

# Development of Corrosion Prediction Software for Designing Weathering Steel Structures with Semi-Eternal Service Life

Hiroshi KIHIRA\*<sup>1</sup>

## Abstract

*Needs for minimum maintenance materials for infrastructure, such as weathering steel are growing. Because corrosion rate of weathering steel is much lower than plain carbon steel, it is possible to construct durable steel structures without painting, or plating, which reduces life cycle cost of the structures to a great extent. To realize this concept, it is very important to select the best alloyed weathering steel, in accordance with corrosiveness of the atmosphere at construction sites. In order to facilitate such assessing processes, long-term corrosion prediction software for weathering steel has been developed.*

## 1. Introduction

Because of its unique property of preventing rust by rust<sup>1)</sup>, weathering steel has been used for many structures including bridges. Many successful instances have been witnessed, in which maintenance and control cost has been reduced by the application of this steel with its functions utilized to the full. On the other hand, a problem was posed sometimes when it was carelessly used in the seaside areas where salt blows constantly thereto in large quantity. In recent years, in the inland areas as well, an abnormal local rust was found formed on it due to the antifreeze agents sprayed.

As represented by the minimum-maintenance bridge concept<sup>2)</sup> proposed by the Ministry of Land, Infrastructure & Transport, the future structures including bridges are required to employ weathering steel, surface treatment technology, and structural design methods that enable to use them reliably for a very long period with maintenance and control cost further reduced. It is essential for our country as a whole to realize safe and reliable LCC-minimum structures that can maintain and develop competitiveness toward the symbiosis with Asian countries as a form of the 21st-century-type infrastructure. The development of technology to make use of weathering steel that can achieve the above objective is therefore much expected.

## 2. Correct Recognition of the Behavior of Corrosion of Weathering Steel and Revision of the Specification for Highway Bridges

Weathering steel has partly been misunderstood so far in that corrosion stops completely when magic rust (so-called *antei-sabi* in Japanese) is formed on it. This misunderstanding has sometimes led to thinking that weathering steel can be used maintenance-free in any corrosive atmospheric environment because the magic rust forms on it. However, the above-described phenomenon is unlikely to occur in physico-chemical manner. Almost all the materials react with the surrounding environment, so that their initial material functions gradually deteriorate.

At a symposium<sup>3)</sup> of the Rust Chemistry Committee (Chairman: Toshihei MISAWA, professor at Muroran Institute of Technology) supporting the 21st-century infrastructure established in the Japan Society for Corrosion Engineers, and at another held by "Research Center for Urban Infrastructure, Science and Technology Research Body (Chief: Professor Chitoshi MIKI)", a project by "Tokyo Institute of Technology", a proposal was made for the basic recognition of the durability of weathering steel bridges<sup>4)</sup>.

With the arguments at those symposia correctly reflected, "Study of Durability" of Chapter 5 was added to the Specification for Highway Bridges<sup>5)</sup>, revised in March, 2002, in which it was clearly prescribed that "The influences of deterioration over time should be taken into account when designing steel bridge members."

\*1 Technical Development Bureau

### 3. Corrosion Prediction and Design of Durable Structures

When trying to realize semi-permanent, almost maintenance-free bridges with weathering steel, one should first recognize the corrosion resistance of the weathering steel correctly. Since the corrosion and deterioration of material are generally due to the chemical reaction between the material and the environment, corrosion performances of the material depends on the degree of corrosiveness of the environment. This also applies to weathering steel. With the addition of alloy elements, weathering steel is more corrosion-resistant than ordinary steel. However, its corrosion resistance depends on the environment to which it is exposed.

**Fig. 1** shows the conceptual image for the durable state of weathering steel to promote a better understanding of the above findings<sup>9)</sup>. When the environment is less corrosive, the amount of rust formed is minimal, because corrosion proceeds only slightly, and less protective rust is formed. However, no abnormal rust is formed either with little change in steel thickness. This is defined to be in a durable state. Again, when the environment is moderately corrosive, the added alloy elements work to form a protective rust, and the rate of corrosion becomes lower over time to reach durable state. In other words, the product of the chemical interaction between the weathering steel and the environment forms a rust on the surface. It therefore follows that the composition and structure of the rust differ depending on the environmental conditions.

Furthermore, when the environment becomes corrosive enough to go beyond a certain limit, protective rust fails to prevent corrosion resulting in excessive corrosion. In this state, the rate of steel corrosion is greater than expected, result in  $[\text{Rust formation rate}] > [\text{Rust weathering rate}]$ . Then, the rust becomes thicker to turn into a fish scaled one or a layered exfoliated one. With regard to the volume of corrosion accumulated over time relating to no abnormal rust occurring, the views of the Ministry of Construction, Public Works Research Institute, the Kozai Club, and Japan Association of Steel Bridge Construction are summarized in the joint research report<sup>7,8)</sup> on Application of Weathering Steel to Highway Bridges: Weathering steel stipulated by JIS G 3114 can be applied under the environmental conditions in which corrosion loss is within 0.3 mm on one side during 50 years of service<sup>9)</sup>.

As clearly given in the revised Specification for Highway Bridges<sup>5)</sup>, those environmental conditions correspond to an area where air-borne salt quantity is less than 0.05 mg/dm<sup>2</sup>/day. In compliance with the revised Specification for Highway Bridges in which a designed service life target is set for 100 years, a curve of corrosion loss accumulated over 100 years was predicted. As a result, weathering steel can be construed applicable under the environmental con-

ditions in which corrosion loss can be limited to within 0.5 mm on one side<sup>10)</sup>. On the assumption that corrosion loss is 0.5 mm on one side and 1.0 mm on both sides after 100 years, residual load capacity was calculated by way of trial. If a bridge is designed as given in the Specification for Highway Bridges, a decrease in ratio of the residual load capacity of a member is insignificant. It can therefore be considered possible to secure sufficient structural stability with safety factor taken into consideration. Therefore, it is generally considered a loss allowance in addition to the stipulation as given in the Specification for Highway Bridges unnecessary.

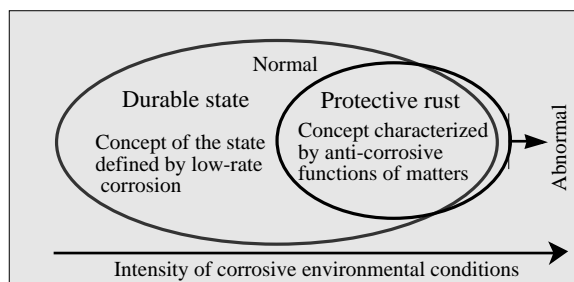
If this way of thinking is to be applied, it is desirable that not only conventional weathering steel but also recently developed 3Ni weathering steel<sup>11)</sup> be used unpainted under the conditions to realize an accumulated corrosion loss of 100 years within 0.5 mm on one side. With the intention of ascertaining the above thinking efficiently, a scheme to predict the corrosion loss of conventional and 3Ni weathering steels over a long period was developed, and integrated into a software for personal computer to simplify complicated calculations<sup>12,13)</sup>.

### 4. Material Selection Simulation with Corrosion Loss Prediction Software

The corrosive environment has so far been defined based only on the quantity of air born salt. In this developed method, however, temperature, humidity, wetting time, wind velocity, and the quantity of sulfur oxides have also been taken into consideration<sup>12,13)</sup>, so that the intensity of the regional corrosive environment could be represented more accurately. The algorithm was developed for estimating values A and B without exposure tests<sup>12,13)</sup>. Since the process of derivation is specific and complicated, another paper is under preparation<sup>9)</sup>. Material selection simulation was conducted using the software. First, the Tokyo bay area was assumed to be a construction site, and six kinds of data were input, including average temperature, average yearly humidity, an average yearly amount of rainfall, average yearly wind velocity, the quantity of air-borne salt, and the quantity of sulfur oxides. Among them, a yearly amount of rainfall is a reference-value input in the present version, because the model calculate on corrosion loss under girders of bridges.

In this simulation, the quantity of air-borne salt and the quantity of sulfur oxides were assumed to be 0.1 mdd and 0.14 mdd respectively, by referring to the example of the exposure data of the Ebigawa Bridge among those of 41 bridges throughout the country. **Figs. 2** and **3** give the graphs of the calculated results. A probability value, in which abnormal rust does not occur, is shown in the lower right corner of the drawing obtained. From the drawing, abnormal rust can be evaluated to occur at a probability of 73% in case of the conventional JIS-SMA weathering steel, while a probability of the occurrence of abnormal rust can be judged minimal in the case of 3-Ni weathering steel.

The corrosion prediction software for weathering steel developed as above will enable not only to judge the applicability of weathering steels, but also to consider the detailed measures to reduce risks, at the time of designing. In this way, the developed software can be utilized effectively in various ways, for example, formulating a maintenance and control plan, extracting important points in terms of corrosion protection, to which attention should be paid.



**Fig. 1** Drawing of conceptual image of durable state of weathering steel

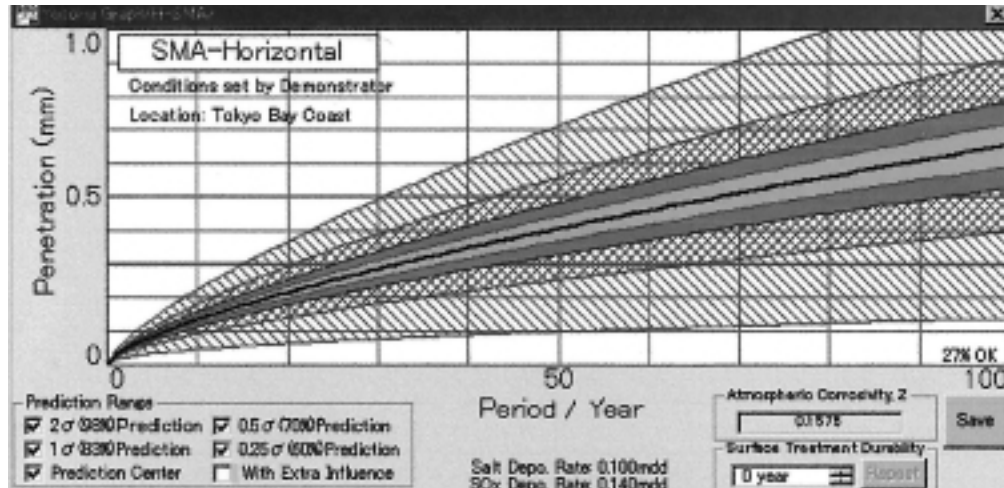


Fig. 2 Results of corrosion loss prediction using bare JIS-SMA weathering steel under the conditions of horizontal exposure in the model environment of Tokyo Bay Coast

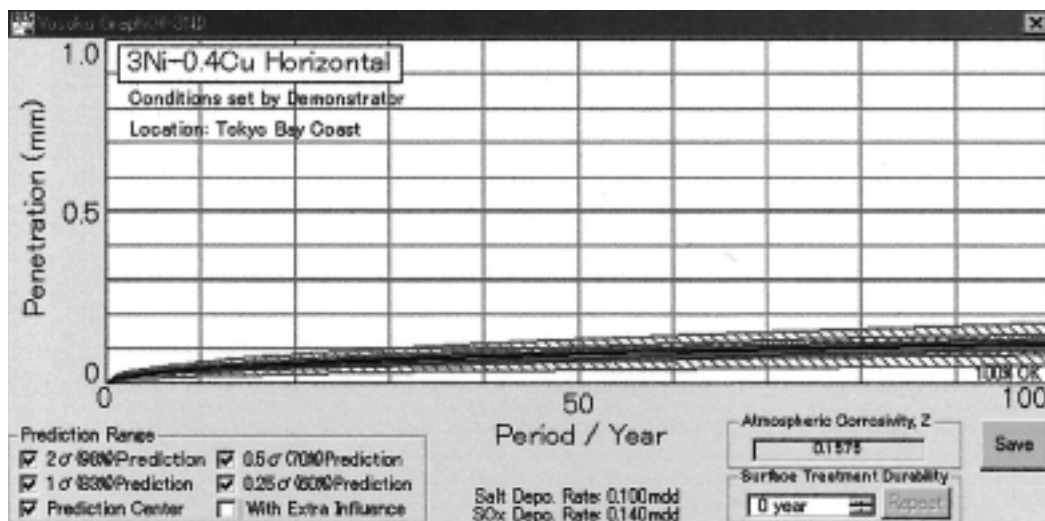


Fig. 3 Results of corrosion loss prediction using bare 3-Ni weathering steel under the conditions of horizontal exposure in the model environment of Tokyo Bay Coast

References

- 1) Okada, H., Hosoi, Y., Naito, H.: Tetsu-to-Hagané. 56, 277 (1970)
- 2) Ministry of Construction, Public Works Research Institute, Bridge Division, Structure and Bridge Department: Minimum Maintenance Bridges, Steel Bridge Chapter
- 3) Ohtsuka, T., Misawa, S.: Reference Materials for the 132nd Corrosion Engineering Symposium. Japan Society of Corrosion Engineering, 2001-06-25
- 4) Ichikawa, T.: Technical Papers Presented at the Symposium for Application of Weathering Steel to Bridges. 2001-04, Research Center for Urban Infrastructure/Science and Technology Research Body, Steel Bridge Design Engineering/Civil Engineering, Tokyo Institute of Technology Department
- 5) Japan Road Association: Specification for Highway Bridges and the Handbook. 2002-03
- 6) Kihira, H.: Reference Materials for the 132nd Corrosion Engineering Symposium. 2001-06-25, p.27
- 7) Ministry of Construction, Public Works Research Institute, the Kozai Club, Japan Association of Steel Bridge Construction: Report on Application of Weathering Steel to Highway Bridges (XX). No. 88. 1993-03
- 8) Ministry of Construction, Public Works Research Institute, the Kozai Club, Japan Association of Steel Bridge Construction: Report on Application of Weathering Steel to Highway Bridges (XV). No. 71. 1992-03
- 9) Kihira, H. et al.: Preparing for Technical Report, Japan Society of Civil Engineers
- 10) The Kozai Club, Japan Association of Steel Bridge Construction: Report on Application of Weathering Steel to Highway Bridges. 2000-08
- 11) Kihira, H., Ito, S., Mizoguchi, S., Murata, T., Usami, A., Tanabe, K.: Zairyo-to-Kankyo. 49, 30-40 (2000)
- 12) Kihira, H.: 17th US-Japan Bridge Engineering Workshop, Tsukuba Japan, 2001-11, Public Works Research Institute, p.337-350
- 13) Kihira, H.: Proc. First International Conference on Advanced Structural Steels (ICASS2002). Tsukuba, May 22-24, 2002, p.291