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VERIFICATION OF REPAIR PAINTING EFFECT OF CORRODED WEATHERING STEEL BY EXPOSURE TEST

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Weathering steel generates dense protective rust on the steel surface. Since this protective rust would reduce corrosion speed, weathering steel can be used without any painting. Furthermore, the Life Cycle Cost of unpainted steel bridges would be lower than ordinary painted steel bridges. Due to these advantages, many weathering steel bridges have been constructed in recent years. Unfortunately, the generation of anomalous rust has been reported in some bridges, cause of water leakage or deicer. It is necessary to repair these bridges, but the repair technique for corroded weathering steel has never been established yet. This study aims to clarify the effect of various repair painting for corroded weathering steel by performing an exposure test. The exposure test has been carried out from September 2015 to Okinawa and Yamaguchi. Test in Okinawa is supplied airborne salt, and the test in Yamaguchi is not supplied airborne salt. Specimens, which produced anomalous rust, were repaired by 19 methods and exposed. As a result, it is effective to repair by organic zinc-rich paint in the area with airborne salt. On the other hand, it is appropriate to remove rust and salt on the steel surface by blasting in the area which is not supplied airborne salt.

Keywords: Anomalous rust, Airborne salt, Organic zinc-rich paint, Epoxy coat, Anti-corrosion performance, Blasting.

1 INTRODUCTION

In Japan, there are many bridges constructed during the period of high economic growth (-from 1955 to 1973), and bridges more than 50 years old occupy 20% of all bridges in 2013 (JSSC 2012). On the other hand, construction investment of structures is decreasing year by year, and it is required not to rebuild but to expand the lifetime of bridges by appropriate maintenance. Lifetime expansion could reduce the life cycle cost of the bridge; here, the life cycle cost is the total cost from new construction to the removal of bridge, including initial cost, maintenance cost and the renewal cost. Due to reduce life cycle cost of bridges, it is important to reduce maintenance costs. Until now, painting has been used for the anticorrosion of steel bridges, but if it is repainted once in 10 years to maintain the anticorrosion performance and appearance, it costs as much as the initial construction cost of the superstructure in about 100 years (JSSC 2012).

Weathering steel is the anticorrosion material, which generates dense protective rust on the steel surface. This protective rust would prevent the steel surface from corrosion factors such as water and salt, so weathering steel can use without any painting. The life cycle cost of unpainted steel bridges would be lower than ordinary painted steel bridges. Due to these advantages, many weathering steel bridges have been constructed in recent years (JSSC 2006). Unfortunately, the generation of unexpected anomalous rust has been reported in some bridges due to adhesion of deicer or water leakage from expansion joints (Imai 2012). However, the repair technique for corroded weathering steel has never established yet. This study aims to clarify the effect of various repair paintings for corroded weathering steel by performing exposure tests.

2 MATERIALS AND METHODS

2.1 Exposure Test

Corroded weathering steel was required to consider the repair method of corroded weathering steel. In this study, 3wt%-NaCl was sprayed on weathering steel plate (150 x 70 x 6 mm) for about 10 months to generate the lamellar rust. Here, components of weathering steel are defined by Japanese Industrial Standards. Various surface preparation and repair painting are applied to corroded weathering steel plates, and these specimens were exposed. The exposure test started in September 2015 at Okinawa and Yamaguchi. Test in Okinawa is placed with a ceiling board to avoid rinsing by rain, but airborne salt will be able to come to the specimen, as shown in Figure 1. Test in Yamaguchi is placed in sealed boxes, which are not supplied airborne salt, as shown in Figure 2. Table 1 shows the exposure environment at each place. In order to observe the re-corrosion of specimens, rust/coating film thickness, ion transfer resistance, and appearance evaluation were measured once every 3 months. Here, ion transfer resistance is the resistance to the movement of ions in material, which is covered steel surface.

Figure 1. Exposure test at Okinawa.

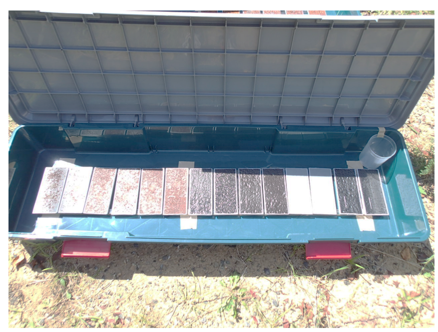


Figure 2. Exposure test at Yamaguchi.

Table 1. Environment of Exposure test sites.

Place	Yearly average temperature (°C)	Yearly average humidity (%)	Airborne salt $(mg/dm^2/day)$
Okinawa	24.0	76.0	0.281
Yamaguchi	17.3	69.8	---

2.2 Test Cases

Table 2 shows the repair method for each specimen. Non-treated cases are specimens with rust appearance level 5-1. Here, rust appearance level is an index to judge rust property by visual observation, and more corrosive as approaching level 1. Unpainted steel is the specimen that only removes rust and does not apply any painting. Various surface preparation methods were applied, such as using power tools, blasting, and only rinsing. Simple painting steel is thinly coated by coating agents such as surface treatment and organic zinc-rich paint after the surface preparation. Heavy-duty painting steel is coated over 3 layers after the surface preparation. There are repair painting methods, Rc-III, Rc-II, and Rc-I (JSSC 2012). These differences are in the degree of surface preparation and anticorrosive primer. Table 3 shows the details of each painting method. Differences between Case 20 and 21, Case 23, and 24 are indicated in Table 3. At present, the heaviest painting Rc-I has been used in general, but a cheaper and simpler method is required because of its high cost and labor.

Table 2. Repair methods.

Categories	Case	Repair methods
Non-treated	1	Rust appearance; Level 5
	2	Rust appearance; Level 4
	3	Rust appearance; Level 3
	4	Rust appearance; Level 2
	5	Rust appearance; Level 1
Unpainted	6	Power tool
	7	Power tool + Rinsing
	8	Blasting (A); amount of adhesion salt < 50mg/m^2
	9	Blasting (B); amount of adhesion salt < 100-150mg/m^2
	10	Blasting (C); amount of adhesion salt < 400-500mg/m^2
	11	Rinsing
Simple painting	12	Modified epoxy coating
	13	Blasting + Surface treatment; Type A
	14	Blasting + Surface treatment; Type B
	15	Blasting + Organic zinc-rich paint
	16	Tar epoxy coating
Heavy-duty painting	17	Rc-III
	18	Rc-II
	19	Rc-II; Blasting-less method
	20	Rc-I (A)
	21	Rc-I (B)
	22	Rc-I; Rinsing method
	23	Rc-I; Rinsing-less method (A)
	24	Rc-I; Rinsing-less method (B)

Table 3. Difference of heavy-duty painting.

No.	Surface preparation		Anticorrosive primer	Coating		
	Rust removal	Salt removal		Under	Middle	Upper
17	Power tool	---	---	Epoxy	Fluro	Fluro
18	Power tool	---	Organic zinc-rich paint	Epoxy	Fluro	Fluro
19	Power tool	Corrosion inhibitor	Organic zinc-rich paint	Polyurethane	Polyurethane	Fluro
20	Blasting	---	Organic zinc-rich paint	Epoxy	Fluro	Fluro
21	Blasting	---	Organic zinc-rich paint	Polyurethane	Polyurethane	Fluro
22	Blasting	Rinsing	Organic zinc-rich paint	Polyurethane	Polyurethane	Fluro
23	Blasting	Sodium carbonate	Organic zinc-rich paint	Polyurethane	Polyurethane	Fluro
24	Blasting	Corrosion inhibitor	Organic zinc-rich paint	Polyurethane	Polyurethane	Fluro

3 RESULTS AND DISCUSSION

In this paper, the ITR method, which can judge the corrosion state of steel by the relationship between rust/coating film thickness and ion transfer resistance, was used (Kihira 2006). Figure 3 shows the classification of the ITR method. Corrosion state can be recognized into 6 grades, I -5 to I -1, as shown in Table 4, depending on range in figure of rust/coating film thickness versus ion transfer resistance. It can be judged that the steel has anomalous rust if it is plotted in I-2 and I-1 area; on the other hand, the steel generates protective rust if it is plotted in the I-4 area. It can also be judged that coating film deteriorates when the ion transfer resistance decreases in painting steel. In this study, the effects of various repair methods were evaluated by the change of plot on the figure. Initial and 39-month measurements are plotted.

Figure 4 shows the corrosion states of each specimen by the ITR method. Here, symbol “O” means test in Okinawa, and symbol “Y” means test in Yamaguchi. The numbers following the symbol indicate case numbers. Figure 4(a) shows that the rust thickness in Case 4 and 5 is decreased due to the rust exfoliation. Figure 4(a) shows that Case 1 to 3 shows almost no change in Yamaguchi, but corrosion of all specimens in Okinawa made progress. This is thought to be because of airborne salt. On the other hand, Case 4 and 5 specimens were corroded even in Yamaguchi. It should be the effect of endogenous salt of rust. Figure 4(b) indicates Case 11 specimens, which were only rinsed by high-pressure water, were corroded in both Okinawa and Yamaguchi. Moreover, Case 6 and 7 specimens which were removed rust by power tool were also corroded a little even in Yamaguchi. On the other hand, Case 8 to 10, which were applied blasting, was corroded only in Okinawa, since non-existent of airborne salt and generating of protective rust in Yamaguchi. According to Figure 4(c), there is a decrease of the ion transfer resistance in Case 13 and 14, which were applied surface treatment in Okinawa, and it is considered that the coating film has deteriorated. On the other hand, other specimens show almost no change after more than 2 years. It is considered that the anticorrosion performance has been maintained. From Figure 4(d), corrosion and degradation of coating film were observed in Case 17 and 19, but other specimens applied blasting were not corroded. These specimens were adjusted by power tools, so it is considered that rust removal is insufficient and anticorrosion performance cannot be demonstrated.

Figure 5 shows pictures of the appearance of blasting specimens (Case 9) after 39 months. According to this picture, the rust has exfoliated and corrosion progresses in Okinawa, but no anomalous rust is observed in Yamaguchi.

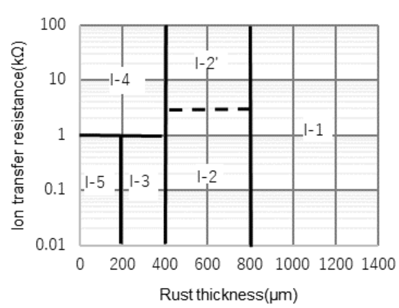
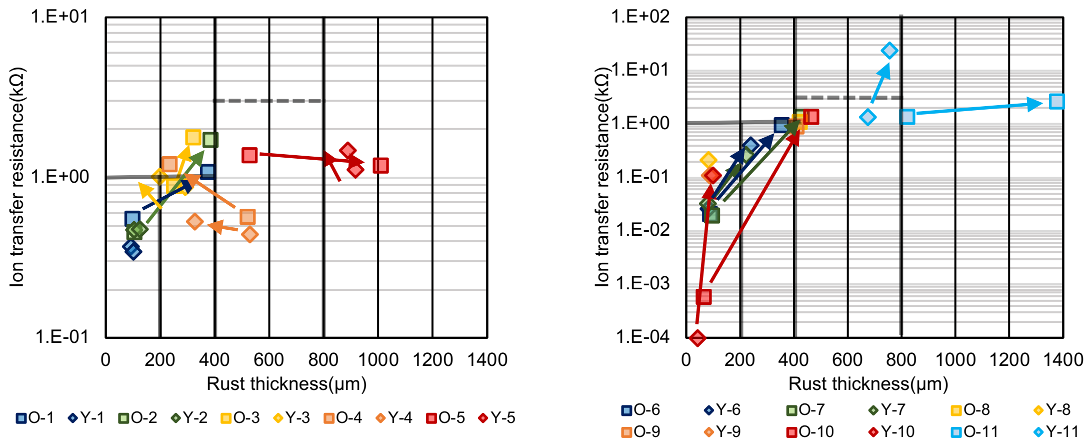


Figure 3. ITR method.

I-5	Immature rust
I-4	Protective rust
I-3	Pre-protective rust
I-2'	Observation rust (Protective rust)
I-2	Observation rust (Scaly rust)
I-1	Abnormal rust (Lamellar rust)

Table 4. Corrosion states.

Table 5 indicates the repair effect of each specimen. In this table, “G” means good, “A” means average, and “P” means poor. In Okinawa, it is effective to repair by organic zinc-rich paint or epoxy coating without Rc-I. In Yamaguchi, almost all methods were effective except for the methods, which were not applied blasting. Therefore, it is considered that re-corrosion can be suppressed by sufficiently removing rust and salt on the steel surface by blasting, in the area not affected by airborne salt.



(a)Non-treated Steel (b)Unpainted Steel

(c)Simple painting Steel (d)Heavy-duty painting Steel

Figure 4. Corrosion states of each specimen by ITR method.

(a)Okinawa (b)Yamaguchi

Figure 5. Appearance of blasting specimens (Case 9).

Table 5. Repair effect of each method.

Categories	No.	Repair methods	Repair effect	
			Okinawa	**Yamaguchi**
Unpainted	6	Power tool	**P**	**A**
	7	Power tool + Rinsing	**P**	**A**
	8	Blasting (A)	**P**	**G**
	9	Blasting (B)	**P**	**G**
	10	Blasting (C)	**P**	**G**
	11	Rinsing	**P**	**P**
Simple painting	12	Modified epoxy coating	**G**	**G**
	13	Blasting +Surface treatment; Type A	**P**	**A**
	14	Blasting +Surface treatment; Type B	**P**	**A**
	15	Blasting + Organic zinc-rich paint	**G**	**G**
	16	Tar epoxy coating	**G**	**G**
Heavy-duty painting	17	Rc-III	**P**	**P**
	18	Rc-II	**G**	**G**
	19	Rc-II; Blasting-less method	**P**	**A**
	20	Rc-I (A)	**G**	**G**
	21	Rc-I (B)	**G**	**G**
	22	Rc-I; Rinsing method	**G**	**G**
	23	Rc-I; Rinsing-less method (A)	**G**	**G**
	24	Rc-I; Rinsing-less method (B)	**G**	**G**

4 CONCLUSION

In this study, the exposure test was carried out with various conditions to examine the appropriate repair method of corroded weathering steel. As a result, no progress of corrosion was observed in almost all specimens except for power tools and rinsing specimens in Yamaguchi. On the other hand, in Okinawa, unpainted steel, surface treatment specimens, and the Rc-III specimen were corroded, but organic zinc-rich paint, epoxy coat, and Rc-I had kept good anti-corrosion performances.

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