ASSESSMENT METHOD FOR ATMOSPHERIC CORROSIVENESS AND DURABILITY DESIGN OF WEATHERING STEEL BRIDGES

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Abstract

The application of weathering steel to bridges increases in Japan in recent years. A study is reviewed to give some idea about the performance of weathering steel bridges in Japan, revealing 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 basis of the durability design of weathering steel bridges and the assessment of atmospheric corrosiveness described in this report are outlined, showing that the basic framework of the durability design of weathering steel bridges has been established.

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 service 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 that that of a conventional steel bridge. This is the driving force behind the popularity of weathering steel bridges in Japan in recent years (Figure 1). In fiscal 2006, weathering steel bridges account for over 30 mass% of steel consumed for the construction of steel bridges. In a local government, some 80% of recent steel bridges are weathering steel bridges.

So far, most of the weathering steel bridges in Japan have utilized JIS-SMA weathering steel (Japan Industrial Standard G 3114 SMA), equivalent to the weathering steel commercialized by US Steel Corporation in 1930s. The construction of a JIS-SMA weathering steel highway bridge without painting is permitted under the atmospheric

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environments where less than 0.3 mm corrosion loss per side is expected for 50-year exposure (Public Work Research Institute 1993). Such environments in Japan are assumed to correspond to the value of air born salt deposition rate less than 0.05 mg-NaCl/dm^2/day (mdd) when measured by the method described in JIS Z2381 (Japan Road Association 2002). For the sake of convenience, Design Specification for Highway Bridges in Japan (Japan Road Association 2002) specifies the areas of those environments in terms of the distance from sea. To that end, Japan is divided into 5 zones: for each zone, the distance from sea is specified, beyond which an unpainted JIS-SMA weathering steel highway bridge can be constructed without the investigation of air born salt deposition rate.

These criteria are based on exposure test. In a sense, the anticorrosion performance of weathering steel in the form of test specimens has been confirmed. However, the development of abnormal rust in a weathering steel bridge is reported occasionally, and the performance of weathering steel in an in-situ bridge has not been thoroughly understood.

The advancement of steel is also noteworthy. A nickel-type weathering steel applicable to severe corrosion environments has been developed and is now available for bridges. However, the criteria for its applicability are not established yet.

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, 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

Volume A also contains the definitions of the terminologies so as to avoid miscomprehension. Volume D, a collection of extensive data, is stored in a CD.

In this paper, the situations of weathering steel bridges in Kyushu-Yamaguchi Region in Japan are briefly reviewed first. The overview of the technical report mentioned above then follows.

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

Level	Description of Rust
5	few in quantity; relatively bright
4	less 1 mm in size; fine and uniform
3	1-5 mm in size
2	5-25 mm in size
1	formation of rust layer

Weathering Steel Bridges in Japan

Several reports have documented the unexpected type of rust (abnormal rust development) in some weathering steel bridges. Herein the study which inspected one of the largest numbers of weathering steel bridges is reviewed to give some idea about the performance of weathering steel bridges in Japan (Yamaguchi et al. 2006).

This study covers 337 weathering steel bridges constructed in Kyushu-Yamaguchi Region, Japan, by member companies of the Japan Bridge Association (JBA). The general information on these bridges was provided by JBA. The field investigation was conducted during the two-year period of 2001 to 2003.

The study consists of general investigation and rust investigation. The former records the bridge type, the environment, the bridge details and so on. The latter checks the overall rust development and the local rust development in a bridge. Since a bridge is a large structure, the development of rust is not uniform in general. Especially, rust near the end of a bridge tends to differ from that in the other part. The rust investigation is therefore made up of the two kinds.

The rust development is judged by conducting the so-called Scotch-tape test, when the bridge can be approached. In this test, the Scotch tape is pressed against the weathering steel. Then the density and the size of rust are examined. The rust development is classified into 5 levels, based on the criteria presented in Table 1 (The Japan Iron and Steel Federation, and the Japan Bridge Association (2003). For the rust of Level 2, frequent observation is recommended and for the rust of Level 1, the repair needs be considered.

The main finings in this study are as follows:

a) Many weathering steel bridges have been constructed in the areas that do not satisfy the distance requirement of Design Specification for Highway Bridges in Japan (Japan Road Association 2002).
b) The number of weathering steel bridges is increasing rapidly in the region. In early

years, quite a few weathering steel bridges with supplemental rust controlling surface treatment were constructed. But in the past 15 years more than 80% of the weathering steel bridges are without the surface treatment.

c) The distance requirement was established in 1993. Even after that, the weathering steel bridges that do not satisfy the requirement have been constructed while the ratio of those bridges has reduced from 15.2% to 9%. The number of weathering steel bridges without the surface treatment increases remarkably after 1993.

d) More than 80% of weathering steel bridges without the surface treatment are located in a mountain, a forest and a farmland. 45.5% of weathering steel bridges with the surface treatment are in urban areas.

e) 1.6% of weathering steel bridges without the surface treatment have the overall rust development of Level 1 or Level 2. 28.8% of weathering steel bridges without the surface treatment have the local rust development of Level 1 or Level 2. While most of the weathering steel bridges in the region are in good shape, more than a quarter of the bridges locally developed the rust that requires attention.

f) The main cause for over 70% of the rust developments of Level 1 or Level 2 has been identified as the leakage of water. In many cases, the expansion joint is considered to be the source of the leakage of water.

The investigation suggests that while the performance of most of the weathering steel bridges in the region is satisfactory, the durability design is not practiced well. There seems to be a lack of understanding of the durability design as well. More consistent and comprehensive durability design of the weathering steel bridges needs be established.

Basis of Durability Design of Weathering Steel Bridges

Weathering steel may not perform as expected, depending on the environment to which it is exposed. Figure 1 shows possible states of rust from various viewpoints. Recognizing that, Volume A describes what needs to be done at each stage of planning, design, construction and maintenance to satisfy performance requirements for weathering steel bridges.

Volume A specifies the following two performance requirements in the durability design of weathering steel bridges:

(1) The corrosion loss during design service life must be controlled so as not to exceed the limit.

(2) Bridge piers and abutments may not be stained by rust during design service life.

As for (1), the commentary suggests three levels of durability design:

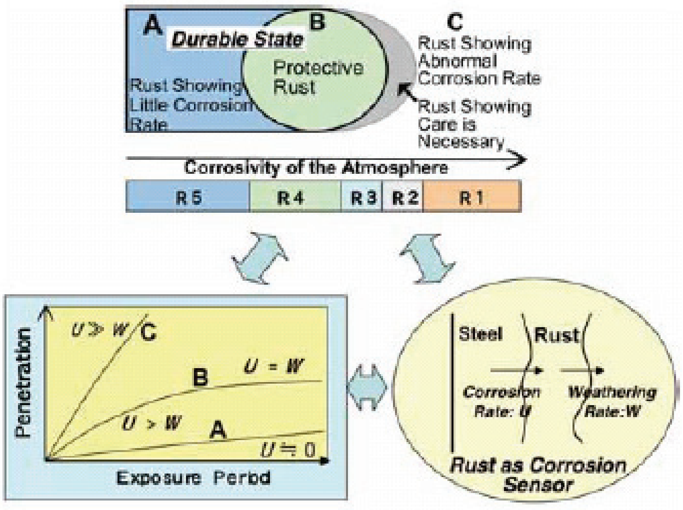

Figure 1. Possible States of Rust in Weathering Steel (Fujii et al. 2007)

Level I

Corrosion loss during design service life is kept so small that its influence on the load-carrying capacity of the bridge is negligible. To that end, in general, the loss per side should not be more than 0.5 mm for 100 years. It is expected that most of weathering steel bridges will employ the durability design of Level I.

Level II

Corrosion loss during design service life could be larger. But using thicker steel plates, the load-carrying capacity can satisfy requirements. To that end, the corrosion loss still needs be controllable: the loss per side should not exceed 1.0 mm for 100 years.

Level III

Replacement is expected. Corrosion loss may not be controllable.

These levels of the durability design can be related to the rust levels given in Table 1: Level I corresponds to Levels 3-5 while Levels II and III permit the rust level down to Levels 2 and 1, respectively.

The durability-design level must be decided first. The performance requirements are then specified, the satisfaction of which shall become the target of the durability design.

Assessment of Atmospheric Corrosiveness

As is mentioned in "Introduction", Design Specification for Highway Bridges in

Japan (Japan Road Association 2002) specifies the areas of applicable environments in terms of the distance from sea. This current practice is very convenient for the assessment of atmospheric corrosiveness. However, the weathering steel bridges outside such areas have not necessarily developed abnormal rust while some bridges inside those areas have (Yamaguchi et al. 2006). The specification in terms of distance from sea is simple and convenient, but its simplicity seems to impose limitations on its validity inevitably.

A problem of the current practice is that the specification has been solely based on the air born salt. However, it is not the only factor that influences the way rust develops. There are many other influential factors such as time of wetness and temperature. Taking those factors into consideration, a sophisticated corrosion prediction method has been proposed. Volume B gives a full detail of the method. It is in fact one of the key technologies for reliable durability design and its outline is described herein.

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

$$Y = A_{SMA} X^{B_{SMA}} \tag{1}$$

where X is time (year), Y is the penetration (mm), A_{SMA} is the first-year corrosion loss (mm) and B_{SMA} is the index of corrosion loss rate diminution. As this function implies, A_{SMA} indicates the severity of the environment while $1/B_{SMA}$ shows the rust-layer effect on the reduction of the corrosion rate.

Based on the exposure test data for JIS-SMA weathering steel in 41 bridges in Japan, A_{SMA} and B_{SMA} are obtained and plotted in Figure 2. While the relationship between the two values is scattered, which is considered mainly due to chronological changes in environmental corrosiveness, some trend is recognized. This implies that B_{SMA} can be evaluated once A_{SMA} is obtained. For the evaluation of A_{SMA}, two formulas have been proposed.

For new steels such as nickel-type weathering steels, A_{SMA} and B_{SMA} in Eq.(1) are replaced with A_S and B_S, respectively. Formulas for the evaluation of A_S/A_{SMA} and B_S/B_{SMA} have been proposed: these values depend on the weathering alloy index V, which is a function of the mass% of alloying elements.

Supplemental rust controlling surface treatments are often applied to weathering steel bridges in Japan. The basic function is to alleviate staining of neighboring objects such as bridge piers and abutments. This is a technology closely related to the second performance requirement stated in the previous section. Some of the surface treatment products are assumed to possess a corrosion control function. The usage of that function in the durability design requires the establishment of the method for corrosion loss evaluation.

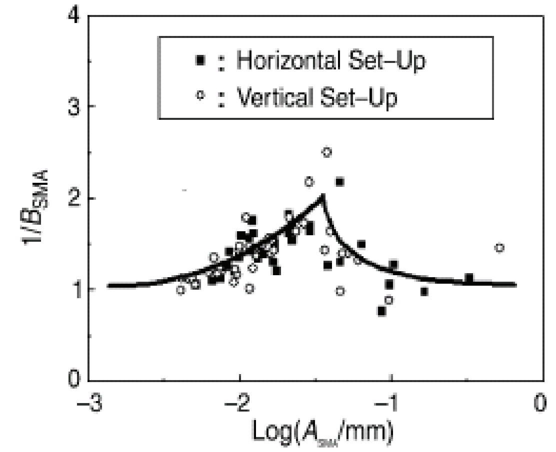

Figure 2. Relationship between A_{SMA} and B_{SMA} (Kihira et al. 2005)

In addition to the two formulas for the evaluation of A_{SMA}, an economical and simple, yet more direct means of assessing A_{SMA} has been proposed. The method has been named the “button test”.

The button test is essentially an exposure test, using button-shaped weathering steel test specimens. In this method, if a steel bridge exists in the neighborhood of the construction site of a new bridge, the exposure test will be conducted by attaching the test specimens to that existing bridge. Otherwise, the test will be done by installing an instrument screen (Figure 3). After the one-year exposure, the weight losses of the test specimens are measured to yield the site-specific value of A_{SMA}.

Using the methods described above, the corrosion loss Y for any type of weathering steel can be evaluated, once the assessment of atmospheric corrosiveness is completed and the value of A_{SMA} is obtained. An illustration is given in Figure 4. This figure readily helps select an appropriate weathering steel for the given condition of the environment corrosiveness in terms of A_{SMA} and the performance requirement in terms of Y. The selection of weathering steel concludes the durability design in relation to atmospheric corrosiveness.

Concluding Remarks

After briefly reviewing the situation of weathering steel bridges in Japan, the overview of JSSC technical report (JSSC 2006) was given in this paper. Only the basis of the durability design of weathering steel bridges and the assessment of atmospheric corrosiveness can be described in this paper, although the technical report addresses many other important issues such as the maintenance and the structural details for the protection

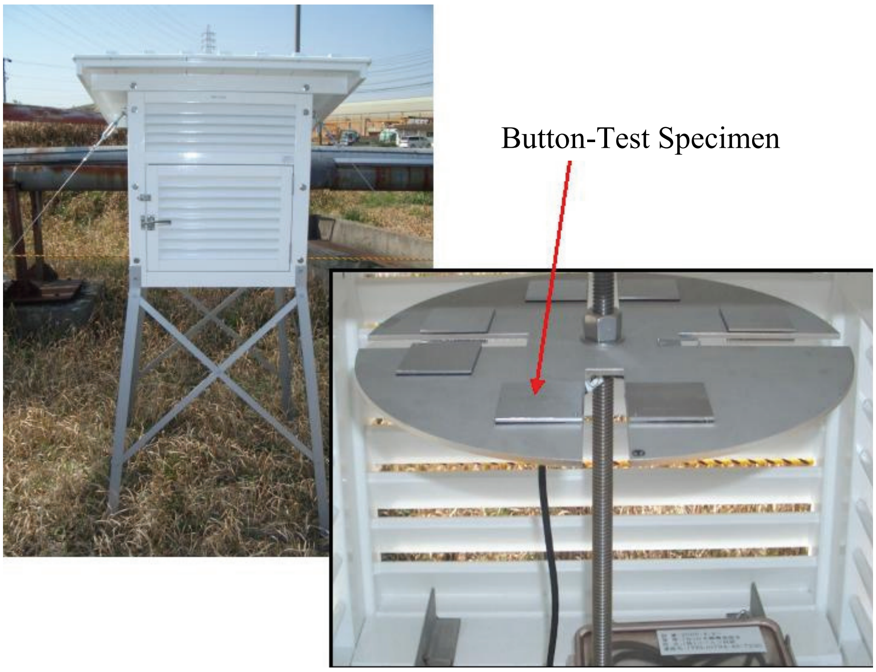

Figure 3. Button Test

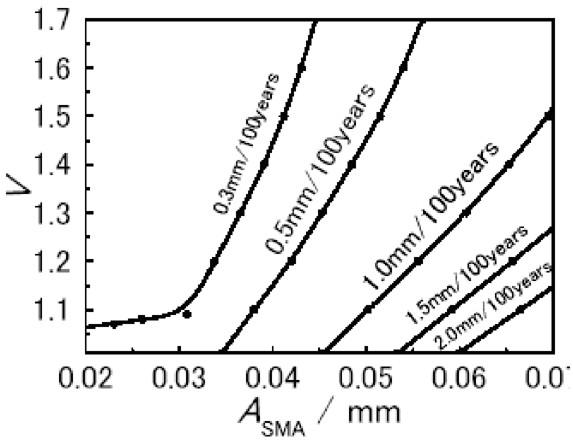

Figure 4. A Relationship between A_{SMA}, V and Y (Fujii et al. 2007)

against local corrosiveness.

As may be realized in this paper, it is believed that the basic framework of the durability design of weathering steel bridges has been established well by the JSSC

Working Group on Weathering Steel Bridges. Yet the activity in JSSC still continues, aiming at the further improvement of the reliability of weathering steel bridges and the establishment of the practical durability design procedure.

Acknowledgments

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