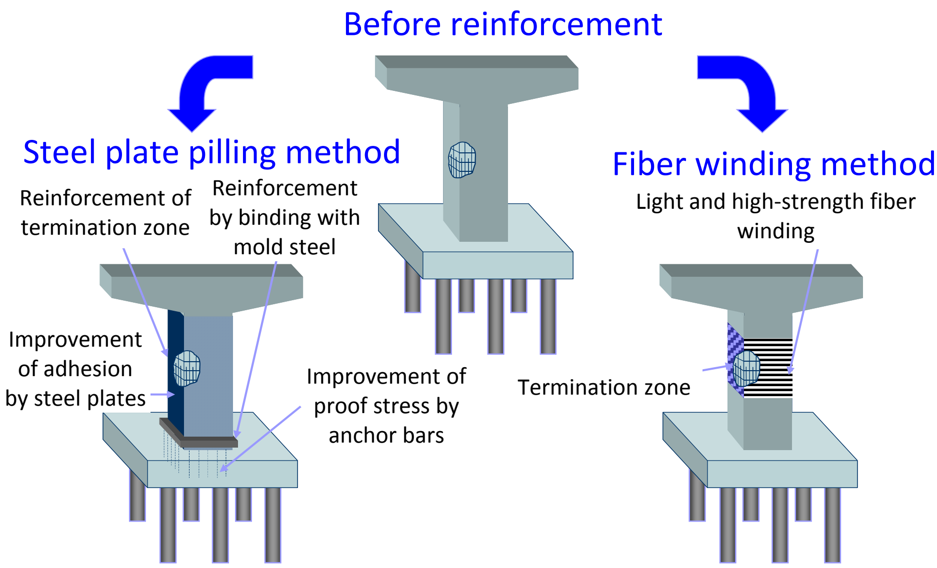

Fig. 14 Example of earthquake reinforcements

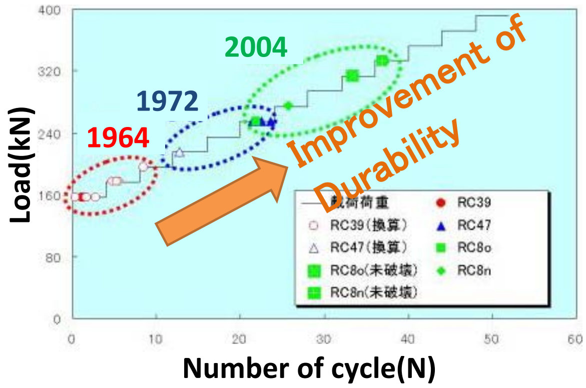

Fig. 15 Example of changes in concrete slab standards and changes in durability

・Differences in initial quality

Figure 16 shows results where some type of distress is found in approximately half of the main elements of spans in the initial inspection after construction. If there is any type of distress, even on a small scale, the element is classified as “with distress.” The impact on the integrity of the bridge is unknown, but many kinds of distress evaluated in inspections can link with a deterioration of durability.

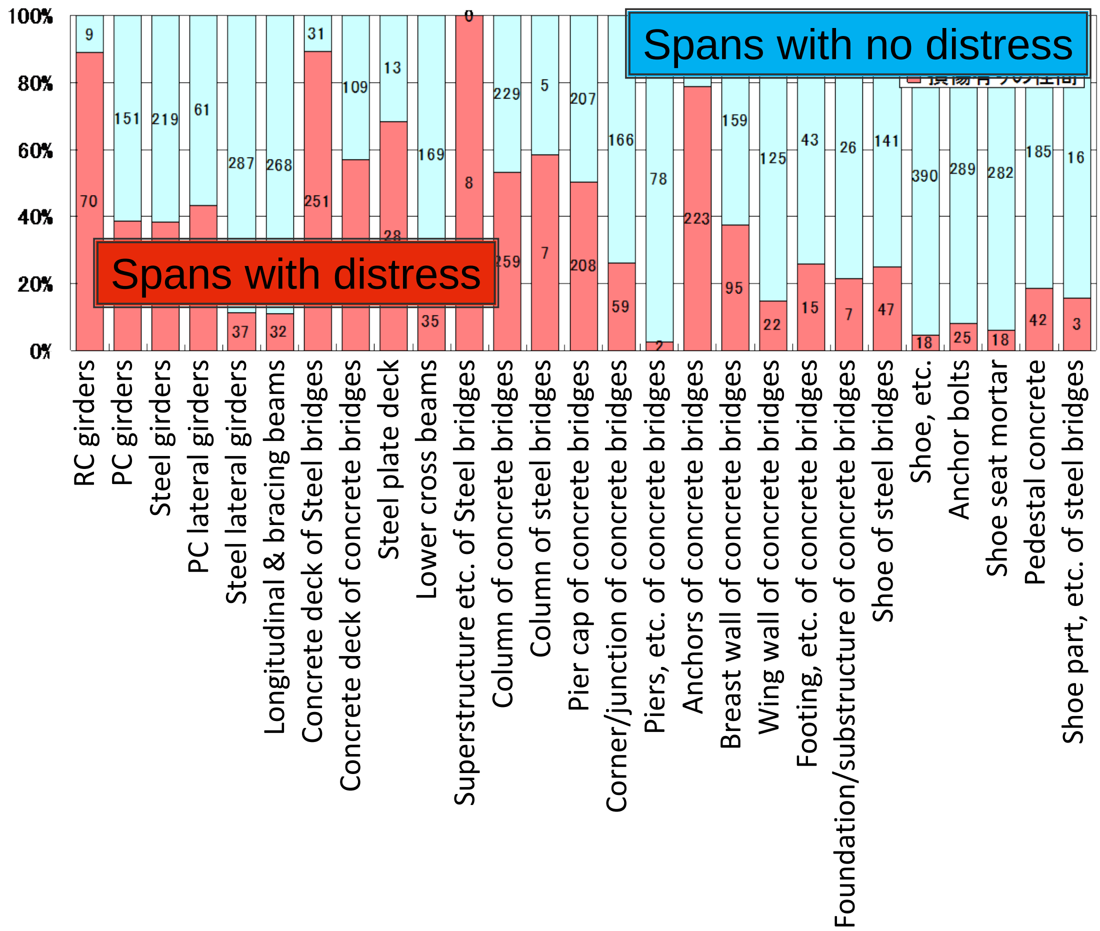

Fig. 16 Percentages of spans with and without distress

・Differences in environment by location

As shown in Fig. 17, there are points that are easily damaged depending on their location in the bridge structure, such as the girder ends being more susceptible to corrosion due to joint defects at the ends of the girders, temperature, or other factors, and the possibility of fatigue cracks forming in welded parts in which stress is concentrated.

Fig. 17 Local damage to bridge parts

As shown above, although there is a limit on the improvement of BMS accuracy, this does not have a great effect on our understanding of long-term maintenance and repair costs for all bridges, because the inaccuracy is canceled out when the number of bridge samples is large.

When all bridges are considered, the accuracy of the BMS is increased by unit-level inspection, and expressing differences in the rate of deterioration results in more accurate predictions when calculating the total cost for a maintenance budget. Furthermore, promoting these investigations enables the advancement of investigations into a more logical inspection method, for example, in which the frequency of inspections and number of inspection points are refined.

4. Advantages and remaining limitations

The next-generation BMS for element units has been developed based on the results of element-level inspections of bridges on the national highways of Japan.

1. BMS allows for limited budgets to be managed through unit-level maintenance
2. BMS for element units can express differences in the deterioration rate of element units. This can provide a more accurate prediction of the total cost of maintenance.
3. There are uncertainties associated with the deterioration curves for individual elements and bridges as well as the prediction of future expenses, and many of these uncertainties are difficult to eliminate.

5. Implementation schedule

The Ministry of Land, Infrastructure, Transport and Tourism (MILT) plans to release the new BMS for element units to calculate financial provisions for the maintenance and refurbishment of all bridges.

MLIT has already started using the new BMS to estimate the mid-term maintenance and refurbishment costs for all bridges in the national highway system.

NILIM will release the unit-level BMS, which includes the following features:

- All deterioration curves based on MLIT inspection results
- Markov transition probability density matrices based on MLIT inspection results
- Theoretical deterioration curves for chloride ingress, fatigue in RC slab decks, fatigue in steel members, etc.

The BMS will be released as an NILIM report along with the source code and a compiled binary program (for local governments). All MLIT NH offices will start using the new BMS regularly in 2013 and will launch the third round of the 5-year bridge inspection program in 2013.