# A PROPOSAL FOR MAINTENANCE MANUAL OF WEATHERING STEEL BRIDGES

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## Abstract

The application of weathering steel to bridges increases in Japan in recent years. However, it is reported that some bridges have developed abnormal rust. JSSC set up the working group to improve the durability design of weathering steel bridges. The working group came up with a technical report entitled “Potentials and New Technologies of Weathering Steel Bridges”. The present paper outlines a proposal for the maintenance manual, the state-of the-art in Japan, of weathering steel bridges based on this technical report.

## Introduction

Anticorrosion is one of the key issues for steel bridges to have a long life. To prevent corrosion, usually steel bridges are painted. Painting is effective but quite costly, amounting to 5-15% of the initial construction cost of a superstructure. Besides, repainting is required every ten years or so during the working life of a bridge. Conventional steel bridges therefore may not be very competitive, especially when a life cycle cost is considered.

One way to reduce a life cycle cost is to apply weathering steel to a bridge. This steel possesses a unique property of suppressing the development of corrosion by a layer of densely-formed fine rust on its own steel surface: the corrosion rate gradually reduces to the level that causes virtually no damage from an engineering viewpoint, as the layer of the rust grows. Thus the painting is not required in the weathering steel bridge, the cost of which therefore can be much lower than that of a conventional steel bridge. This is the driving force behind the popularity of weathering steel bridges in Japan in recent years. In fiscal 2006, weathering steel bridges account for over 30 mass% of steel consumed for the construction of steel bridges. As the number of weathering steel bridges increases, however, the reports of the of abnormal-rust development in a weathering steel bridge are coming out (Yamaguchi et al. 2006).

In light of the current situation, the Working Group on Weathering Steel Bridges, under the Committee to Improve Steel Bridge Performance of the Japanese Society of Steel Construction (JSSC), was set up in 2003. The members of the group consist of a wide range of engineers including practitioners, bridge owners and academics. The Working Group studied the state of the art information on weathering steels, conducting additional research,

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so as to improve the durability design of weathering steel bridges. In 2006, at the end of its activity, the Working Group came up with a technical report entitled “Potentials and New Technologies of Weathering Steel Bridges”, which has been published by JSSC (JSSC 2006). The technical report consists of four volumes:

Volume A: Recommendations for Durability Design of Weathering Steel Bridges (Draft)
Volume B: Technologies for Durability Design of Weathering Steel Bridges
Volume C: Weathering Steel Bridge Maintenance Manual
Volume D: Collection of Data

The objective of the present paper is to outline a maintenance manual, the state-of the-art in Japan, of weathering steel bridges based on Volume C of the above JSSC technical report.

**Basics**

The ways that the corrosion loss of weathering steel plate varies are depicted in Figure 1: The curve “a” corresponds to the environment that develops the corrosion as expected, and the curve “b” is observed when environmental condition is so severe that corrosion advances faster.

It is known that the corrosion loss (the penetration curve) of weathering steel can be expressed generally in the following type of function:

$$Y = AX^{B} \qquad (1)$$

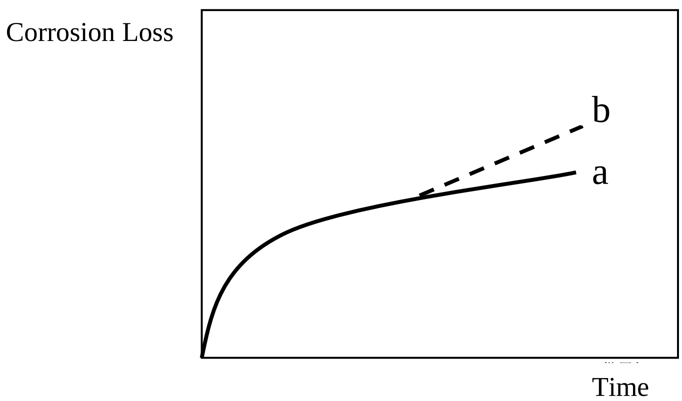


Figure 1. Schematic of Corrosion-Loss Variation with Time

where $X$ is time (year), $Y$ is the penetration (mm), $A$ is the first-year corrosion loss (mm) and $B$ is the index of corrosion loss rate diminution. As this function implies, $A$ indicates the severity of the environment while $1/B$ shows the rust-layer effect on the reduction of the corrosion rate. The two coefficients have been found related to each other (JSSC 2006).

If the two coefficients, $A$ and $B$, are given, the corrosion loss can be estimated for the entire period of design working life. For the maintenance of a weathering steel bridge, it is important to predict the variation of corrosion loss as a part of durability design and compare the actual corrosion loss with the predicted value in order to verify the performance of weathering steel during the working life of the bridge.

Two classes of corrosion–oriented inspection of a weathering steel bridge are to be performed: the initial inspection and the periodic inspection. All the bridges, regardless of the type, are subjected to general inspections periodically. For example, bridges on national highways are inspected every five years. Therefore, it is convenient and economical to conduct the corrosion–oriented inspections on those occasions of the periodic general inspections.

## Inspections

The initial inspection of a weathering steel bridge is conducted at an early stage of its working life. It is intended to detect initial defects. The standard method is a visual inspection, which should be carried out from very near the bridge. If the bridge is not approachable, tools such as a pair of binoculars must be used. Specifically, the existence of water leakage must be carefully checked.

If unexpected (abnormal) overall rust development is observed, the misjudgment of the environmental condition is doubted. The maintenance scheme will be reviewed and revised if necessary. If localized abnormal rust development is observed, there is a chance of water leakage in the neighborhood, which should be fixed immediately. If the rust layer has been formed, the cause must be identified and a measure is taken to remove it as soon as possible.

The main purpose of the periodic inspection is to estimate corrosion loss. To this end, this class of inspection is conducted after rust development is stabilized. It is therefore generally recommended that the corrosion-oriented inspection of this class is started after about ten years pass since the erection of the bridge.

The mainstay of corrosion-loss estimation is the evaluation of the external rust appearance by a visual inspection from very near. Close-up pictures of the rust should be taken for the record as well. The Scotch tape test and the rust-thickness measurement are also conducted to obtain auxiliary information for the estimation of the corrosion loss. General remarks about how to conduct these inspection items will be given in the next section.

The frequency of the corrosion-oriented periodic inspection should be determined based on the condition of the rust development. If it is in good shape, a ten-year interval can be recommended since the corrosion rate does not change much in general. Even in such a case, however, if the bridge is located in the region where a large quantity of antifreeze material is used, the inspection interval had better be made shorter, since abnormal rust could develop very fast once it is initiated under that environment.

If the estimated corrosion loss is significantly different from the predicted value, further investigation is required, which will be described in the section “Performance Verification.”

Even in periodic general inspections where no corrosion-oriented inspection is conducted, corrosion environment must be observed: even after rust development becomes stable once, the corrosion rate can pick up again if corrosion environment deteriorates. To this end, although the whole bridge is the target of the inspection, particular attention has to be paid to the points closely associated with the corrosion environment such as the breakage of drainage pipes, the clogging of ditches, the water leakage from concrete slabs/expansion joints and water/sand deposit around bearings. The condition of rust must also be studied. If rust layers are found, they must be taken care of immediately. If rust development in some portion is different from that of the other part, closer inspection is required and photos are taken for the record.

## Inspection Methods

Three inspection items are mentioned above and remarks about them are given in this section. In addition, the method for measuring plate thickness is described at the end.

Evaluation of External Appearance:

(1) The rust appearance reflects environmental condition. The color and the size of the rust yield the information on corrosion rate.

(2) The visual inspection is the mainstay for this evaluation. When the bridge is not approachable, tools such as a pair of binoculars must be used.

(3) Close-up pictures of the rust are taken for the record. A scale and a color sample are attached to the bridge and included in the pictures of the rust (Photo 1).

(4) The rust development is evaluated by the definition given in Table 1. It is noted that the definition has been prepared for those rust of over 9 years old and cannot be applied to younger rust.

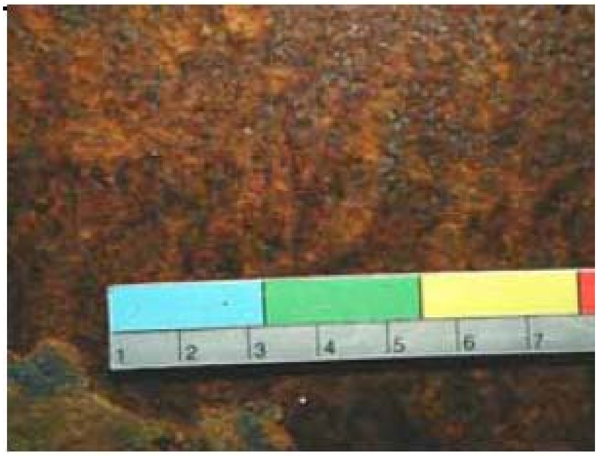


Photo 1.  Close-Up Picture with Scale and Color Sample (JSSC 2006)

Table 1. Criteria for Rust Level (The Japan Iron and Steel Federation, and the Japan Bridge Association 2003)

| Level | Description of Rust | Rust Thickness |
|---|---|---|
| 5 | few in quantity; relatively bright | less than about 200 $\mu$m |
| 4 | less 1 mm in size; fine and uniform | less than about 400 $\mu$m |
| 3 | 1-5 mm in size | less than about 400 $\mu$m |
| 2 | 5-25 mm in size | less than about 800 $\mu$m |
| 1 | formation of rust layer | more than about 800 $\mu$m |

Scotch-Tape Test:

(1) Scotch tape is pressed against weathering steel. Then the density and the size of rust in the tape are examined.

(2) The test should be conducted at the same points as those of the close-up pictures.

(3) Dust must be removed before Scotch tape is pressed. It is conducted only once at each point.

(4) Scotch tape with 50mm wide is recommended. Alternatively, the one with 24mm wide may be used. The tape is pressed against weathering steel lightly and uniformly by a rubber roller or a finger.

(5) After removal, the tape is attached to a sheet such as transparency and is kept for the record. It would be useful to take a photocopy of the sheet.

Measurement of Rust Thickness:

(1) An electromagnetic coating-thickness tester is used.

(2) Measurement by the electromagnetic coating-thickness tester is influenced by the surface roughness. The sensitivity depends on the sensor shape. It is recommended that the sensor be placed at the convex portion of the rust surface.

(3) Rust thickness is measured without cleaning rust surface, unless materials such as dust appear to influence the measurement greatly. In case of abnormal rust, the cleaning should not be done.

(4) Rust thickness is measured at 9 points in the 10 centimeters square region. The average of them is treated as the representative thickness. Alternatively, it is measured at 10 points, and the average of 8 thicknesses excluding the largest and smallest values may be assumed the representative thickness.

Measurement of Plate Thickness:

Although not mentioned in the above, plate thickness may be measured as an inspection item on a regular basis, which directly provides the corrosion loss. When abnormal rust development is found, the plate-thickness measurement may also be conducted to judge the necessity of the reinforcement at the portion of the corrosion.

(1) An ultrasonic thickness gauge with the precision down to 0.01mm is used.

(2) For a regular measurement, monitoring points are set in the 10 centimeters square region. The other plate surface of the region of interest is painted right after abrasive blast cleaning. When the thickness is measured, the coating must be removed, and it is painted again after the measurement. Since larger scatter tends to be observed as corrosion progresses, plate thickness is measured at points as many as possible in the region.

(3) To see the variation of plate thickness, the measurement interval should be around 10 years in general, while in the case of abnormal rust development the interval can be made shorter.

(4) For the thickness measurement of a badly corroded plate, the probe is placed on the plate surface with a better rust condition. The rust around the contact point must be removed until steel surface comes out. If an electric tool is used for the removal, caution must be used so as not to damage the steel surface.

(5) The number of measurements is decided considering the remaining plate thickness and

Table 2. Corrosion Loss at End of 100-Year Working Life (JSSC 2006)

| Level | Corrosion Loss |
|---|---|
| 5 | less than about 0.5mm |
| 4 | about 0.5mm |
| 3 | about 0.5mm |
| 2 | 1.0-2.0mm |

its variation. The measurements at 10 points are preferable: at least 5 measurements are needed. The average of the plate thicknesses is then computed and is treated as the representative thickness.

(6) The accuracy of the measurement is low where the steel surface is rough. Therefore, the judgment as to the necessity of the reinforcement, for example, must be made carefully.

**Performance Verification**

From the evaluation result of the external appearance, the corrosion loss at the end of the 100-year working life can be estimated, as indicated in Table 2. The rust development of Levels 3-5 is a satisfactory performance and no further actions are needed.

The rust development of Levels 1-2 may not be a satisfactory performance. If the cause for this rust development is indentified and removed successfully, no further actions are needed in the case of Level 2. Otherwise, the plate thickness is measured. The following three cases are possible:

(1) If the corrosion loss turns out to be smaller than the predicted value at this time of the working life, no further actions are needed.

(2) If the corrosion loss is bigger than the predicted value at this time of the working life, yet smaller than the predicted value at the end of the working life, no further actions are needed at this stage. However, it is recommended that the next inspection be conducted earlier and with greater care.

(3) If the corrosion loss already exceeds the expected value at the end of the working life, further investigation needs be conducted to estimate the rust condition of the bridge at the end of the working life. The investigation includes the distribution of corrosion loss over the bridge, and the safety at the end of the working life is then examined. If the safety requirement is found satisfied, no further actions are needed at this stage. However, it is recommended that the next inspection be conducted earlier and with greater care. On the other hand, if the examination concludes the violation of the safety, a measure must be taken immediately to improve the situation and ensure the safety.

## Concluding Remarks

Since corrosion environment varies from bridge to bridge and from portion to portion, so largely, and may also change as time goes by, it is inevitable and essential to conduct the corrosion-oriented maintenance of a weathering steel. To this end, the present paper provides the overview of a proposal: Weathering Steel Bridge Maintenance Manual of JSSC technical report (JSSC 2006) that takes advantage of the state-of-the-art technology for corrosion-loss prediction outlined in the previous paper (Yamaguchi 2007). In a sense, this is the state-of-the-art maintenance manual in Japan. Nevertheless, it has been recognized that the technologies for the improvement of corrosion environment and the evaluation/improvement of safety level after the occurrence of abnormal corrosion loss needs further studies. These are the subjects to be investigated in this field in due coarse.

## Acknowledgments

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