Application of RFID Corrosion Environment Sensing System to Repair Work and Results of 10-year study

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Abstract. To perform preventive maintenance of reinforcing steel corrosion in reinforced concrete, developed an RFID corrosion environment detection system that can wirelessly measure iron sensors that simulate reinforcing bars. This system can be embedded in concrete for a long period of time according to the life cycle of the structure, and semiconductor parts can be used for the passive RFID used in the communication interface. Therefore, it is necessary to confirm long-term durability. In this study, applied an RFID corrosion environment detection system to the repair work of bridge piers in addition to the conventional method of diagnosing rebar corrosion, and this paper report the results of our research conducted over a period of 10 years. The RFID corrosion environment detection system was compared with the expansion ring sensor system and the rebar self-potential measurement results. In addition, EPMA was used to analyze the chloride ion permeation of cores sampled from 5- and 10-year-old structures. The reaction results of the RFID corrosion environment sensor were compared with the permeation of chloride ions inside the structure.

1 Introduction

The RFID corrosion environment detection system non-destructively measures whether the steel material inside the concrete is in a corrosive environment. This system uses a passive RFID as a communication interface to measure the electrical resistance of iron sensors that simulate rebar. A passive RFID connected to a iron sensor and cable is buried inside the structure, and measurement is conducted by applying radio waves to the embedded passive RFID from the concrete surface with a dedicated reader/writer. Therefore, realized a system that can perform long-term measurement without a battery. The electrical resistance of the iron sensor in a normal state is several ohms, but when corroded, it shows a resistance of 100 Ω or more.[1], [2]

This system is mainly applied to coastal structures that are subject to salt damage from the sea, road structures that are sprayed with anti-freezing agents, and for corrosion detection of internal steel materials of structures that are expected to be neutralized. Additionally, the applicable structure is applied not only to new construction work, but also to repair work after the structure has deteriorated.

Meanwhile, concrete structures are used over a life cycle of several decades. Therefore, long-term durability is also important for sensor systems used for monitoring concrete structures. As the RFID corrosive environment detection system uses semiconductor components for the passive RFID used in the communication interface, it is necessary to confirm long-term durability when embedded in concrete.

In this study, applied the RFID corrosion detection system to the repair work of bridge piers in Japan and used it as a monitoring system to confirm the effectiveness of the repair work. This paper the results of a 10-year chronological survey that confirmed system operation and investigated issues regarding applications of the above-mentioned method as a monitoring method.

2 Structures to be monitored

The structures targeted for monitoring are the piers of a bridge built in 1973 in Hokkaido, Japan. This bridge is located approximately 200 m from the coast and is in a severe salt-damaged environment. Hence, conducted a survey in 2009. As a result, deterioration such as the exposure of some corroded reinforcing bars was confirmed. Thus, in 2010, a full-scale repair work was conducted. During the repair work in 2010, various sensors were installed to detect rebar corrosion, and periodic surveys were planned using the conventional self-potential measurement method, with the aim of confirming the effects of the repair work over the long term. Additionally, core boring was conducted in the 5th and 10th years, and the permeation of chloride ions in the concrete were analyzed via an electron probe micro analyzer (EPMA).

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3 Sensors for detecting rebar corrosion

3.1 Expansion ring sensor system [3], [4], [5]

As shown in Fig. 1, the expansion ring sensor is a cylindrical sensor with six stages of detection parts, and is generally installed in a hole drilled in an existing structure via core boring. To measure the potential difference and current density with each detection part, a cathode part was installed separately.

Typically, it is possible to monitor the progress of corrosion in the depth direction, assuming that corrosion progresses in order from the A1 part, which corresponds to the detection part near the surface.

3.2 RFID corrosion environment sensor

As shown in Fig. 2, the detection and communication parts of the RFID corrosion environment sensor are connected via a cable. The detection part simulates a reinforcing bar with a film-like iron, and the corrosion environment is evaluated by determining whether the iron film breaks due to corrosion using electrical resistance values. When measured, the value of the electrical resistance between both ends is 15 Ω or less. However, if the sensor itself becomes corroded enough to disconnect, it will show a resistance of 100 Ω or more. A feature of this device is that the resistance is measured wirelessly using a passive RFID, and long-term durability is excellent because the detection part, RFID part, and cable are all buried.

This system enables completely non-destructive measurement with no need to expose the cables to the surface of the structure. To take a measurement, an electromagnetic wave is simply transmitted from the RFID reader/writer to the surface of the structure in which the RFID unit is embedded. The embedded sensors and RFID units do not require batteries, making them ideal for long-term maintenance without the hassle of battery replacement.

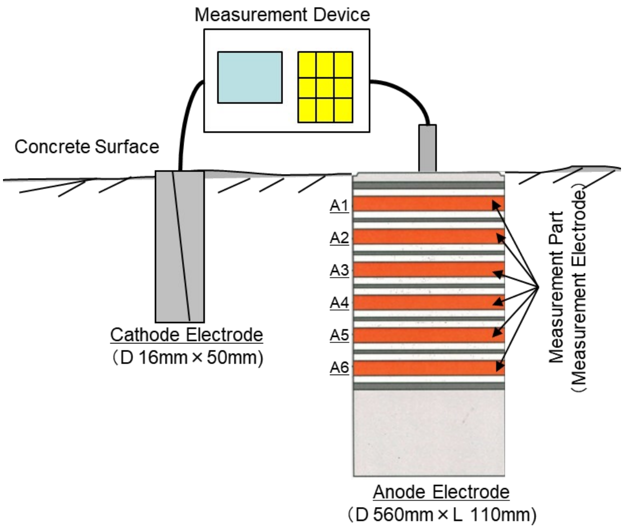

Fig. 1. Expansion Ring Sensor System.

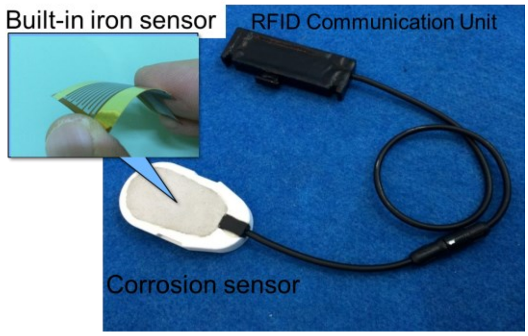

Fig. 2. RFID Corrosion Environment Sensor.

4 Installation of various sensors

Expansion rings are generally installed in holes drilled in existing structures via core boring. However, as the aim was to repair the cross section, as shown in Fig. 3, after the existing concrete was chipped up to the reinforcing bars, the surface was installed according to the design cover thickness. After the cathode electrode was sprayed with concrete for cross-sectional repair, it was buried before it hardened.

As shown in Fig. 4, the RFID corrosion environment sensor was fixed with anchor bolts after chipping the existing concrete, and was installed such that two-step measurement is possible at the 40-mm (M-1, C-1, S-1) and 80-mm(M-2, C-2, S-2) positions of the design cover. The communication part was fixed with fast-hardening mortar at a position of 50 mm from the cover.

As shown in Fig. 5, each sensor was installed to detect the difference between the sea side, center, and mountain side of the pier. Two expansion ring sensors were installed in the central and on the sea side, and a total of six RFID corrosion environment sensors were installed in two stages in three locations, that is, the sea side, center, and mountain side.

In addition, connected a cable to the rebar and measured the self-potential to compare the measurement results of each sensor using the conventional self-potential method.

5 Measurement method and measurement items

5.1 Measurement method

Fig. 6 shows the measurement situation of the expansion ring and RFID corrosion environment sensor. The expansion ring sensor measures the potential difference and corrosion current with the separately attached cathode using a dedicated measuring instrument.

The RFID corrosive environment detection sensor uses a dedicated reader/writer to transmit radio waves to the embedded RFID unit, measure the resistance value of the detection unit, and receive the resistance value measured by the reader/writer.

The self-potential was measured between the cable attached to the rebar and concrete surface during construction.

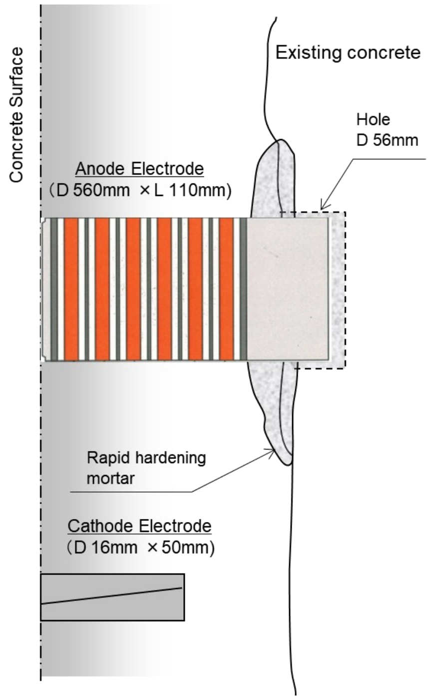

Fig. 3. Installation status of Expansion Ring Sensor System.

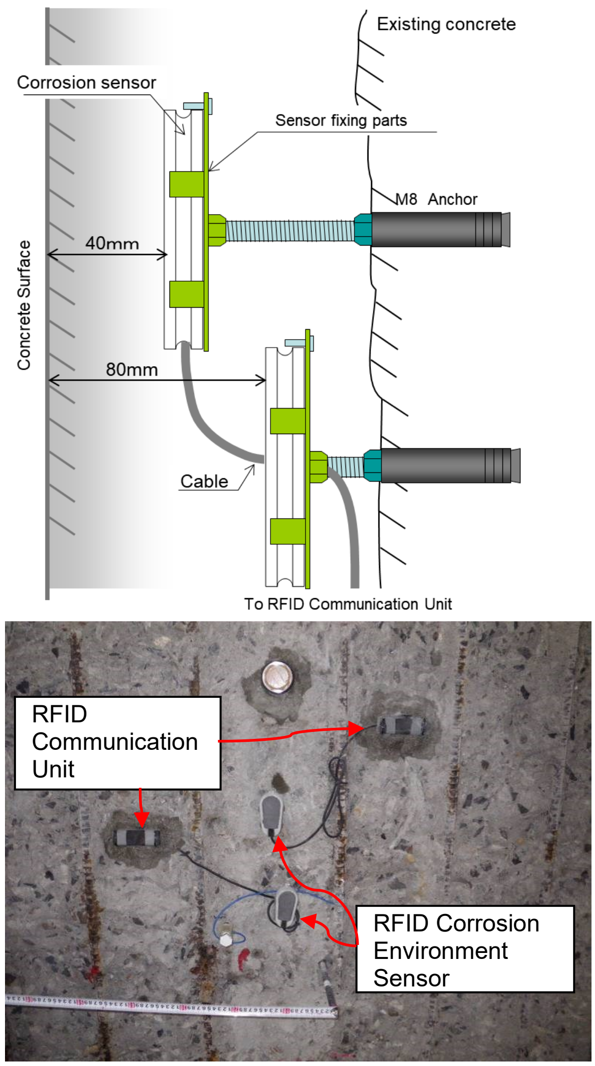

Fig. 4. Installation status of RFID Corrosion Environment Sensor.

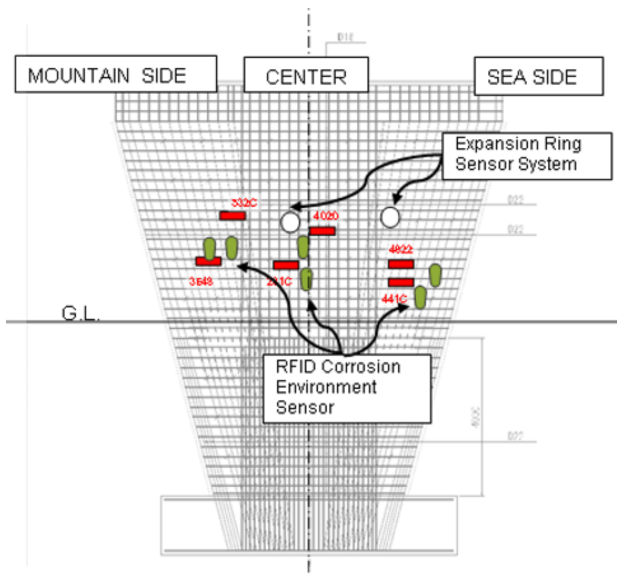

Fig. 5. Installation positions of various sensors.

Fig. 6. Measurement status of various sensors. (Up : Expansion Ring Sensor System, Under : RFID Corrosion Environment Sensor.)

5.2 Measurement timing

Periodic measurements were conducted once a year for the first five years. Then, the measurements were conducted once each in the 7th and 10th years, for a total of seven times over the 10-year period. In the 5th and

10th years, collected cores from the structure and determined the status of permeation of chloride ions.

6 Measurement result

6.1 Current density change in expansion ring sensor

Fig. 7 shows the change in the current density of the expansion ring sensor installed on the sea side, and Fig. 8 shows the measurement results of the sensor installed in the central part. With the expansion ring sensor installed on the sea side, it took 4.5 years for the detection part from 1 to 4 cm to detect corrosion, and 5.5 years for all detection parts to detect corrosion. With the expansion ring sensor installed in the central part, all the detection parts detected corrosion after 2.5 years.

Originally, the expansion ring sensor corresponded to a structure that measures corrosion in stages via salt penetration from the surface. However, it is presumed that the salt penetrated the contact interface (cylindrical side) between the main body of the sensor and structure and corroded to the deepest detection part at 6 cm in a short period of time.

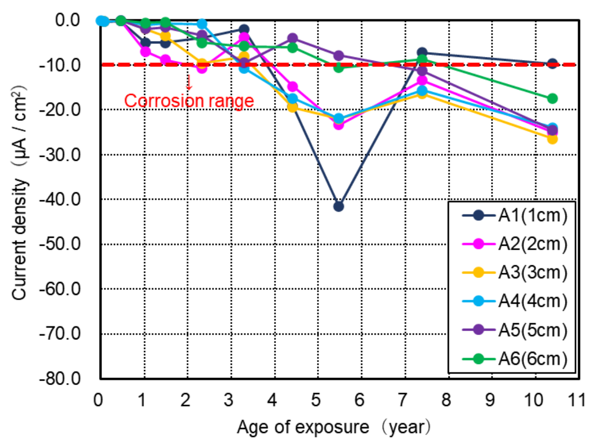

Fig. 7. Measurement results of Expansion Ring Sensor System. (SEA SIDE)

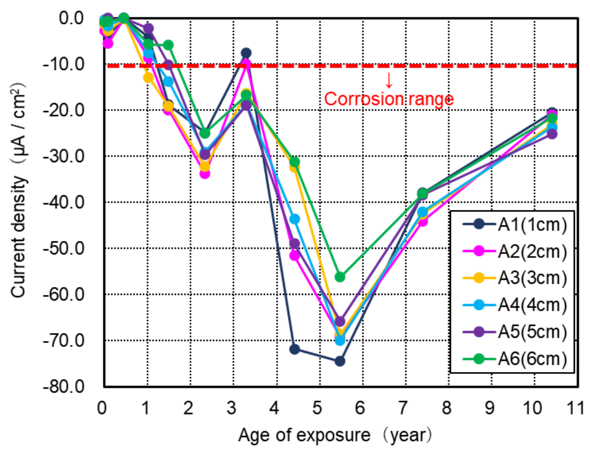

Fig. 8. Measurement results of Expansion Ring Sensor System. (CENTER)

6.2 Measurement results of RFID corrosion environment sensor

With respect to the RFID corrosive environment detection system, measurement was possible without any problems even after 10 years, confirming its long-term durability. As shown in Fig. 9, even after 10 years, 5 out of 6 pieces were estimated to be in a good state without corrosion. However, one sensor installed in the central part, 80 mm from the cover, was determined to be corroded. Additionally, a crack with a width of approximately 0.2 mm was observed on the surface of the installation part of the sensor, which was used to determine corrosion. Furthermore, it was presumed that the crack penetrated to the sensor position and chloride ions entered from the surface along with moisture, or that the chloride ions that were present before the repair moved to the repaired area, as described below. This resulted in the, corrosion of the sensor.

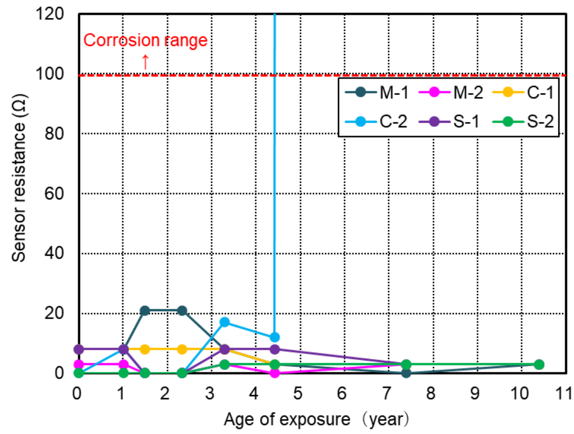

Fig. 9. Measurement results of RFID Corrosion Environment Sensor.

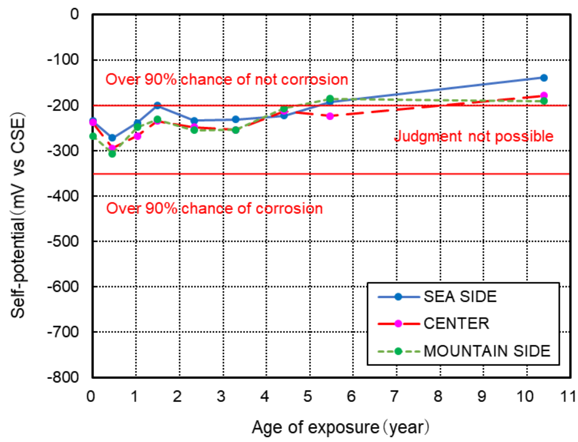

Fig. 10. Measurement results of self-potential

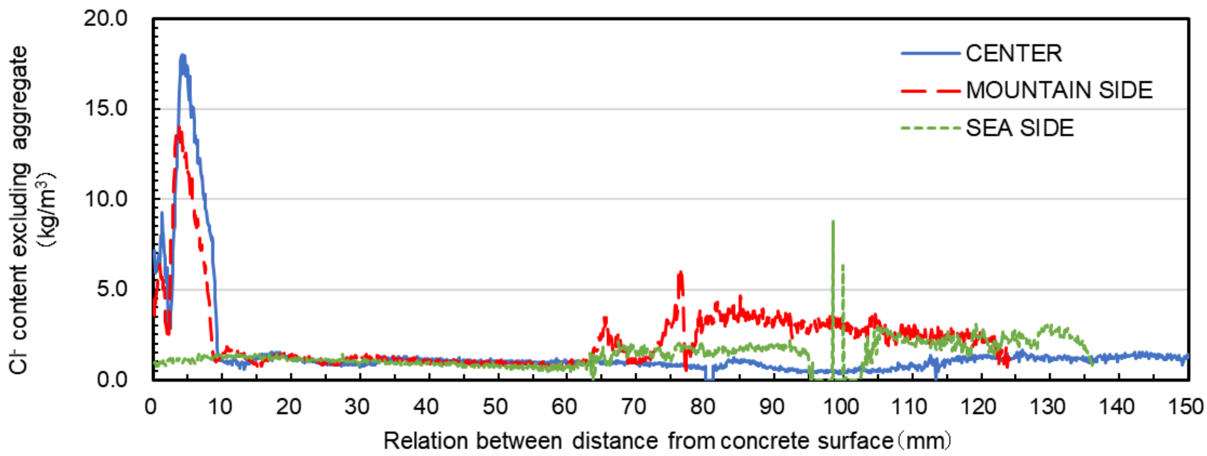

Fig. 11. Results of EPMA analysis of chloride ions in collected cores. (5th year)

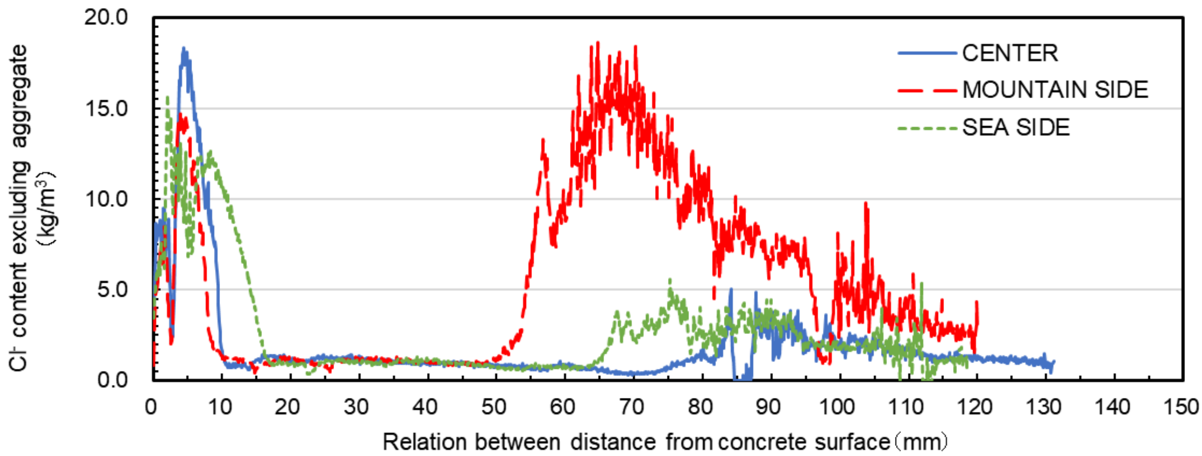

Fig. 12. Results of EPMA analysis of chloride ions in collected cores. (10th year)

6.3 Results of self-potential measurement

Fig. 10 shows the results of self-potential measurement of internal reinforcing bars. As for the self-potential, the occurrence of corrosion was in an uncertain region from the beginning of construction regardless of the position of the reinforcing steel. Even after 10 years, there was no significant change, and it did not reach the area where corrosion was 90% or more. A visual inspection conducted in 2010 revealed multiple cracks on the surface of the entire structure, suggesting that chloride ions penetrated locally.

6.4 Progress of distribution of chloride ions

Figs. 11 (5th year) and 12 (10th year) show the results of EPMA analysis of the state of chloride ion permeation in the cores sampled in the 5th year and 10th year. In the 5th year, except for the sea side, the highest salinity concentration was approximately 14 to 18 kg/m^3 at a depth of 5 mm from the surface. At the 40-mm cover position, where the RFID corrosion sensor is installed, the salinity concentration was approximately 1 kg/m^3 at all positions. At the 80-mm position, the salinity concentration was in the range of 0.7–3 kg/m^3, showing a significant difference depending on the location, with the highest salinity concentration on the mountain side.

The 10th year result showed the highest salinity concentration of 15–18 kg/m^3 at the 5-mm position from the surface, which was similar to that in the 5th year. At the 40-mm position of the cover, the salinity was approximately 0.9–1 kg/m^3, and at the 80-mm position, the salinity was in the range of 1.6–10 kg/m^3, showing a significant difference based on the location.

This result shows that the salinity near the surface is affected by the airborne salinity from the sea, and it is speculated that the salinity concentration, which is deeper than that at approximately 90 mm, is due to the internal salinity that permeated before repair.

Additionally, when comparing the 5th year and 10th year, the salinity concentration at the 80-mm position on the mountain side was more than three times higher in the 10th year than that in the 5th year. This is presumed to be due to the concentration difference between the repaired part and internal salt content that permeated before the repair and moved to the surface side over time.

7 Comprehensive evaluation of various measurement results

Corrosion has also been confirmed in the RFID corrosion environment detection system and expansion ring sensor. Hence, it is necessary to prepare a repair plan again. Furthermore, from the results of the EPMA analysis, depending on the analysis position and depth position, the salinity concentration reached a level that corrodes the rebar, and it is considered that some type of treatment will be required at the 10th year.

Additionally, although chloride ions penetrated from the surface, they did not reach the position of the reinforcing bars, and it can be determined that there is a high possibility that the migration to the surface side of the internal salt in the existing part before repair will corrode the reinforcing steel.

However, given that the self-potential measurement does not capture reliable corrosion in the actual rebar, it does not lead to rebar corrosion that reduces the structural strength. Furthermore, at the 10th year, it is presumed to be at a level where some minor rebar corrosion has occurred.

Some of the RFID corrosion environment sensors are expected to react due to salt penetration from cracks on the surface or due to the migration of internal salt to the surface side. Therefore, the state inside the structure can be evaluated appropriately. Furthermore, even when compared with the results of self-potential, it can be estimated that appropriate evaluation can be performed as preventive maintenance. Additionally, the concrete surface, where the RFID corrosion environment sensor is installed, is the same as other locations, and the sensor does not adversely affect the structure.

Conversely, corrosion was confirmed in all the detection parts of the expansion ring sensor, and the result differed from the actual degree of penetration of chloride ions and corrosion state of the rebar as observed from the self-potential. Hence, it is suggested that, while sensors exposed to the surface, such as expansion ring sensors, are easy to install and measure, installation of the sensor itself may promote the intrusion of salt.

8 Conclusions

The following points were clarified based on the results of this research.

(1) It is expected that the RFID corrosion environment sensor appropriately captures the permeation state of chloride ions inside the structure.
(2) Some parts of the expansion ring sensor are exposed from the surface, allowing salt to enter the sensor. Hence, there is a concern with respect to early detection of corrosion.
(3) The target structure of this study is expected to require early repair due to the intrusion of chloride ions from the surface and migration of internal salt to the surface side.

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