Study on Rating the Deterioration of Weathering Steel Bridges

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Abstract

Applying rust stabilization process to weathering steel encourage the steel to form a tight, stable protective iron oxide film on the surface, which retards corrosion. Once such a film forms, no coating is needed for many years, thereby reducing maintenance costs. However, on some bridges with such steel, this film has failed to form and the base metal has become corroded; as a result, the specification has been changed to painting. There are also cases where serious corrosion has required a bridge to be reconstructed. It is necessary to fully understand corrosion conditions through inspections and investigations and to conduct proper maintenance such as by removing and minimizing the causes of corrosion.

In 2003, the authors proposed criteria for rating the deterioration of weathering steel bridges.[Sato, T. et al.,] Designed to be specific to the harsh natural environment of Hokkaido, the criteria were based on a detailed corrosion survey conducted in 2003 of weathering steel bridges along a section of National Highway 36 called Muroran Shindo. A follow-up survey of the same bridges was conducted in 2010 to rate the validity of the criteria, and the results are reported below.

Introduction

Muroran is a city in Hokkaido, the northernmost island of Japan, and the natural conditions here in winter are particularly harsh (Fig-1). Muroran Shindo extends for 8.3 km and is used as a bypass to relieve traffic congestion in the city. Construction began in 1970 and was completed in 1980.

The highway section includes eight bridges of weathering steel. They were built using a total of about 7,800 tons of corrosion-resistant steel (Table 1). The bridges (Fig-2) are 0.5 to 3 km from the shoreline and are affected by windborne sea salt. In addition, the formation of stable rust is considered to be affected by smoke from the factories in this

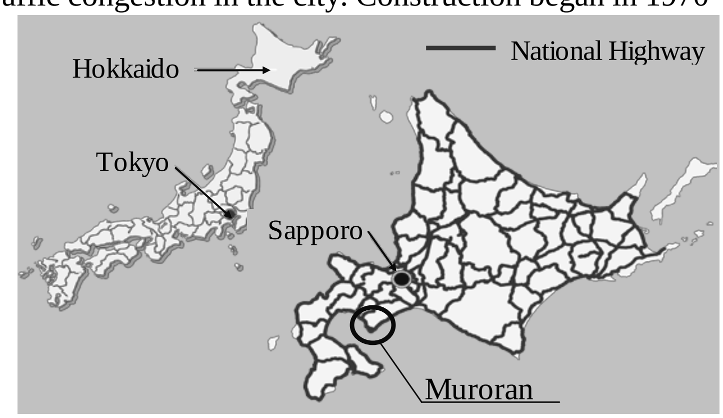

Fig-1 Study location

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area, the largest industrial district in Hokkaido. The rust stabilization process was applied to cause the formation of a tight, stable, protective rust layer, in order to reduce maintenance costs and to prevent rust-containing water from splashing off the steel. Table 2 outlines the process of applying the rust stabilization process rust-stabilizing system.

Table-1 Overview of weathering steel

Bridge Name	Span #	Type of Bridge	Span Length	Completion
Bokoi OB(1)	2	Open Girder	22.0+28.0	1977
Bokoi OB(2)	2	Open Girder	2×35.0	1977
Bokoi OB(3)	3	Box Girder	40.0+50.0+40.0	1977
Bokoi OB(4)	2	Open Girder	28.0+22.0	1977

Bridge Name	Span #	Type of Bridge	Span Length	Completion
Nakamachi OB(1)	3	Open Girder	3×25.0	1976
Nakamachi OB(2)	3	Open Girder	3×25.0	1976
Nakamachi OB(3)	3	Open Girder	3×25.0	1976
Nakamachi OB(4)	3	Open Girder	3×25.0	1976
Nakamachi OB(5)	3	Open Girder	3×25.0	1976
Nakamachi OB(6)	3	Open Girder	3×25.0	1976
Nakamachi OB(7)	3	Open Girder	3×23.2	1976
Nakamachi OB(8)	3	Open Girder	3×25.0	1976
Nakamachi OB(9)	3	Open Girder	3×25.0	1976
Nakamachi OB(10)	3	Open Girder	3×25.0	1976
Nakamachi OB(11)	3	Open Girder	3×25.0	1976

Bridge Name	Span #	Type of Bridge	Span Length	Completion
Wanishi OB(1)	2	Box Girder	2×52.0	1977
Wanishi OB(2)	2	Box Girder	2×52.0	1977
Wanishi OB(3)	3	Open Girder	30.5+39.5+30.5	1977

Bridge Name	Span #	Type of Bridge	Span Length	Completion
Hinode OB	2	Box Girder	22.4+31.2	1975

Bridge Name	Span #	Type of Bridge	Span Length	Completion
Misaki OB(1)	2	Open Girder	2×35.0	1976
Misaki OB(2)	2	Open Girder	2×35.0	1976
Misaki Ramp(1)	2	Open Girder	33.0+23.0	1973
Misaki Ramp(2)	2	Open Girder	2×23.12	1973
Misaki Ramp(3)	3	Open Girder	3×23.12	1973
Misaki Ramp(4)	3	Open Girder	3×23.12	1973
Misaki Ramp(5)	2	Open Girder	2×23.12	1973
Misaki Ramp(6)	2	Open Girder	2×23.12	1973
Misaki Ramp(7)	3	Open Girder	3×23.12	1973
Misaki Ramp(8)	3	Open Girder	3×23.12	1973
Misaki Ramp(9)	2	Open Girder	2×23.12	1973

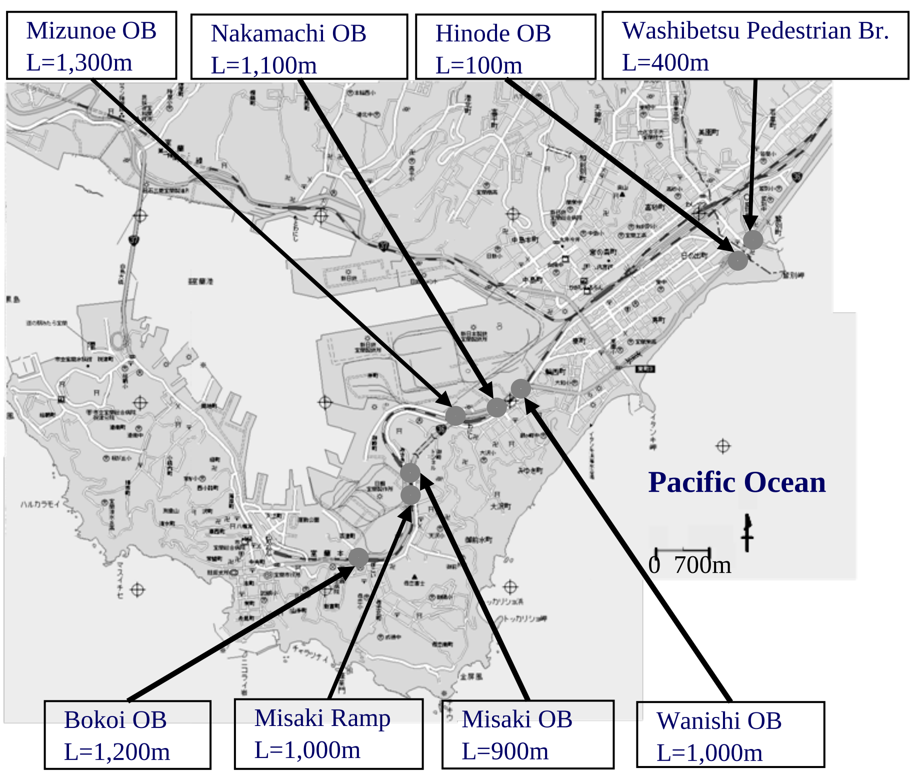


Fig-2 Sites of corrosion-resistant steel bridges

Table-2 Procedure of rust stabilization process

Step	Procedure
1	Shot-blast the surface clean.
2	Apply a rust stabilization process to form a protective film.
3	Wash it with water.
4	Leave it to dry.
5	Apply Prepalen as the surface treatment to a thickness of 10-20 μ.
6	Allow for at least 12 hours of drying.

The Criteria Proposed for Rating the Deterioration

A regular inspection is conducted every five years by means of close visual survey of the bridges. To provide a measure for rating the deterioration conditions by visual survey, the authors proposed rating criteria (Table 3) based on the results of a visual survey, a survey on the protective film thickness and core analysis of the bridges on Muroran Shindo. The external appearance of the bridges is rated on a scale of A to E (Figure 3). On bridges rated A and B, the protective film on the bridge surface has not deteriorated and the corrosion of steel is minimal. On bridges rated C, the protective film has deteriorated to form a fully effective, dense, tight protective rust layer on the steel surface, which retards the formation of rough, red rust. On bridges rated D and E, the iron oxide layer that has formed on the steel surface is not tight enough to act as a protective film; thus, the amount of red rust on the steel is expected to increase. Before setting the criteria for the deterioration ratings described in Table 4, the external appearance and the protective film thickness of the bridges were correlated in the provisional rating criteria shown in Table 3. Then, the results of visual survey, protective film thickness measurement and core analysis, all at 27 observation points, were used for finalizing the criteria (Table 4).

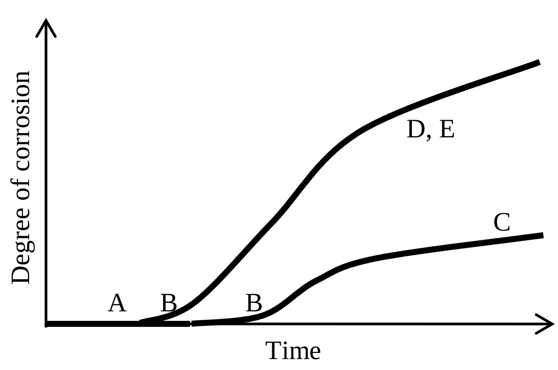


Fig-3 Expected ratings over time with rust stabilization process

Table-3 Provisional rating criteria

Appearance of coat / rust		Percentage of rusted surface (%)	External appearance	Rust layer thickness (μ)				
			Rust layer thickness (?) Status of coat / rust	5	4	3	2	1
				< 200	< 300	< 400	400 ～ 800	> 800
A		< 0.3	Free of rust	A5	A4	A3	A2	A1
B		< 0.3	Spotted with rust	B5	B4	B3	B2	B1
C	C1	< 3	Spotted with rust areas whose average external diameter is approx. 5 mm	C1-5	C1-4	C1-3		
	C2	< 30		C2-5	C2-4	C2-3		
	C3	30 or more		C3-5	C3-4	C3-3		
D	D1	< 3	Scaly rust with external diameter of approx. 5 – 25 mm				D1-	D1-
	D2	< 30					D2-	D2-
	D3	30 or more	Tubercles (small)				D3-	D3-
E	E1	< 3	Rust with laminar detachment				E1-2	E1-
	E2	< 30	Tubercles (large)				E2-2	E2-
	E3	30 or more					E3-2	E3-

A, B, C: The conditions pose no problems.
D, E: The rust layer is not expected to act as a protective film for the weathering steel. Only the pattern and the thickness of red rust on the steel surface are used for rating, irrespective of the remaining of the protective film.

Table-4 Criteria for deterioration rating

Appearance of coat / rust		Deterioration rating	Percentage of rusted surface	Remarks
Normal	Free of rust	A	＜0.3	-"Free of rust" means that the coated steel is in a good environment. -The steel surface is protected by the coat.
	Spotted with rust	B		-In the initial stage of rust formation, rust begins to form under the coat while spots of rust are found on the surface. -Assuming that the environment stays as it is, the condition will progress to B and C.
	Spotted with rust areas whose average external diameter is approx. 5 mm	C1	＜3	The coat has largely turned into protective rust. Assuming that the environment stays as it is, the condition will stay at C.
		C2	＜30	
		C3	＞30	
Needs monitoring	Scaly rust with external diameter of approx. 5 – 25 mm	D1	＜3	-Locate and eliminate the cause (water leakage, salt
		D2	＜30	The rust needs periodic monitoring for possible advance to E.
	Tubercles (small)	D3	＞30	
Needs review / action	Rust with laminar detachment	E1	＜3	-Locate and eliminate the cause.
	Tubercles (large)	E2	＜30	-Draft and review repair methods for possible implementation
		E3	＞30	

Outline of the Follow-up Survey and Review of the Criteria for Deterioration Rating

(1) Outline of the Follow-up Survey

The bridges used for determining the criteria for deterioration rating in 2003 were surveyed and rated again in 2010 in order to assess the validity of the criteria. External appearance and protective film thickness of the bridges were surveyed for this purpose.

(2) Results of the Follow-up Survey

1) Hinode Overbridge

Hinode Overbridge is a two-span continuous, double-box-girder bridge whose span lengths are 22.4 m and 31.2 m. When the bridge was completed, survey points were established on the web plates of the main girders of the abutments, shown as A1 and A2 respectively in figures 4 and 5. Their external appearance was rated C in 2010 and 2003. Film thickness over time for the Hinode Overbridge is shown in Figure 4. At both A1 and A2, the film increased in thickness with time. It increased to 234 μm from 158 μm at A1 and to 301 μm from 268 μm at A2 between 2003 and 2010. It is presumed that because the bridge is close to a frontage road and there is little clearance under the girder, various substances containing anti-freezing agents, which hinder the formation of stable rust, have been splashed up by travelling vehicles and have adhered to the bridge. The volume of chemicals applied to prevent ice formation on the road surface has been increasing since the 1980s. The ratings by external appearance of C in 2003 and 2010 are appropriate because no residual protective film was observed (Figure 5) and the films were 300 μm thick. Considering that the film thicknesses increased and are expected to keep increasing as long as the bridge continues to be exposed to the various substances that hinder the formation of stable rust, it is necessary to monitor the bridge over time.

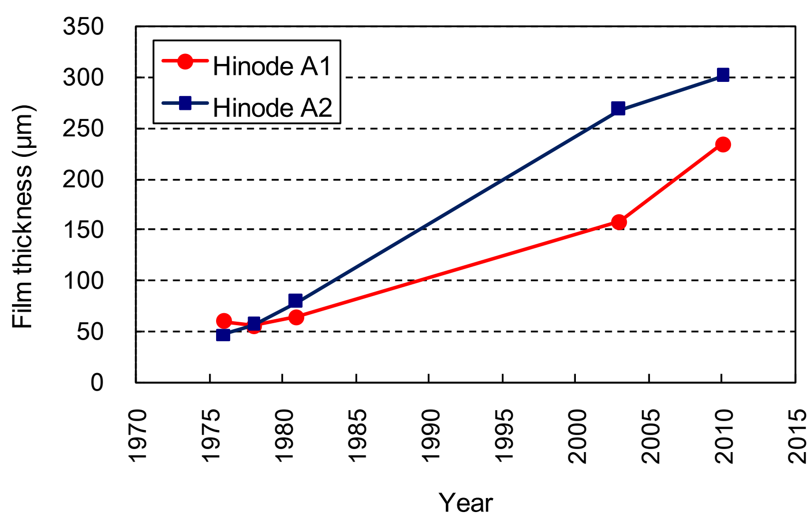
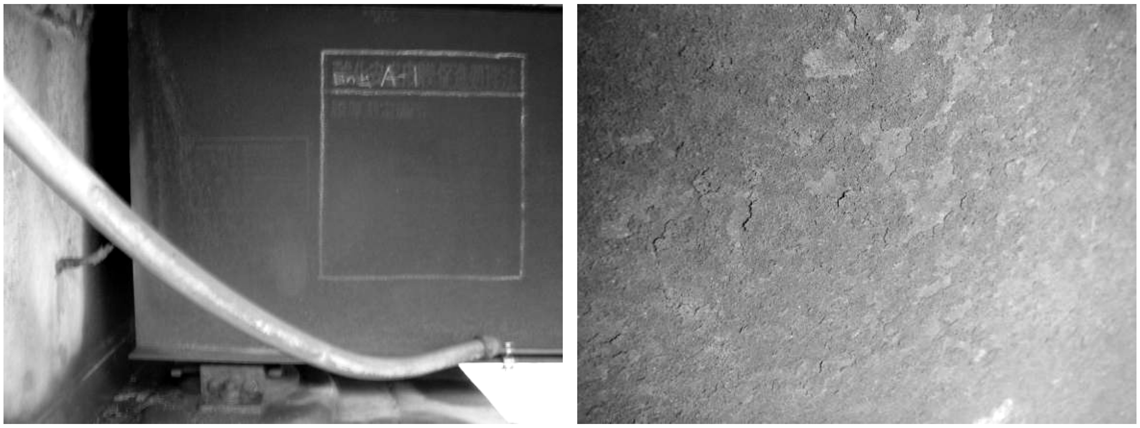


Fig-4 Film thickness over time (Hinode)



(a) Hinode A1 2003 (b) Hinode A1 2010

Fig- 5 The surface condition of Hinode Overbridge

2) Wanishi Overbridge

Figure 6 shows the changes in the film thickness over time for Wanishi Overbridge. Since 1978, the film has become thicker only gradually. As compared to the 136 μm measured in 2003, the film thickness surveyed in 2010 evidenced a slight increase to 164 μm. As shown in Figure 7, the external appearance did not change greatly in the same period. Residual protective film was observed and a stable iron oxide film is unlikely to have formed. The external appearance was rated B. Judging from the external appearance and the film thickness at present, the bridge remains at B. The rating of the bridge is likely to shift to C as a stable iron oxide protective film gradually forms. However, because the protective film is not thick enough, it is also possible that the bridge will be down-rated to D or E in the future, due to the effects of snow-melting agents.

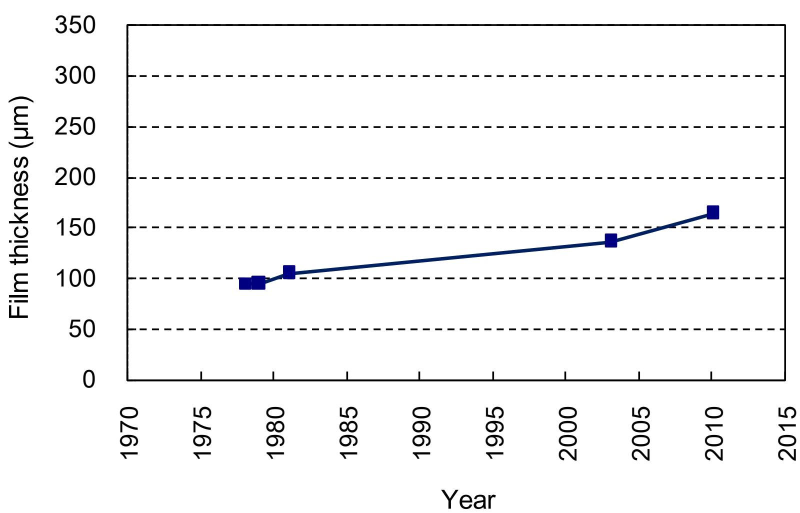
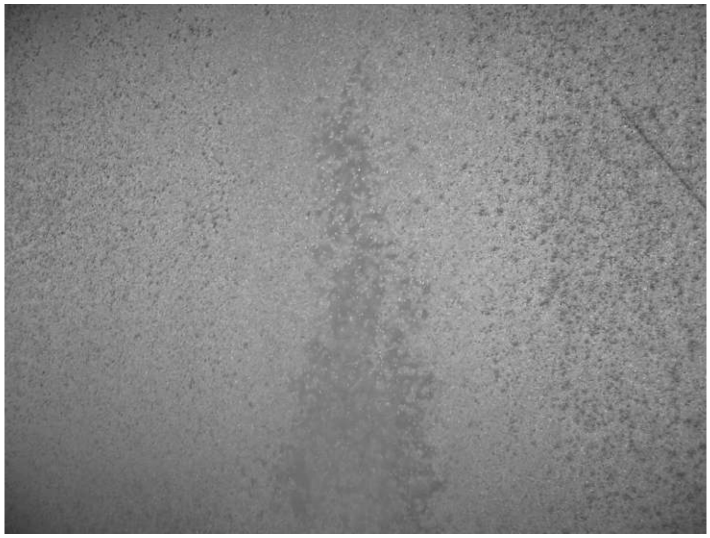


Fig-6 Film thickness over time (Wanishi)



(a) Wanishi 2003

(b) Wanishi 2010

Fig-7 The surface condition of Wanishi Overbridge

<u>3) Misaki and Bokoi Overbridges</u>

In the 2003 survey, Misaki Overbridge was rated B and its film thickness was 95 μm. In the 2010 survey, it was found that the bridge had undergone little change in external appearance and that the film thickness had increased to 115 μm. Because the film has not formed to a sufficient thickness, the bridge is not in a stable condition and needs to be monitored. As with Wanishi Overbridge, this bridge seems to be in the process of a gradual shift to C (Figure 8) .

The observation point of Bokoi Overbridges has changed because of partial corrosion of the girder end where the observation point was set. The speciation of that part has changed from weathering steel to painting. Although this makes difficult to apply the same rating criteria as were applied to the above-mentioned overbridges, this bridge was rated C (stable) in the 2003 survey, and the condition of the bridge around its observation point was also rated C in the 2010 survey (Figure 9) .

Fig-8 Surface condition at Misaki viaduct

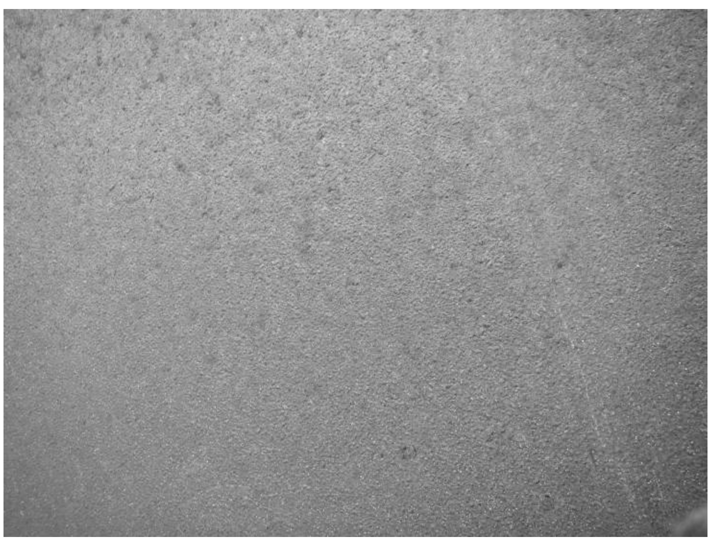


Fig-9 Surface condition at Bokoi viaduct

Summary

(1) The criteria for deterioration rating proposed in 2003 were used in 2010 for re-rating the conditions at the predetermined observation points on the same bridges as those rated in 2003. It was confirmed that the external appearance of these bridges had not changed, being rated the same in 2003 and 2010. This underlines the necessity for continued monitoring of the bridges to determine whether each bridge that has developed

a stable protective film will remain in the C-rated condition and to observe how the bridges rated B, i.e., having a smooth surface and a relatively thin film, will undergo shifts to C or D.

(2) The protective film formed at the predetermined observation points tends to be relatively thin. A stable protective film has not satisfactorily formed even though more than 30 years have passed since the construction of the bridges. The environment to which the bridges are exposed is considered to be relatively mild, because residual protective film is found even at the observation points that are close to the shore and subject to damage by windborne sea salt.

(3) At some points on the bridges, partial corrosion has been expanding due to water leakage from expansion joints or water seepage from floor slabs. Figure 10 shows affected girder ends observed in the 2004 and 2009 inspections at Wanishi Overbridge. The damage was minor in 2004, but partial sectional loss and layer-by-layer rust exfoliation were observed in 2009. The damage has worsened to the point of requiring remedial measures. To ensure the safety of weathering steel bridges, it is critical to precisely understand the changes in the surface conditions at the observation points that are chosen to determine the general condition of each bridge. Monitoring and maintenance toward eliminating the causes of corrosion are particularly important at girder ends that are vulnerable to corrosion.

(a) 2004 (b) 2009

Fig-10 Corrosion due to water leakage at girder ends (Wanishi Overbridge)

References

Sato, T., Ishikawa, H., Nishi, H. and Watanabe, K. " Study on Evaluation of Deterioration of Atmospheric-Corrosion-Resistant Steel Bridges " 20th, US-JAPAN Bridge Engineering Workshop, Oct 2004.