

Steel Bridge Maintenance in Japan

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Abstract

Steel bridge maintenance in Japan is introduced. First, inspection and its importance are introduced, and the preventive maintenance strategy follows. On establishing maintenance strategy, it is emphasized that accurate assessment or rating of the performance of damaged structures and their deterioration rate are very important and control the estimation of the budget for maintenance. Structural Health Monitoring, Life Cycle Cost evaluation and weathering steel are briefly introduced. Finally, examples of the damage in steel bridges and the repair methods are also introduced.

1. Introduction

Current steel bridge maintenance situation in Japan is introduced. In Japan, we have around 670,000 steel and concrete bridges and, among them, 150,000 bridges have a span exceeding 15 meters, and old bridges have been increasing year by year. It has been reported that the ratio of highway bridges over 50 years after opening to traffic to all bridges is 6% in 2006. However, in 20 years, the ratio will reach around 50%. In recent years, many of seriously damaged bridges mainly due to corrosion have been

revealed. Hence, establishing the efficient maintenance strategy with minimum budget will be the most important technological subject to be attacked and solved in the next stage of bridge engineering field in Japan, and it is also an urgent subject.

Inspection and its importance are explained, and the preventive maintenance strategy recently started in Japan follows. Structural Health Monitoring (SHM) and use of weathering steel in steel-concrete hybrid bridges related to Life Cycle Cost (LCC) minimization are briefly introduced. Finally, the damage examples due to corrosion, fatigue and so on and repair of them or replacement examples are introduced.

2. Inspection¹⁾

On appropriately maintaining the existing steel bridges, the role of inspection is important. It is starting and key works. Normally, visual inspection by accessing bridges has been carried out, and highly skilled inspectors are necessary in order to find damage and make an accurate technological judgment on performance of the inspected bridges. Even though central government offers technical supports such as lectures or guidelines for inspection, it has been pointed out that their evaluation is subjective. From this reason, one way to catch the current state of bridges correctly, Structural Health Monitoring System (SHMS) is expected, in which many devices such as optical sensor and so on are now being developed and employed.

Table 1 Type of visual inspection

Type	Aim
Initial	Grasp the structural damage just after completion or repair work
Daily	For user's safety (by patrol)
Regular	Grasp the structural damage
Special	Grasp the structural damage just after earthquake attack, typhoon attack, collision, fire and so on
Detail	Grasp the degree and cause of the damage

Table 2 Cycle of inspection

	MLITT*	Expressway Company	Railway Company
Issued year of manual	2004	2006	1987
Target	bridges (span \geq 2 meters)	bridges	steel structures
Regular inspection	5-year (Initial inspection within 2 years)	5-year	2-year
How to inspect	Access and visual	Access and visual	Access and visual

* Ministry of Land, infrastructure, Transportation and Tourism

Main objective of inspection is to find or detect damages, such as corrosion, cracks, deformation and so on, and to record of them. Accumulation of these dates will help constructing Bridge Management System (BMS), which will be explained later. Further, inspectors have to judge whether or not the detailed inspection is necessary. There are five types inspection, and they are given in Table 1. The inspection cycle depending on organizations is also listed in Table 2.

Another important point on inspection is that inspectors can easily access to every member in the bridge. At the original design stage, designers have to take care of easy-access to all members. This consideration will contribute to expand a life span of the bridge. For the access of bridge, in case of plate girder bridges and truss bridges, an inspection walkway has been installed. Photos 1-2 show inspection vehicles.



Photo 1 Inspection vehicle¹⁾
(for high position work)

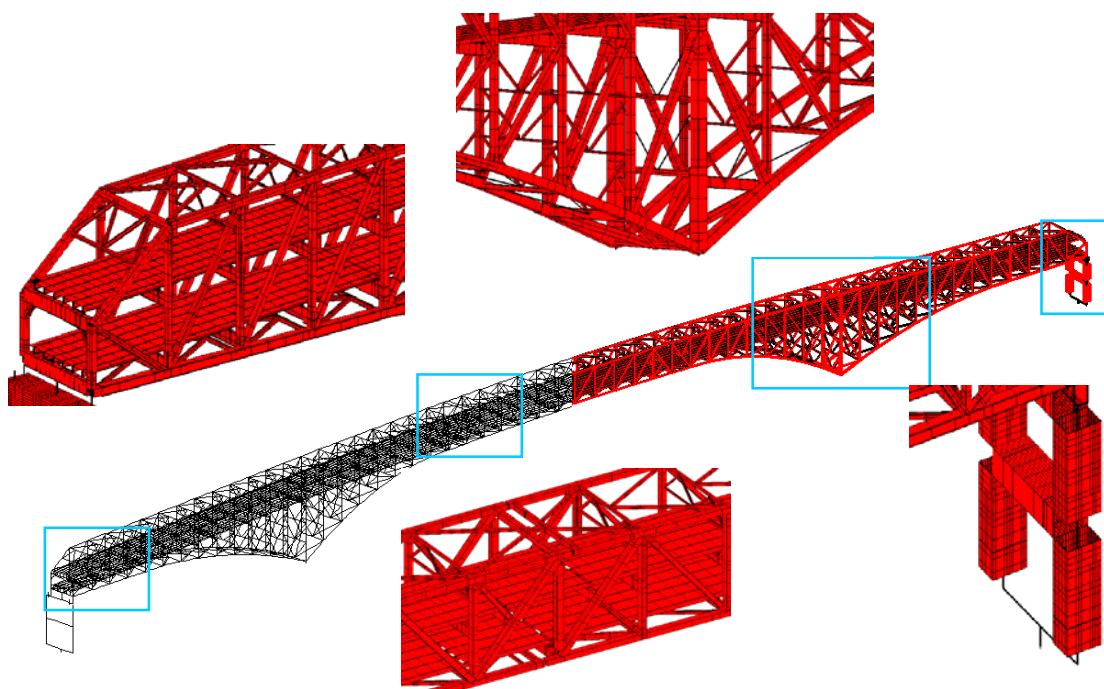


Photo 2 Inspection vehicle¹⁾

In case of long-span bridges, such as truss bridges, arch bridges, cable-supported bridges, it is easily understood that there are many access points. It means that full

inspection takes a long time and that inspection cost becomes relatively high. Hence, the development of an efficient inspection strategy for large-scale bridges is desirable. The followings are recent examples being studied in Japan.

Figure 1 shows finite element model (fiber model) of a long-span truss bridge. It is the Minato Bridge owned by Hanshin Expressway Company Ltd, whose bridge length is 980 meters and the center span length is 510 meters. In this analysis, it is assumed that the plate thickness of each member is reduced due to corrosion, and change of the behavior, such as deflection is checked. We call this kind of analysis “aging analysis”, and the image of it is given in Figure 2. The horizontal axis is the corrosion rate, which has the relation to time after opening, and the vertical axis is the displacement of the bridge. The most or more influential members on the collapse of the whole bridge are identified by this analysis, and the results are reflected to inspection priority and cycle. Based on the results, the cycle of regular inspection of every 5 year may be prolonged for some member.



Courtesy by Hanshin Expressway Company Ltd.

Figure 1 Fiber model for the Minato Bridge (long-span truss bridge)

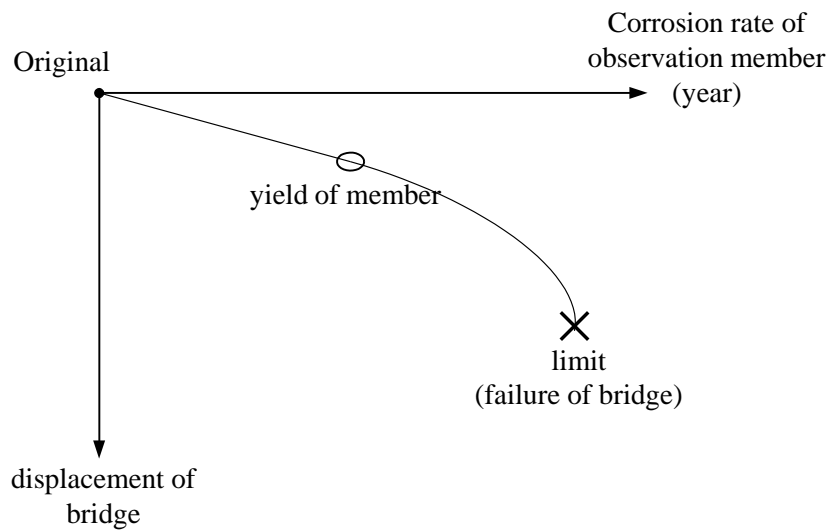


Figure 2 Aging analysis

Figure 3 shows one example of “redundancy analysis” of the existing truss bridge, which is 74-year old bridge. The influence of removal of one member on global instability of the whole bridge is analyzed based on Finite Element Analysis. By removing one member, whether or not the load-carrying capacity of the remaining members exceeds the ultimate strength is checked. In Figure 3, the value of R is a ratio of working force after removal of one member to strength of the observation member. If R exceeds 1.0, there is a possibility of collapse of the member observed. After the removal of all members one by one, the most influential member on the collapse of the whole bridge is identified. These results are expected to be utilized for the efficient inspection strategy, such as the determination of efficient inspection cycle of each member.

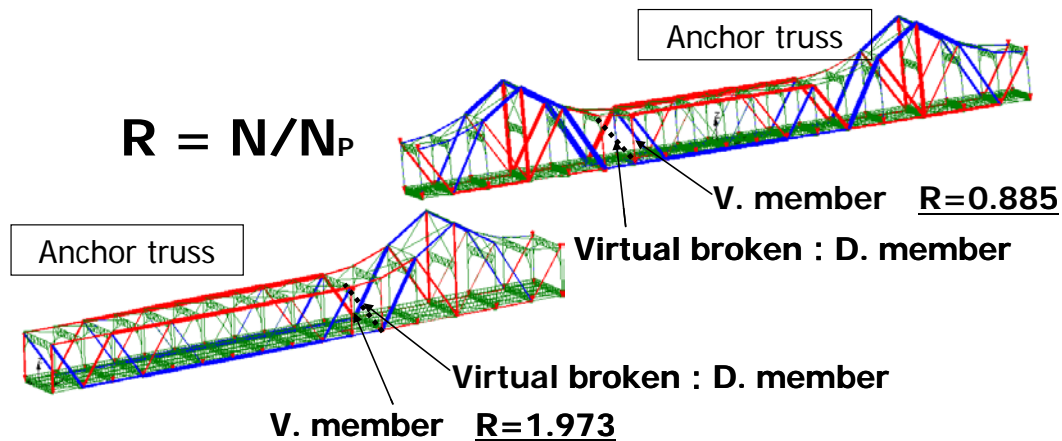


Figure 3 Redundancy analysis using an existing truss bridge

3. Preventive maintenance strategy in Japan

After the collapse of I-35W interstate bridge in Minnesota, USA, shown in Figure 4, Ministry of Land, Infrastructure, Transportation and Tourism (MLITT) belonging to central government of Japan decided to change the policy. It is from remedial repairing or rebuilding to preventive inspection and repair work, which will be carried out cyclically. Bridges owned and managed by MLITT have been inspected every five years as explained in Chapter 2, and the repair has been carried out, if judged to be necessary. However, more than 80% of bridges in Japan are owned by local or regional government (prefectures, cities, towns and villages), and most of them have not been inspected since opening to traffic. It is due to lack of financial budget.

Hence, in 2007 fiscal year, MLITT decided to finance the local bridge inspection and repair, in which a target life span is set to be more than 100 years. In Japan, normally, a life span of the bridges was considered from 50 to 60 years. If we estimate the cost for replacement of 50 to 60 years old bridges, huge budget was predicted. On the contrary, if we continue preventive procedure such as cyclic inspection and, if necessary, repair work, it is natural to think that maintenance cost will be saved even a life span is set to be 100 years more. This is the reason why MLITT changed the policy and started the preventive maintenance strategy.

Figure 5 shows the difference of preventive and remedial repair. The vertical axis is

the soundness of structural performance and the horizontal one is the duration for calculating LCC. Curves of No.1 and No.2 correspond to “preventive strategy” and “remedial repair”. The former cost for the repair to restore the original performance is expected to be low. MLTTT ordered the local government (prefectures) to inspect and check the performance (remaining capacity and deterioration rate) of all existing bridges and prepare the repair plan and the cost, in which LCC minimization is required.

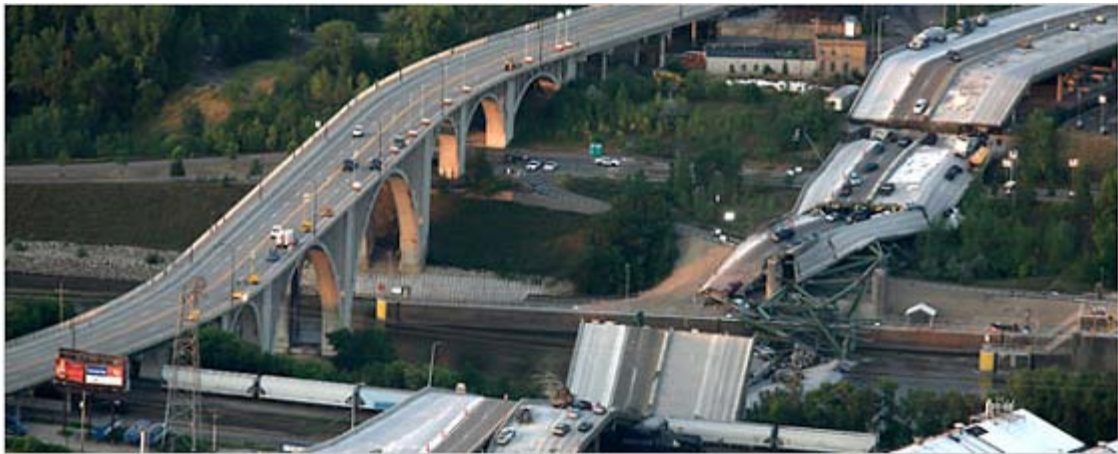


Figure 4 Collapse of I-35W truss bridge, Minnesota, USA

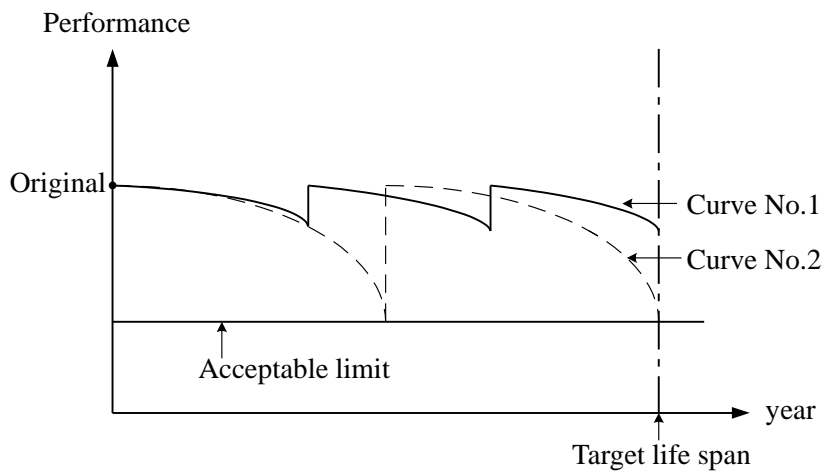


Figure 5 Deterioration of performance and restoration timing

In order to decide the priority of the repair work with minimum LCC, BMS has been used. This is strategy of minimizing the LCC. The flow of one example is as follow; 1) Inspection, 2) Assessment of structural capacity from bridge appearance and set performance (soundness) rank depending on the degree of damage, which is based on inspectors judgment, 3) Prediction of deterioration rate, 4) Estimation of LCC, 5) Priority of repair work, in which the urgency related to the collapse and importance of

road (heavy traffic or not) are taken into account.

The subjects of the above procedure being used for preventive maintenance strategy are summarized as follow;

- 1) Scatter of assessment or rating, since it depends on inspector's ability
- 2) Relationship between appearance obtained by visual inspection and real performance (load –carrying capacity) of the bridge has not been clarified
- 3) Difficulty in predicting correctly the deterioration rate

The above items strongly affect the budget estimation for the bridge maintenance. Hence, we have to further continue to make an effort for accumulating inspection record, particularly the data related to the deterioration rate. In addition, in order to identify the relationship between bridge appearance, such as corroded pattern obtained by visual inspection and real remaining load-carrying capacity of the bridge, Finite Element Analysis (FEA) will be helpful and its adoption is strongly recommended.

At the present moment, from the start of this project, in which targeting bridges are owned and managed by prefectures only (not including bridges owned by cities, towns and villages), it has been estimated, during 50 years from the start of this preventive maintenance strategy, that 23 trillion Japanese Yen (around 27 billion US dollar) is needed. If we do not select this preventive strategy, it has been also reported the total cost required during next 50 years will be 40 trillion Japanese Yen.

4. Structural Health Monitoring System

At 2008 Jakarta Seminar, I introduced advanced SHMS. They are Laser Doppler Vibrometers, one of devices to measure velocity, monitoring of a Shinkansen (high-speed train) steel box girder bridge and Shinkansen concrete viaducts. Furthermore, remote non-contact monitoring system for identifying tensions in many cables in long-span cable-supported bridges was introduced.

Instead of visual inspection, in order to assess the performance accurately, the development of health monitoring system is high now in Japan.

5. Competitive steel bridge solution from LCC evaluation and weathering steel

At 2008 Jakarta Seminar, I also introduced newly developed plate girder bridges. The number of main girder has been reduced and also transverse stiffening system has been simplified. Figure 6 shows newly developed I-girder bridges. In Japan, when the span length ranges from 40 to 60 (sometimes 70) meters, this type of bridge has been evaluated the most economical alternatives. In fact, in Japan, this type of bridge has been dominating the market.

In addition, activity on providing the Limit State Design (LSD) method for

steel-concrete hybrid bridges was introduced. Photo 3 is the experimental test on ultimate strength of composite and double-composite girders under flexure and shear. These tests were carried out in order to establish LSD.

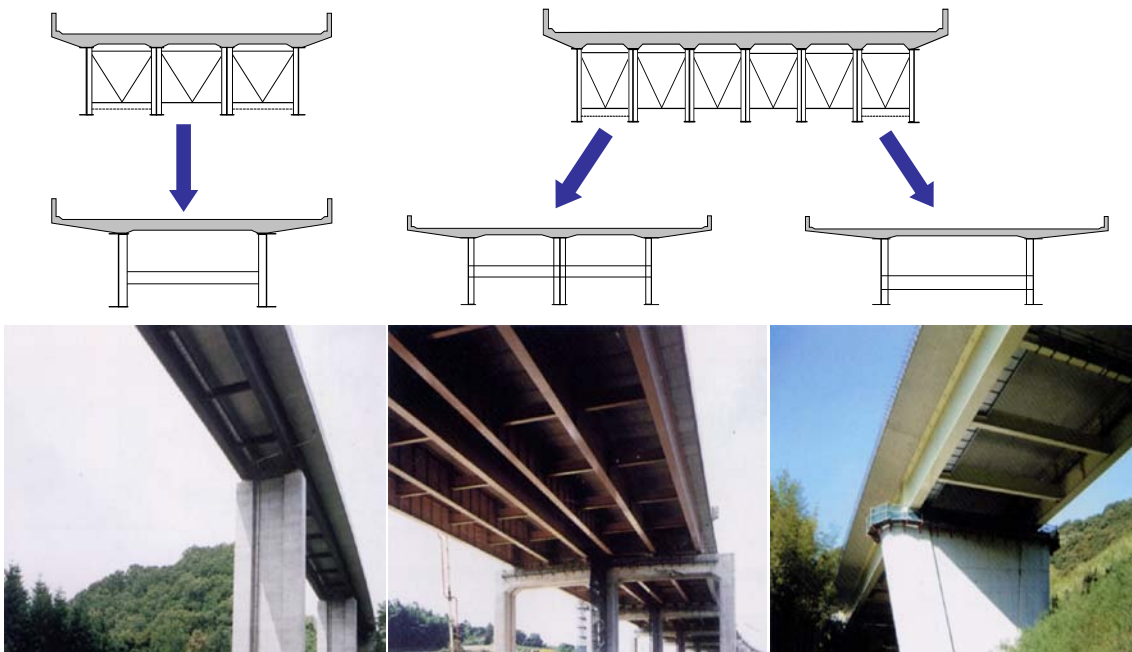


Figure 6 Newly developed I-girder bridges

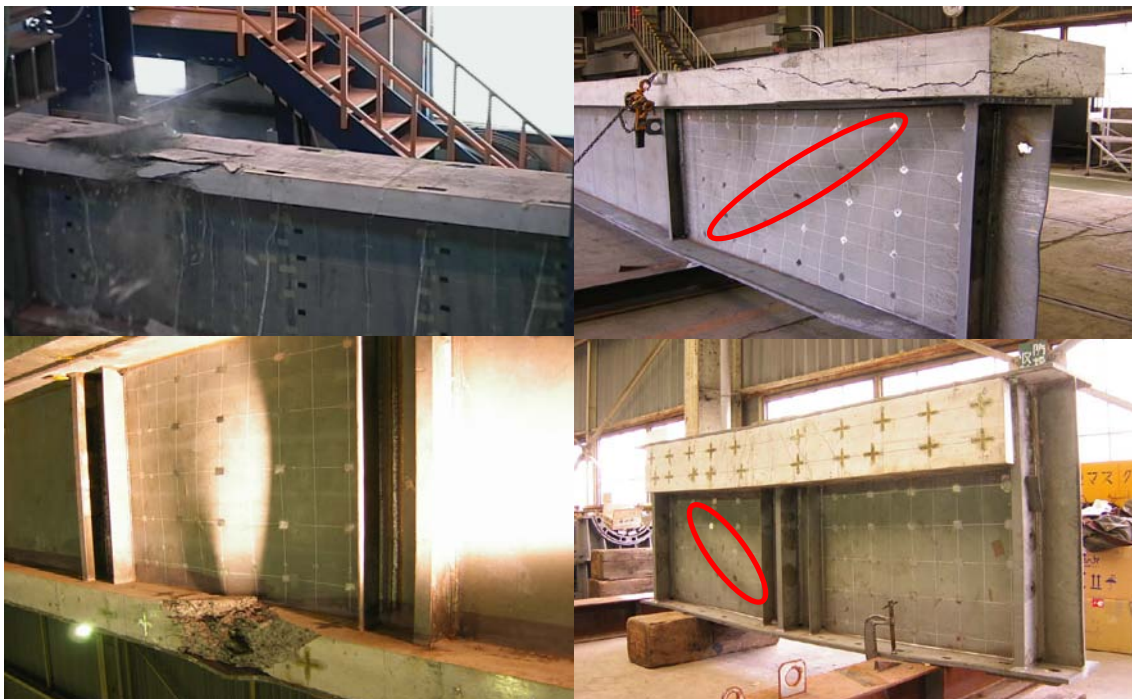


Photo 3 Experiments on ultimate strength of composite and double-composite girders

Photo 4 shows the montage of 5-span continuous composite twin-I-girder bridge

under construction near Tokyo, and it is expected to complete in this year of 2010. The bridge is owned by East Nippon Expressway Company Ltd. The bridge length is 185.3 meters and the central span length is 38.3 meters. The width of the bridge is 11.15 meters. The web depth selected is 1.5 meters, whose span-to-depth ratio is 25, which is higher value compared to conventional Japanese practice. The LSD was employed for the design of this bridge, and it is the first time composite girder bridge designed based on LSD in Japan.

Compared to the total steel volume estimated at the original design stage based on the Allowable Stress Design (ASD), around 16% reduction was attained. The reduction of steel main girder itself was around 10%. Since the welding connection was employed instead of bolt connection planned at the original design, further reduction of steel volume was attained. It is clear, by employing LSD, that further high competitiveness is expected. Hence, for the design of steel-concrete hybrid bridges, the shift from ASD to LSD is strongly recommended.



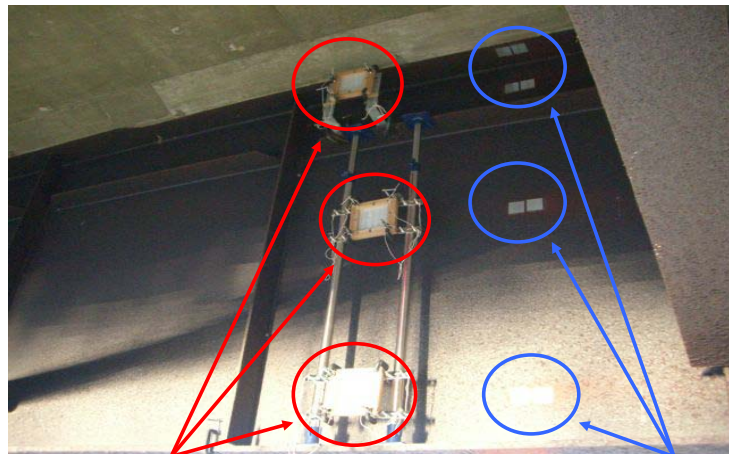
Photo 4 Continuous composite girder bridge designed based on LSD (montage)

In the competition of bridge alternatives, LCC evaluation has been made. In case of steel bridges, the cost for repainting has been counted, and the cycle has been assumed to be around 10 years or less. It means, when 100-year life span is set, 10 times

repainting is made. In order to cope with this subject, long-life painting system, such as 30-year cycle repainting system has been developed. However, in reality, since the maintenance cost of concrete bridges has not been included, the concrete bridge is competitive from a view point of LCC evaluation.

As one of countermeasures, the weathering steel is highlighted. Stabilized corrosion layer delays the further corrosion of steel plate. Hence, whether or not such layer is produced is the crucial problem, and it strongly depends on climate condition or atmosphere at the construction site. In Japan, normally, when the airborne salt volume is less than 0.02mdd/year. The weathering steel can be adopted. If the weathering steel is applicable to the above explained bridge system designed based on LSD, the most competitive solution from a viewpoint of LCC evaluation can be obtained.

In order to enhance the reliability of evaluation of performance of weathering steel, the study is being continued in Japan. Photo 5 is the measurement of the airborne salt density. Figure 7 is an analytical approach, which is finite element mesh division to predict the salt distribution in steel plate girder bridges.



Instrument for gathering flying salt

Exposure piece

Photo 5 Measurement of airborne salt

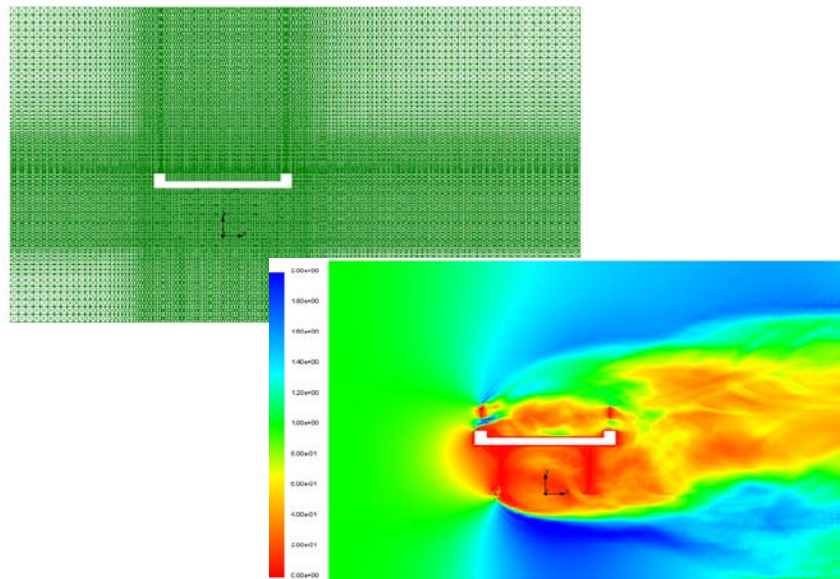


Figure 7 FEA under airborne salt

6. Examples of damage and repair or replacement¹⁾

In this chapter, damage examples with repair methods are introduced.

6.1 Damage due to corrosion and repair

Typical damages in steel bridges are due to corrosion and fatigue. However, from a mechanical viewpoint, most of replacement or rebuilding of steel bridges were due to corrosion. It means that a life span of steel bridges depends strongly on the way of corrosion protection. Hence, the corrosion protection is one of important design items to be taken into account at the practical design stage. Herein, several damages and their repair are introduced. As a repair method, steel plate attachment by bolting has been preferably selected and the replacement of the member itself is another selection, which is sometimes applied to seriously damaged members. Recently, instead of steel attachment, carbon fiber reinforced plastics (high strength and light weight) bonding has been used. However, at the present moment, the steel plate attachment is a major work.

Photo 6 shows the corrosion detected at the bridge end (supporting point) and its repair. Photo 7 shows the corrosion at connection (fillet welding) between web and lower flange and its repair. Photo 8 shows brokenness of the flange plate in a diagonal member in a truss bridge and its repair. It is seen, in these three cases, that the steel plate attachment by bolting were used for the repair. The steel plate attachment by bolting is the major repair method now in Japan.

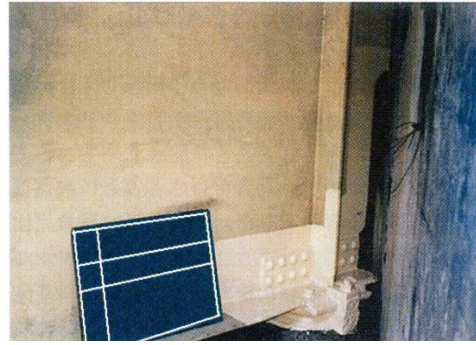


Photo 6 Corrosion at girder end¹⁾



Photo 7 Corrosion at fillet welding between web and lower flange¹⁾

6.2 Damage due to fatigue and repair

Photo 9 shows cracking at the girder end and one example of the repair. In case of Gerber type, at the supporting part, web depth is designed to be low for the installation space of shoes. The reason of cracking will be stress concentration and split force produced between curved flange and web. In the photo of the left hand side, at the tip of cracking, stop (round) holes can be seen. These are to stop the crack propagation. The photo of the right hand is an example of the steel plate attachment by bolting for the repair.

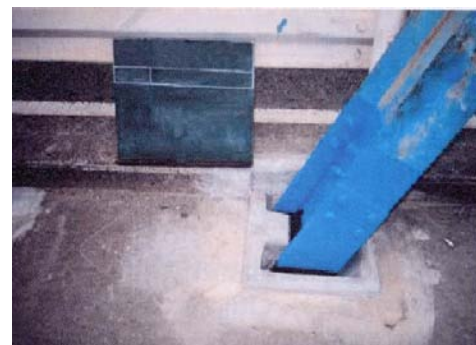


Photo 8 Brokenness of flange in a diagonal member in a truss bridge¹⁾



Photo 9 Fatigue crack at corner cut of girder end¹⁾

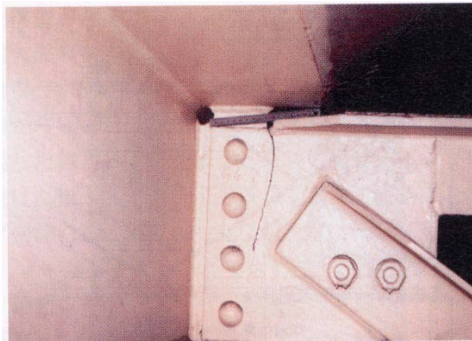


Photo 10 Fatigue crack in gusset plate¹⁾

Photo 10 shows the cracking produced in the gusset plate at the position where the cross bracing member is attached to the main I-girder. This is also due to stress concentration. In this case, as a countermeasure, cross beams were added. This is supposed to mitigate the above stress concentration.

Photo 11 shows the steel plate attachment by bolting. At the intersection of flange of beams and columns in the rigid frame steel piers, many of the cracking was detected. The steel plate attachment was a major countermeasure.

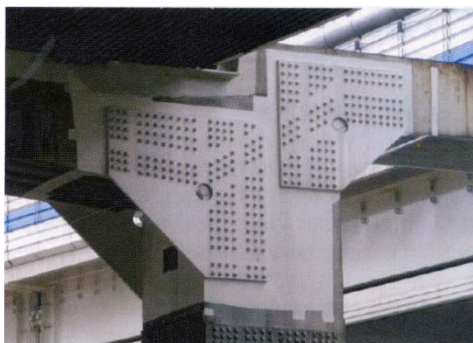


Photo 11 Fatigue crack in rigid frame type piers¹⁾

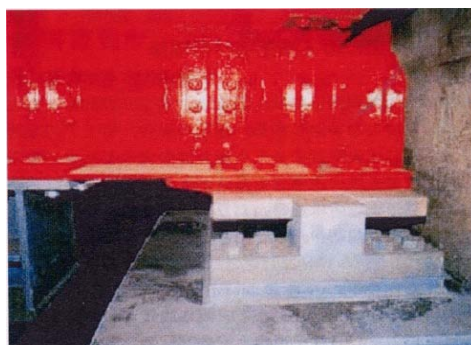


Photo 12 Replacement of shoe¹⁾



Photo 13 Replacement of concrete deck slab¹⁾

6.3 Replacement

Photo 12 shows the replacement of metal shoe, which is seriously deteriorated, to rubber shoe. Photo 13 shows the damage of concrete slab, which was observed from beneath of the deck. The corroded steel reinforcing bars is clearly seen in the photo. The number of this kind of damaged concrete slab is now increasing in Japan. The right hand side of the photo is the replacement work. The deteriorated slab is removed and new slab, pre-cast PC slab, is put in position. Since a quick erection is required, pre-cast type slab has been preferably selected.

7. Concluding Remarks

Current steel bridge maintenance situation was explained. In Japan, since the service of road network has reached advanced stage, new construction business is now decreasing. On the contrary, old bridges are increasing year by year. In 20 years or so, a half or more of bridges with a span exceeding 15 meters will be over 50 years old. However, since the lack of financial budget, sufficient maintenance work may not be expected.

After the collapse of I-35W interstate bridge in Minnesota, USA, MLITT in Japan has changed the maintenance strategy. It is from remedial repair or rebuilding to

preventive maintenance, in which cyclic inspection is carried out and the repair is also carried out if judged to be necessary. This is due to the recognition of the importance of maintenance work and also to reduce the cost for maintenance.

In this paper, relating to the bridge maintenance, inspection and the detail of the preventive maintenance strategy were introduced. In order to appropriately establish preventive maintenance strategy, it was emphasized that accurate assessment or rating of the performance of the damaged bridges and their deterioration rate were important. The estimation of budget for the maintenance strongly depends on them.

After brief introduction of SHMS, steel-concrete hybrid bridges with minimum LCC, including weathering steel, several examples of damaged steel bridges and their repair methods were presented.

References

- 1) Japanese Society of Steel Construction (JSSC) : Inspection, diagnosis and measure for civil steel structures, 2009 (in Japanese)