Study on Evaluation of Deterioration of Atmospheric-Corrosion-Resistant Steel Bridges

Takashi Satoh[1)], Hiroyuki Ishikawa[1)], Hiroaki Nishi[1)], Kazunori Watanabe[1)]

Civil Engineering Research Institute of Hokkaido[1)]

Abstract

Atmospheric corrosion-resistant steel is unique in forming a tight and stable rust layer on its surface, which acts as a protective film that retards the corrosion of steel. Once stable rust forms, no coating is needed for many years, thereby reducing maintenance costs. However, on some bridges with such steel, stable rust fails to form and the base metal becomes 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 or investigations and to conduct proper maintenance such as by removing and minimizing the causes of corrosion.

Hokkaido Development Bureau is developing a technique for evaluating the deterioration of bridges built with atmospheric-corrosion-resistant steel. The evaluation method is suited to the severe natural environment of Hokkaido. In 2003, this development program started with corrosion investigations on an atmospheric-corrosion-resistant bridge on Muroran Shindo (National Highway 36). This paper introduces a deterioration evaluation method that was developed based on the investigation results.

1. Introduction

Muroran Shindo in Muroran City (Figure 1) is a section of National Highway 36. The section extends for 8.3 km and is used as a bypass to relieve traffic congestion in the city. Its construction began in 1970 and was completed in 1980.

The highway runs over 8 bridges, which were built using about 7,800 tons of atmospheric corrosion-resistant steel (Table 1). The bridges are 0.5 to 3 km from the shoreline and are affected by windborne sea salt. In addition, the formation of stable rust is hindered by smoke from the factories found in this area, the largest industrial district in Hokkaido. The Weather Coat rust-stabilizing system was adopted for bridges to promote the formation of stable rust at an early stage toward reducing maintenance costs and preventing water that splashes on the bridge from picking up rust.

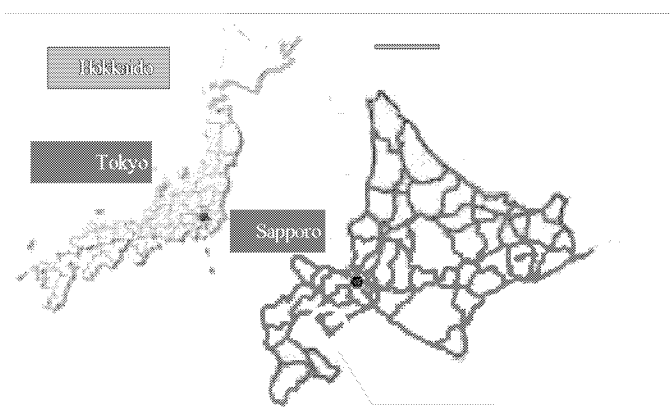


Figure 1. Location of the route

Table 1. Surveyed overpasses

Overpass	# of span	Bridge type	Span length (m)	Completion
Bokoi Overpass (1)	2	Open Girder	22.0+28.0	1977
Bokoi Overpass (2)	2	Open Girder	2×35.0	1977
Bokoi Overpass (3)	3	Box Girder	40.0+50.0+40.0	1977
Bokoi Overpass (4)	2	Open Girder	28.0+22.0	1977

Overpass	# of span	Bridge type	Span length (m)	Completion
Nakamachi Overpass (1)	3	Open Girder	3×25.0	1976
Nakamachi Overpass (2)	3	Open Girder	3×25.0	1976
Nakamachi Overpass (3)	3	Open Girder	3×25.0	1976
Nakamachi Overpass (4)	3	Open Girder	3×25.0	1976
Nakamachi Overpass (5)	3	Open Girder	3×25.0	1976
Nakamachi Overpass (6)	3	Open Girder	3×25.0	1976
Nakamachi Overpass (7)	3	Open Girder	3×23.2	1976
Nakamachi Overpass (8)	3	Open Girder	3×25.0	1976
Nakamachi Overpass (9)	3	Open Girder	3×25.0	1976
Nakamachi Overpass (10)	3	Open Girder	3×25.0	1976
Nakamachi Overpass (11)	3	Open Girder	3×25.0	1976

Overpass	# of span	Bridge type	Span length (m)	Completion
Wanishi Overpass (1)	2	Box Girder	2×52.0	1977
Wanishi Overpass (2)	2	Box Girder	2×52.0	1977
Wanishi Overpass (3)	3	Open Girder	30.5+39.5+30.5	1977

Overpass	# of span	Bridge type	Span length (m)	Completion
Hinode Overpass	2	Box Girder	22.4+31.2	1975

Overpass	# of span	Bridge type	Span length (m)	Completion
Misaki Overpass (1)	2	Open Girder	2×35.0	1976
Misaki Overpass (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

Table 2. The Weather Coat rust-stabilizing system

Step 1	Clean surface	Shot blasting
Step 2	Weather-resistance coat	Weather Coat 1000
Step 3	Washi	With water
Step 4	Dry	Natural
Step 5	Treat	Prepalen: 10 - 20 μ
Step 6	Dry	Over 12 hours

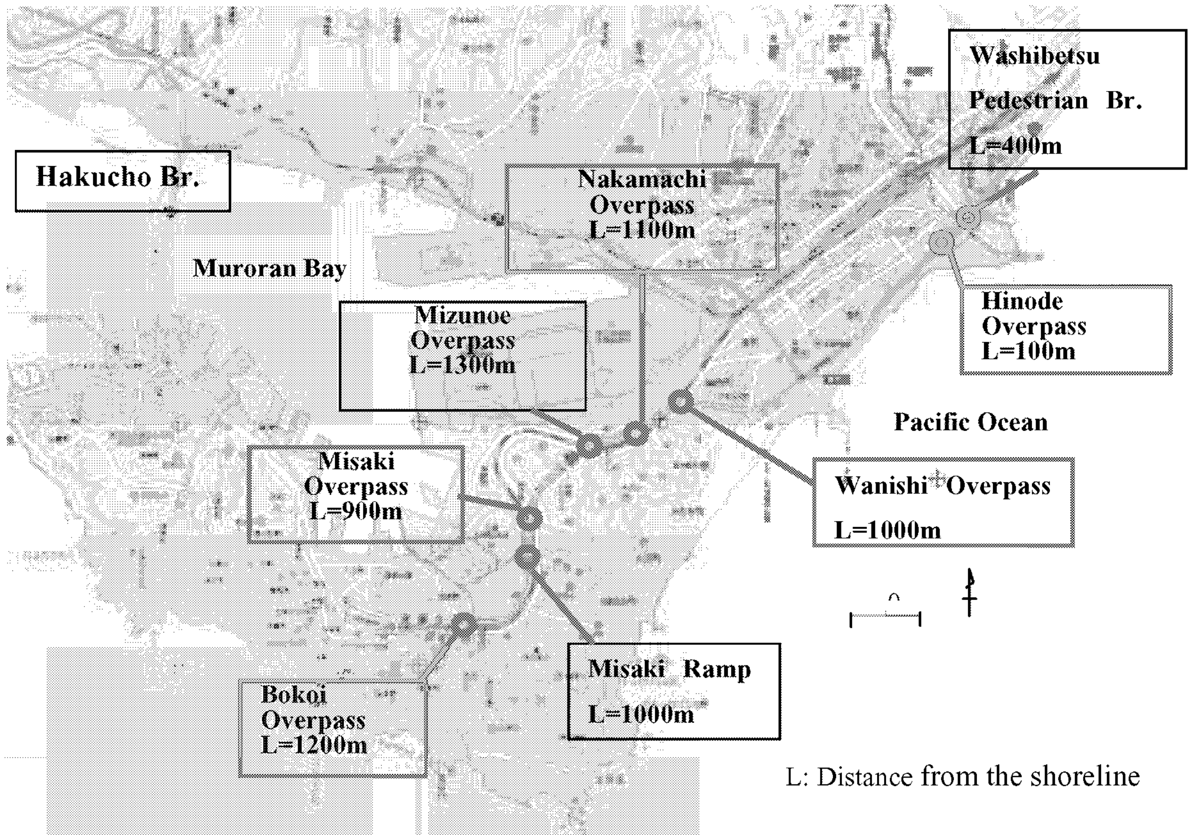


Figure 2. Locations of corrosion-resistant steel bridges on the Muroran Shindo

2. Outline of investigation

2.1 Purpose

Today, the condition of surface-treated atmospheric-corrosion-resistant steel is evaluated largely by measuring the thickness of the protective coat. However, bridge inspections are normally performed only visually. To evaluate the deterioration of atmospheric-corrosion-resistant steel on bridges without measuring the protective coat, it will be necessary to establish appropriate indexes of visual appearance. Our investigation attempted to establish standards for visually evaluating the soundness of atmospheric-corrosion-resistant steel by observing the external appearance, measuring the protective coat thickness, and analyzing sampled cores, and then comparing the results of visual analysis to those of measuring observations.

2.2 Flow of study

Figure 3 shows the flow of our analysis in which parts of bridges were visually inspected and their cross sections were observed for rust.

Inspected parts of the bridges included main girder webs and flanges with relatively bad surface condition, taken from the Hinode Overpass, Wanishi Overpass, Nakamachi Overpass, Misaki Overpass and Bokoi Overpass. Inspected crossbeam webs were those of the Hinode Overpass. The types and numbers of the samples are summarized in Table 3.

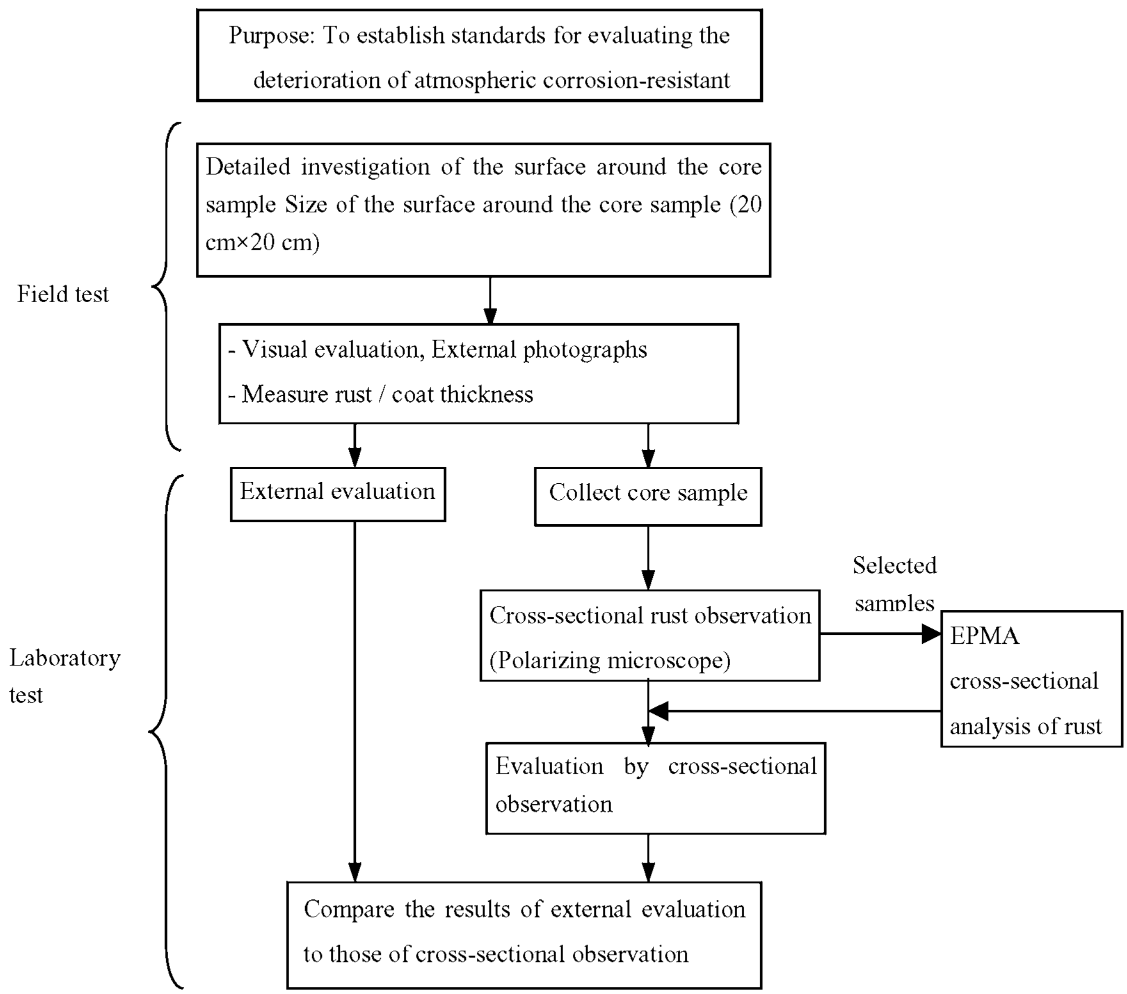


Figure 3. Flow of study

Table 3. Number of sample

Bridge	Web	Flange	Cross beam	Total
Hinode Overpass	4	3	2	9
Bokoi Overpass	4	2	—	6
Misaki Overpass	4	4	—	8
Nakamachi Overpass	2	2	—	4
Total	14	11	2	27

2.3 Method of investigation

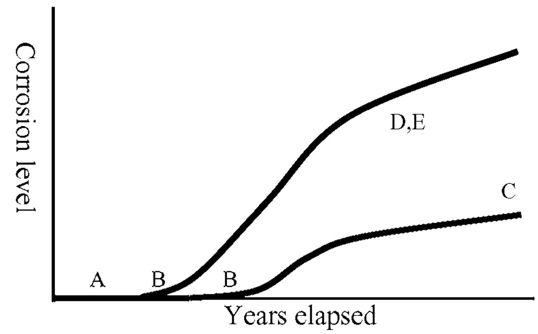


Figure 4. Expected progress of corrosion of surface-treated atmospheric-corrosion-resistant steel

1) Visual evaluation

Standards were drafted for visual evaluation of atmospheric corrosion-resistant steel deterioration (Table 4). These were used in our investigation. Figure 4 shows the relationship between corrosion of atmospheric-corrosion-resistant steel and time. The upper line represents a bridge in a corrosion-prone environment, and the lower line represents a bridge located in a corrosion-free environment. In Figure 4, the relevant deterioration ratings are described as follows: A = The coat remains largely intact and there is no rusting of steel; B = The coat remains largely intact, and there is a minimum of steel rusting; C = The coat has deteriorated as designed, while a dense layer of rust has formed over the steel, apparently preventing the steel from rusting further; D and E = A layer of rust has formed but it is not dense enough to protect the steel, and therefore the rusting is expected to progress.

Using the standards, the 27 samples listed in Table 3 were visually evaluated.

Table 4. Standards for visual evaluation of atmospheric-corrosion-resistant steel deterioration (draft)

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 damage, etc.).
		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	

2) Measurement of rust/coat layer thickness

Around each core, a frame measuring 200 mm by 200 mm was set up (Figure 5). The frame was then divided into 25 sub-frames. On each sub-frame, measurements of rust/coat layer thickness were taken at five points and the average of the measurements was used to represent the sub-frame.

Previous studies indicate that rust layers with a thickness of approx. 400 μ or less are protective and those with a thickness of approx. 400 μ or more need monitoring or are prone to abnormality. Our survey adopted 400 μ thickness of corrosion as the threshold between good condition and poor condition. Table 5 shows rating of deterioration of atmospheric corrosion resistant steel based on the standards for visual evaluation (Table 4) and the thickness of rust/coat layer.

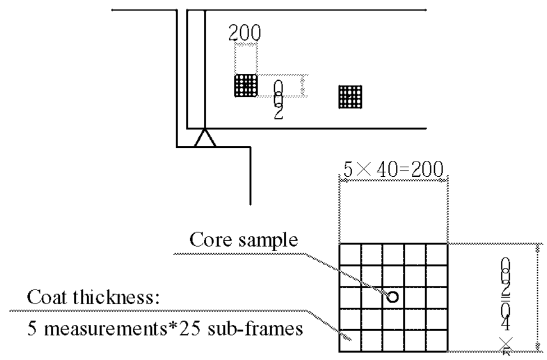


Figure 5. Measurement of rust/coat layer thickness

Table 5. Evaluation based on rust layer thickness

Appearance of coat / rust		Percentage of rusted surface (%)	External appearance: Status of coat / rust \ Rust layer thickness (μ)	Rust layer thickness 5 (< 200)	4 (< 300)	3 (< 400)	2 (400～800)	1 (> 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				D1-2	D1-1
	D2	< 30					D2-2	D2-1
	D3	30 or more	Tubercles (small)				D3-2	D3-1
E	E1	< 3	Rust with laminar detachment				E1-2	E1-1
	E2	< 30	Tubercles (large)				E2-2	E2-1
	E3	30 or more					E3-2	E3-1

A, B, C: Posing no problem.

D, E: Weather-resistant coat not performing as designed.

Example: C3-3

External evaluation (C3) — Rust layer thickness (3)

3) Cross-sectional observation of core samples

Core samples were observed using polarizing microscopy for rust and protective layers.

3. Results of external and core-sample observations

The following photographs show typical findings of the external and core-sample observations.

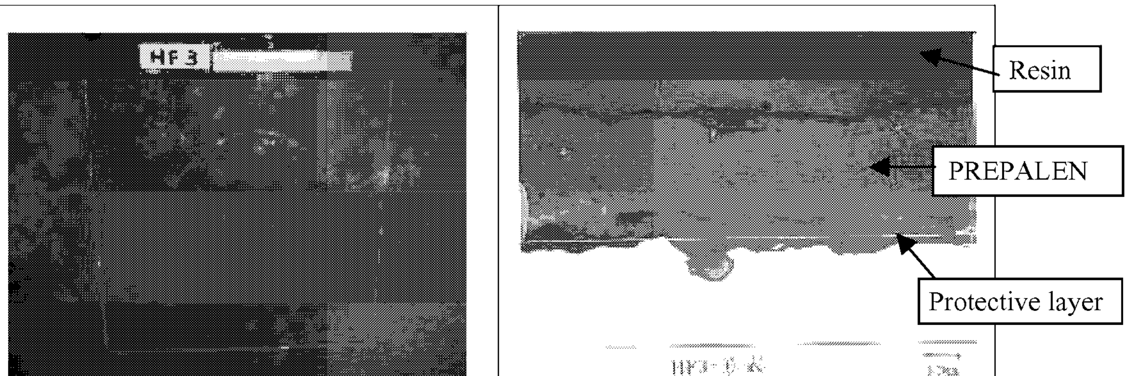
3.1 Hinode Overpass (Web Plate No. 3)

External appearance: While some spots of rust are observed on the surface of the plate, the Weather Coat (Prepalen) still remains. For this, a deterioration rating of B is given.

Layer thickness: The rust/coat layer is 180 μ thick and is rated at 5.

Core status: The Weather Coat remains on the surface of the plate and a thin protective layer has formed.

Evaluation: The plate seems to have been subjected to an environment of moderate corrosiveness. The rust is expected to not grow further in 30 years. It was possible to evaluate the level of deterioration of the plate by external inspection.



External appearance

Thickness of layer: 180 μm

Figure 6(1). Observation results for web plate (3) of Hinode Overpass

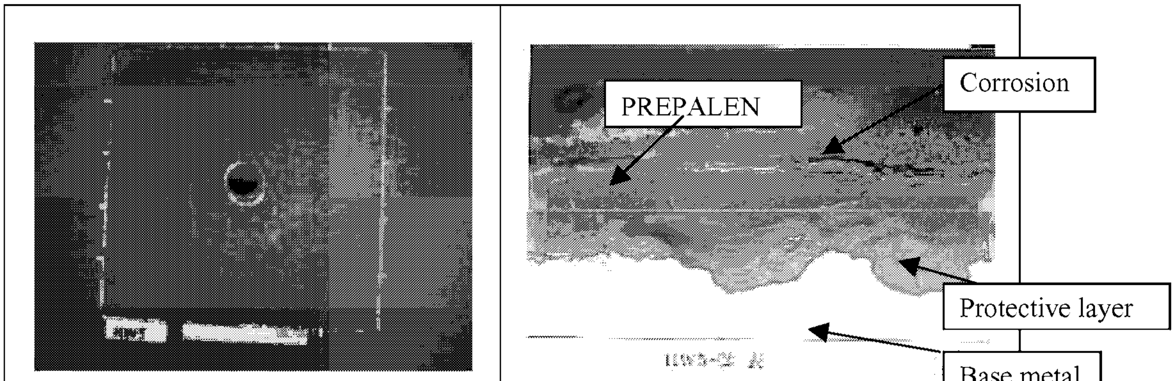
3.2 Hinode Overpass (web plate No. 2)

External appearance: Small areas of rust have formed on the entire surface of the plate. For this, a rating of C3 is given.

Layer thickness: The rust layer is 100 μ thick and is rated at 5.

Core status: PREPALEN remains inside while a protective layer is being formed.

Evaluation: The plate seems to have been subjected to an environment of relatively moderate corrosiveness. The rust is expected not to grow further inwards in 30 years. A solid protective layer is seen to have formed. It was possible to evaluate the level of deterioration of the plate by external inspection.



External appearance | Thickness of rust/coat: 100 μ m

Figure 6 (2). Observation results for web plate (2) of Hinode Overpass

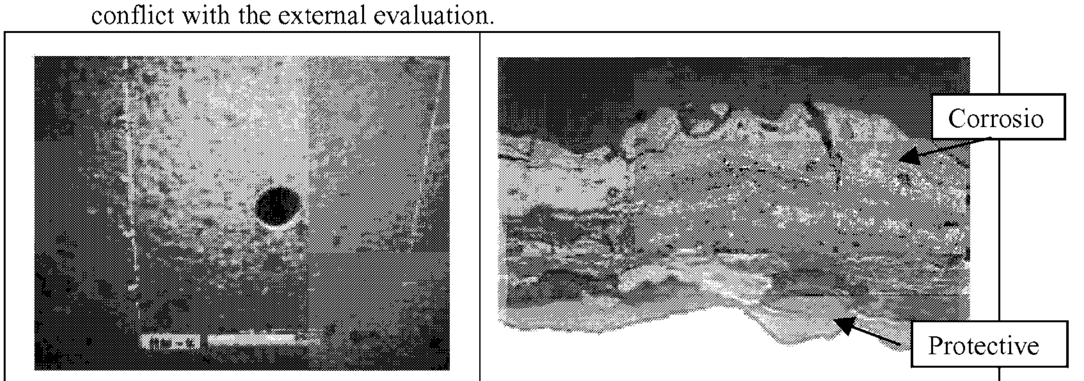
3.3 Misaki Overpass (web plate No. 1)

External appearance: Rust with laminar detachment has formed over the entire surface of the plate. For this, a rating of E3 is given.

Layer thickness: The rust layer is 325 μ thick and is rated at 3.

Core status: A thick layer of corroded material has formed on the surface of the plate. A protective layer has formed on the surface of the base metal.

Evaluation: While a layer of rust with laminar detachment has formed on the surface of the plate, a good protective layer has also formed. For this, a rating of C3 has been given which is in conflict with the external evaluation.



External appearance | Thickness of rust / coat: 325 μm

Figure 6(3). Observation results for web plate (1) of Misaki Overpass

3.4 Evaluation results for the samples (27 in total) are summarized in Table 6.

Table 6. Evaluation result for all of samples

Bridge	Member	No #	External appearance	Thickness of rust layer	Agreement with cross-sectional observation results of core sample	re-evaluation	Remarks
Hinode	Web Pl	1	E2	2	△	C3-3	A
	Web Pl	2	C3	5	OK		
	Web Pl	3	B		OK		
	Web Pl	4	C3	3	△	C3-4	A
	Flange	5	C3	3	OK		
	Flange	6	C3	5	OK		
	Flange	7	E2	1	OK		
	Cross	8	C3	5	OK		
	Cross	9	B		OK		
Mokoi	Web Pl	1	C2	5	OK		
	Web Pl	2	C2	5	OK		
	Web Pl	3	C2	5	OK		
	Web Pl	4	C2	4	△	C2-5	A
	Flange	5	C2	5	OK		
	Flange	6	E3	2	OK		
Misaki	Web Pl	1	B		OK		
	Web Pl	2	C3	5	OK		
	Web Pl	3	B		OK		
	Web Pl	4	E3	1	△	C3-3	A
	Flange	5	B		OK		
	Flange	6	C3	5	OK		
	Flange	7	E3	1	OK		
	Flange	8	E3	2	△	C3-3	A
Nakamachi	Web Pl	1	C3	3	△	C3-5	B
	Web Pl	2	C3	3	△	C3-5	B
	Flange	3	C2	3	△	C3-5	C
	Flange	4	E3	1	△	E3-2	B

OK: Agreement between the external observation results and the core sample observation results

△: Disagreement between the external observation results and the core sample observation results

A:Formation of protective layer

B:Disagreement between core analysis and survey on rust thickness

C:Intermittent protective layer

4. Conclusions

From a comparison between external observations and cross-sectional observations of core samples, the following conclusions were drawn.

(1) In 18 of the 27 samples, there was agreement between external and cross-sectional core observations. In 9 of the 27 samples, there was no such agreement.

(2) In the 9 cases of disagreement, 3 were between the thickness of the rust/coat layer visually observed and that measured in core observation. Six were due to incorrect external observations (e.g., rated C in core observation while rated E in external observation).

(3) In all six of the incorrect external observations, the corresponding rating from core observation was higher, which means that all of the external observations were on the safe side of the evaluation scale.

(4) Bridges rated B or C by external observation had largely corresponding ratings by core observation.

These finding suggest that it is possible to use the external evaluation method shown in Table 4 to rate the deterioration of bridges built with surface-treated atmospheric-corrosion-resistant steel.

Finally, the bridges built with atmospheric-corrosion-resistant steel on the Muroran Shindo tend to be in good condition, although some need monitoring.