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Study on Durability and Corrosion Protection Performance of Concrete Cover Method for Port Steel Pipe Structures

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ABSTRACT

Researching on corrosion protection technologies for steel pipe piles have been under operation by the exposure test using real pier in HASAKI since 1984. This paper is reporting the durability and corrosion protection performance of concrete cover method obtained from the exposure test. Deterioration of concrete cover was differed by materials and environments. Concrete cover in splash zone and marine atmospheric zone after 25 years was spalled off and fracture of reinforcing bar due to corrosion was occurred. On the other hand, concrete cover in tidal zone was sound. Despite the chloride ion concentration at steel surface in concrete was about 20 kg/m^3, steel had not been corroded. It is considered that diffusion of oxygen into the concrete was limited to the level that could not generate the steel corrosion.

Keywords. Corrosion protection, Corrosion, Chloride ion induced deterioration, Marine environment, Exposure test

INTRODUCTION

Port steel structures are exposed to very severe environment for corrosion of steel. Corrosion rate in marine environment will be estimated from 0.1 to 0.3 mm/yr. in Japan (CDIT, 2009). In the past construction, corrosion prevention of steel structures was designed by theory of corrosion allowance, however, we have experienced the collapse accident of structures by concentrated corrosion of steel as shown in Figure 1. Concentrated corrosion occurs just below the L.W.L., and its corrosion rate is very high in marine environment.

Suitable corrosion protection and suitable maintenance are important for the sustainable marine infrastructures. At present, steel structures are protected by the combination of the protective coating and cathodic protection for the long term service life as shown in Figure 2 (OCDI, 2009). Steel in submerged zone and the mud zone are protected by cathodic protection. On the other hand, steel in tidal zone, splash zone and atmospheric zone is protected by coating. However, corrosion protection performance and durability of the protective coating is not clear yet.

So, research on corrosion protection technologies for steel pipe piles by the exposure test using real pier in HASAKI has been continued since 1984 (Research group on corrosion protection technology for steel pipe piles, 2010). Concrete cover method is one of the protective coating methods, and has been experimented in HASAKI. This paper is reporting the durability and corrosion protection performance of concrete cover method.

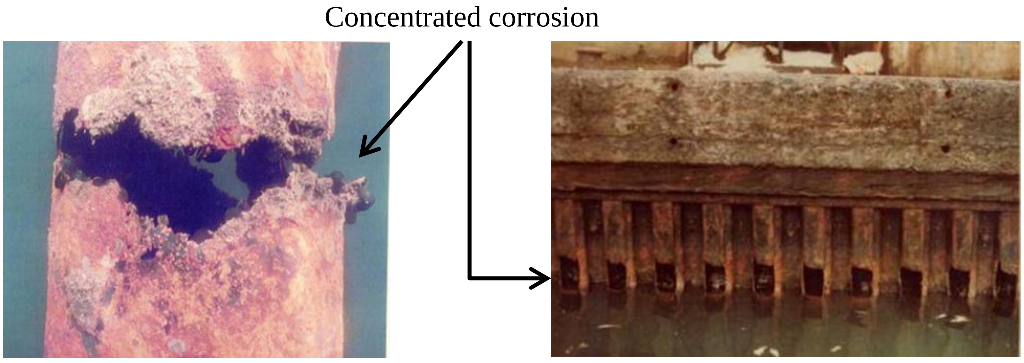


Figure 1. Concentrated corrosion of steel structures

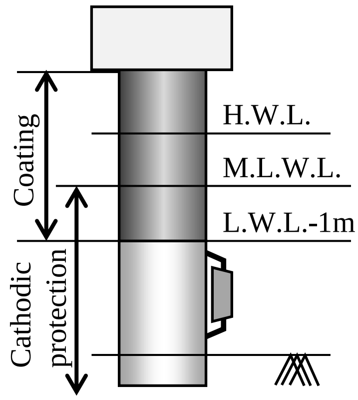


Figure 2. Protective methods for port steel structures

OUTLINE OF EXPOSURE TEST IN HASAKI PIER

HASAKI pier. HASAKI pier was built in 1985 as a research facility. This facility has been built to stick out in a direction perpendicular to the shoreline facing to the Pacific Ocean as shown in Figure 3. Total length of HASAKI pier is 427m, depth of the tip is about -5m. Exposure environment is very severe corrosive environment, prone to the action of intense waves and fast tidal current. Tide level difference is a 1.4m, and the significant wave height is about 0 ~ 3m. At the time of stormy weather, the HASAKI pier receives the strong impact force by the wave as shown in Figure 4. And, the aerosol chloride ion concentration at the level of L.W.L.+7m is 88mg/m^2/day. Therefore, it can be said HASAKI environment is very severe compared to the ordinary port environment.

Figure 3. Bird-eye view of the HASAKI pier

Figure 4. HASAKI pier at the time of stormy weather

Exposure test in HASAKI pier. The exposure test was carried out to confirm the durability and protective performance of several types corrosion protection methods. Tested corrosion protection methods were summarized in Table 1. Total 51 protective coatings were applied to the steel pipe piles in the HASAKI pier in 1984 (Miyata, 2006). These methods were applied to real port and marine steel structures before. Concrete cover method is classified in the inorganic coating.

Table 1. Corrosion protection methods

Protection Method		Number of methods
Protective coating	Painting	13
	Organic coating	13
	Inorganic coating	11
	Petrolatum coating	14
Cathodic protection	Galvanic anode method	1

Concrete cover method. Concrete cover method is one of the inorganic coating methods. Figure 5 shows schematic of the concrete covering method. This method forms the protective layer by filling mortar or concrete inside the outside cover (FRP, GRC, etc). And, this method can reinforce the steel structures by using RC member mechanically.

This paper reports the three kinds of concrete cover methods shown in Table 2.

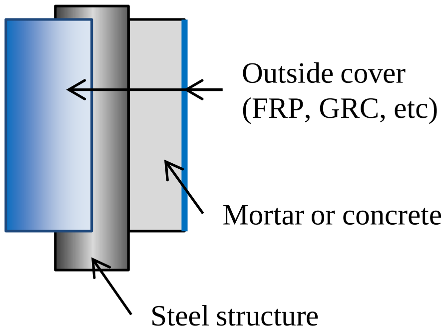


Figure 5. Concrete cover method

Table 2. Concrete cover method using in the experiment

Type	Steel rein-forcement*1	Concrete	Outside cover*2	Protection range from L.W.L. (m)
A	RC	Antiwashout under water concrete	-	-1.23-+1.27
B	RC	Antiwashout under water Mortar	GRC	+0.77~+4.27
C-1	C	Polymer cement mortar	GFRP	+0.42~+5.15
C-2				+0.55~+5.15

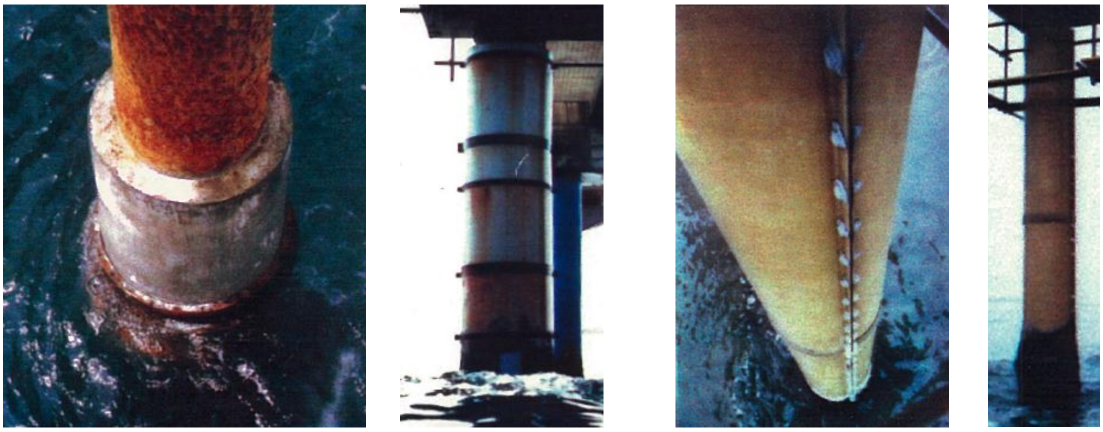
*1: RC: Reinforced concrete, C: Concrete
*2: GRC: Glass fibre reinforced concrete, GFRP: Glass fibre reinforced plastics

Type A is RC member without outside cover (Masuda, 2009). This Type A was applied in the location of about 320m from the shoreline in 1984. Protection range is under sea water and tidal zone. Thickness of concrete cover is 150mm. Cover depth to the steel reinforcement is 80mm. Concrete used was the antiwashout under water concrete. Table 3 shows mixture proportion of concrete. Cement used was Ordinary Portland cement. Maximum size of coarse aggregate is 25mm. Water-cement ratio of concrete is 50.5%. The slump flow of fresh concrete is 515mm, and 4.8% in air content. Appearance after the completion is shown in Figure 6. Defects such as cracks are not observed. The outer surface of the steel pipe pile was not protected since 1997, it has been protected with petrolatum coating with titanium outside cover.

Table 3. Mixture proportion of concrete in Type A

W/C (%)	s/a (%)	Unit (kg/m^3)				Ad1 (kg/m^3)	Ad2 (l/m^3)	Ad3 (l/m^3)
		Water	Cement	Sand	Gravel			
50.5	40.0	240	475	592	906	3.8	4.75	5.25

* Ad1: Acrylic antiwashout under water admixture, Ad2: Melamine sulfonic acid-based super-plasticizer, Ad3: air entraining and water reducing agent



Type A Initial exposure | Type B 1 year exposure | Type C-1 Type C-2 1 year exposure

Figure 6. Appearance of concrete cover methods during the exposure

In Type B, RC is used with GRC cover (Abe, 1990). This Type B was applied in the location of about 160m from the shoreline in 1985. Protection range is from splash zone to atmosphere zone. Thickness of concrete cover is 110mm, and thickness of GRC is 12mm. Cover depth is 62mm. Concrete used was anti-washout under water mortar. Table 4 shows mixture proportion of mortar. Cement used was Ordinary Portland cement. Water-cement ratio of concrete is 48%. The slump flow of fresh mortar was 550mm, and 4.0% in air content. Appearance after 1 year exposure is shown in Figure 6. Rust stain due to the steel cover band is observed, however change of the appearance of GRC cover is not observed.

Table 4. Mixture proportion of mortar in Type B

W/C (%)	S/C	Unit (kg/m^3)			Ad1 (kg/m^3)	Ad2 (l/m^3)
		Water	Cement	Sand		
48	1.10	381	790	870	4.95	12.74

* Ad1: Cellulose based antiwashout under water admixture, Ad2: Melamine sulfonic acid-based super-plasticizer

Type C is made of concrete with GFRP cover. This method was applied in the location of about 20m and 80m from the shoreline in 1985. Protection range is from tidal zone to atmosphere zone. Thickness of concrete cover is 25mm, and thickness of GFRP is 5mm. Concrete used was polymer cement mortar. The materials and the mixture proportion are unknown. Appearance after 1 year exposure is shown in Figure 6. The change of the appearance of GFRP cover of both steel pipe piles (C-1, C-2) wes not observed.

RESULT AND DISCUSSION

Durability of concrete cover method. Figure 7 shows appearance of concrete cover methods after 26years. The part of member of Type A was repaired after 13 years exposure. Repair range of Type A was 300mm from the top of the coating. The other type has not been repaired.

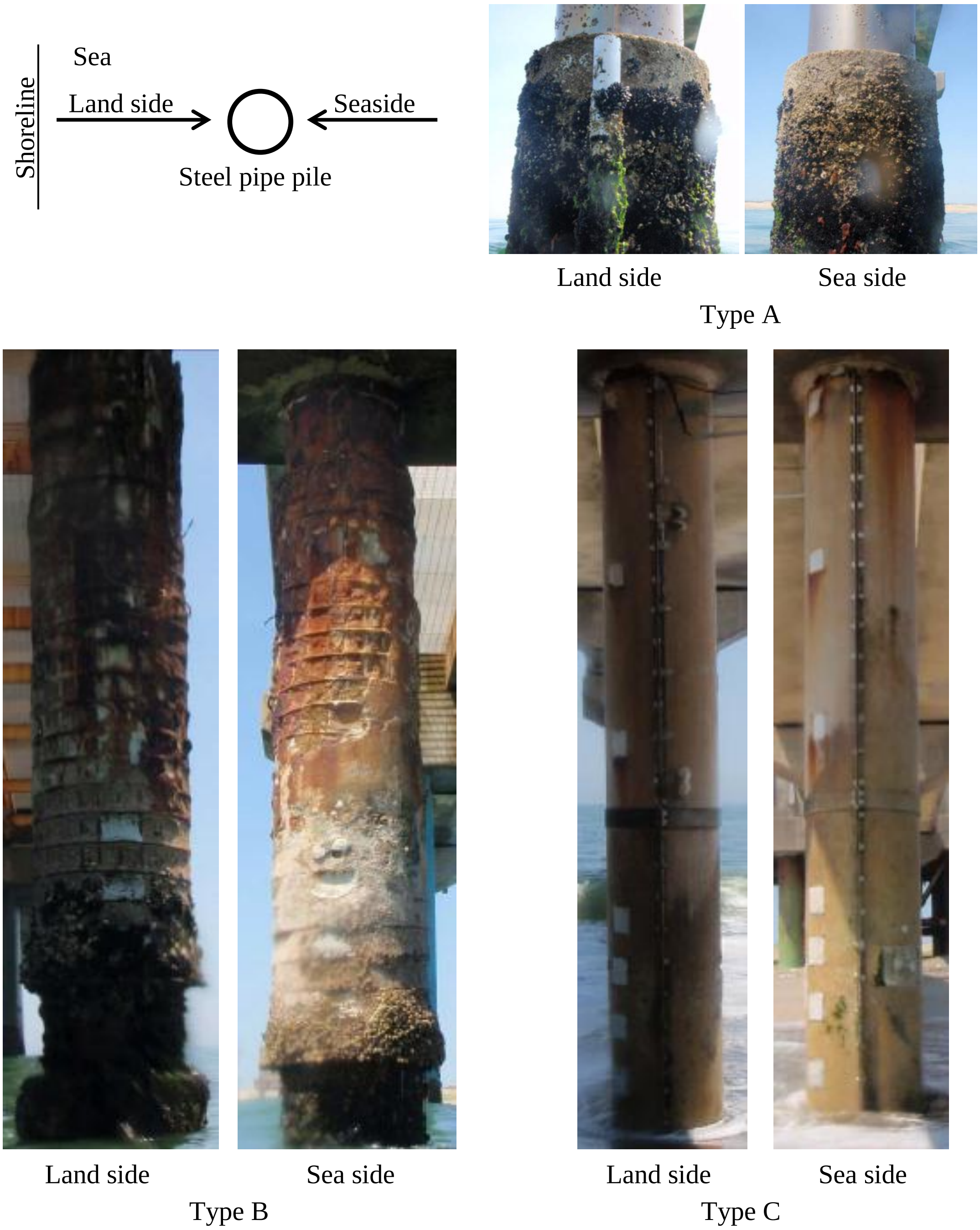


Figure 7. Appearance of concrete cover methods after 26years

In Type A, a crack in the horizontal direction of 1~3mm in width was observed at a position of 20 cm from the upper side after 13 years exposure. This crack was caused by corrosion from the non-protection range of steel pipe pile, as shown in Figure 6. Therefore, in Type A, little erosion due to wave is observed, but it is considered that it has been maintained in a sound condition. However, it was suggested that in order to ensure the long-term durability, both end of the concrete cover should be surely protected. Figure 8 shows chloride ion concentration profiles after 21 years exposure. Chloride ion concentration in concrete is very high. Therefore, it is considered that passive films of pile and rebar were already destroyed by the chloride ion. Figure 9 shows rebar in concrete of Type A after 14 years, and Figure 10 shows steel pile of Type A after 21 years. Despite high chloride ion concentration, corrosion of rebar and steel pile were not observed at all.

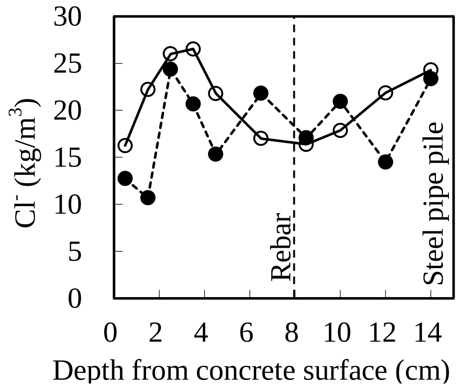


Figure 8. Chloride ion profiles (Type A, 21 years)

Figure 9. Rebar in concrete of Type A after 14 years

Figure 10. Steel pile of Type A after 21 years

On the other hand, GRC cover of Type B was fallen away, and the cover concrete was spalled by the corrosion of rebar due to chloride induced deterioration over the entire surface. And also, in Type B, fracture of rebar was confirmed. In the appearance, Type B is already deteriorated. Therefore, it is estimated that it has already reached to the limits of performance.

Type C is maintained in a sound condition, although the GFRP cover has been slightly deteriorated by choking.

From the results of appearance, it is considered that the durability of concrete cover methods vary depending on the difference of the protective range and also on the difference in types. Durability of RC member in the splash zone and atmosphere zone is low, because penetration of chloride ion and oxygen into the concrete is high. On the other hand, durability of RC member in the tidal zone and under-seawater zone is high, because the penetration of oxygen into the concrete is low, and in addition it is likely that the RC member of concrete cover method is protected by the cathodic protection of steel in seawater. About the effect of the types, it is considered that durability of concrete cover method is improved by using the FRP cover, because the FRP cover can inhibit the penetration of chloride ion into concrete.

Corrosion protection performance of concrete cover method. Steel pipe pile protected by type A was not corroded as shown in Figure 9 and Figure 10. Therefore, it is considered that steel pipe piles protected by concrete cover method in tidal zone have a high corrosion protection performance.

Thickness of the steel pipe pile protected by Type B, Type C and non-protection after 25 years exposure were measured. The thickness of steel pipe piles was measured using an ultrasonic thickness gauge. Measurement in one measuring point is 5 spots × 3times, as shown in Figure 11. Therefore, the average thickness of the steel pipe pile at that point was set to the average of 15 measurement results. Figure 12 shows corrosion loss, corrosion rate and Ratio of corrosion rate of steel pipe piles protected by Type B and Type C. These figures also show the result of the non-protection pile. A result of each point is the average value of the measurement result of the land side and sea side. The result of the corrosion loss was calculated by using the nominal thickness. The result of corrosion rate was calculated assuming the constant corrosion rate from the initial exposure. Ratio of corrosion rate was calculated by the ratio of the protected to the non-protection.

Corrosion was observed in either case. However, corrosion loss of concrete covered pile is small compared to the non-protection piles. Corrosion of concrete covered piles in splash and atmosphere zone are decreased to 15~30%. This corrosion rate is estimated to be the same as the corrosion rate of steel in seawater protected by cathodic protection. Therefore, it is considered that concrete cover methods has a high corrosion protection performance.

The Type B showed a tendency to increase the corrosion rate with increasing the height from the sea level. On the other hand, corrosion rate of Type C was almost constant along the height from sea level. As shown in this Figure 12, corrosion rate of type B is smaller than that of Type C. This result coincides with deterioration condition of the appearance. In any case, the corrosion rates of 20~60μm/year is categorized as "high corrosion rate", referring to the corrosion rate of reinforced concrete. Therefore, it is estimated that high concentrations of chloride ions are accumulated on the steel surface in concrete. In future, the spalling and cracking of the concrete cover by the expansion of the corrosion products will be expected. Therefore, in order to construct the sustainable infrastructures, it is necessary to set a limit on the corrosion protection performance.

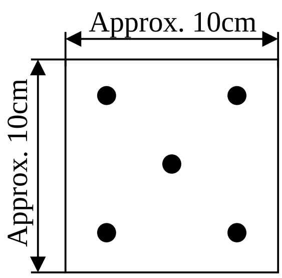


Figure 11. Measuring spots

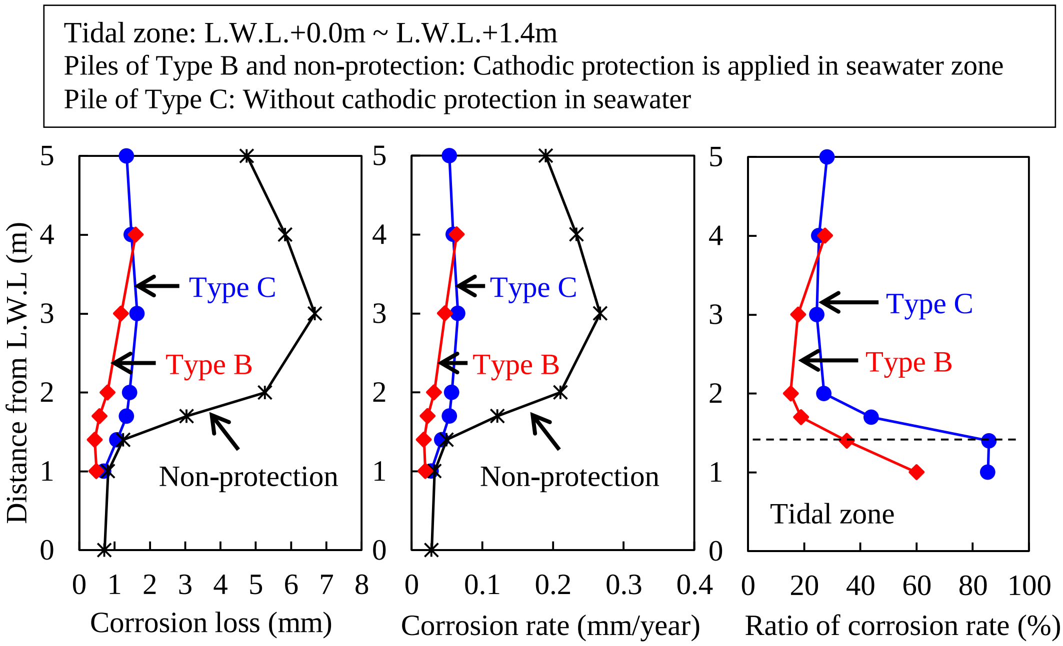


Figure 12. Corrosion loss and corrosion rate of steel pipe piles

In the concrete cover using RC members (type B), the spalling of cover concrete occurs in the early time, but corrosion protection performance of steel structures is no lost. The concrete cover is considered to be adhered by rebar restraining. Therefore, it is thought that one of the indicators of limit of the corrosion protection performance is the corrosion of the rebar, which cause the spalling of the concrete cover, or the fracture of the rebar. Moreover, in order to improve the durability, it is understood that high corrosion resistance reinforcement bar, such as stainless steel rebar and epoxy rebar, can be used.

On the other hand, in the concrete cover method with FRP cover (type C), the confirmation of the change on the appearance is difficult. Therefore, it is said that one of the indicators of limit of the corrosion protection performance can be the deformation of FRP cover, for example, falling or cracking of FRP cover, etc. However, it is necessary to inspect the concrete surface by opening the FRP cover in a regular inspection, because the concrete condition and corrosion of steel can not be checked from out side of FRP.

CONCLUSION

Corrosion protection technologies for steel pipe piles by the exposure test using actual pier in HASAKI has been continued since 1984. This paper is reporting the durability and corrosion protection performance of concrete cover method from the exposure test result. The obtained results are shown below.

1) The durability of concrete cover method varies depending on the difference of the protective range and the difference in types of method. The durability of RC member in splash zone and atmosphere zone is low. On the other hand, the durability of RC member in tidal zone and under-seawater zone is high. These were considered to have been due to diffusion of oxygen into the concrete and the cathodic protection applied in seawater pipe pile.

2) Concrete cover methods in tidal zone have a high corrosion protection performance. And also, in splash and atmosphere zone, concrete cover methods has a high corrosion protection performance even after 25 years. In future, the spalling and cracking of the concrete cover by the expansion of the corrosion products will be expected. Therefore, in order to construct the sustainable infrastructures, it is necessary to set a limit on the corrosion protection performance.

ACKNOWLEDGMENT

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