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Corrosion Monitoring of Steel Bars in Port Concrete Structures

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ABSTRACT

To enhance durability of port concrete structures and prolong their service life, it is of importance to evaluate residual structural performance of the structures based on results of periodical inspection. Normally, the inspection is conducted by visual observation of surface appearance of the structures. However, it is impossible to detect initiation of corrosion of steel bars by the visual observation since the corrosion occurs inside the concrete, although the corrosion of steel bars is the most influential factor of degradation of port concrete structures. To realize preventive maintenance of the structures aiming to lifecycle cost reduction and sustainability, it is necessary to detect the corrosion of steel bars as early as possible by continuous monitoring. This paper describes the result of corrosion monitoring of steel bars in concrete of superstructure of an existing port structure, indicating the effectiveness of corrosion monitoring by measuring half-cell potentials of steel bars continuously.

Keywords. corrosion monitoring, port structure, half-cell potential, preventive maintenance

INTRODUCTION

For strategic maintenance of port structures, information about deterioration and deformation occurring in the structures shall be obtained from periodical inspection and real-time monitoring to assess the residual performance of the structures and also predict the future change in the performance. Based on the results of assessment and prediction, appropriate countermeasures shall be planned and executed if necessary. The flow of strategic maintenance of port structures is illustrated in Figure 1. At present, periodical inspection to port structures depends on visual observation to surface appearance of the structures. However, quantitative and reliable information is not always obtained from the periodical inspection. It is because the results of the visual observation are qualitative, and also differ inspector by inspector.

On the other hand, nondestructive testing methods are widely used not only in the field of electrical and mechanical engineering and medicine, but also in the field of civil engineering. For example, some of deterioration and deformation such as flaws and cracks can be detected in steel structures and concrete structures by nondestructive testing methods. However, at present, nondestructive testing methods are not utilized in periodical inspection to port concrete structures, and in also real-time monitoring, that is useful for integrated maintenance, is not applied to the actual maintenance of port concrete structures.

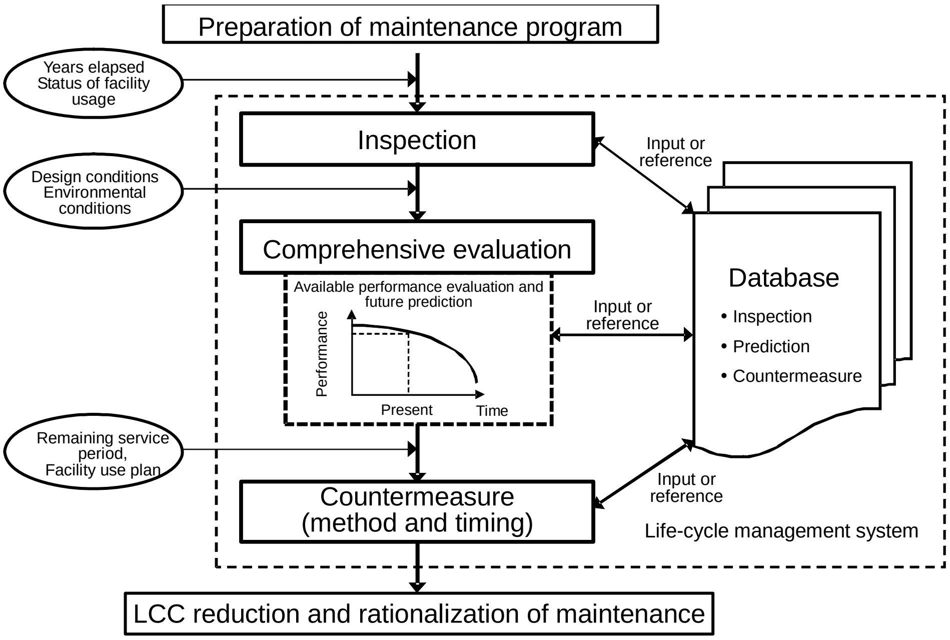


Figure 1. Flow of strategic maintenance of port facilities

Corrosion of steel bars is often observed in port concrete structures, resulting in degradation of structural performance. However, since corrosion of steel bars occurs inside of concrete, it is impossible to detect the initiation of corrosion from surface appearance of the structures by periodical inspection. Once the corrosion starts, it is rather difficult to stop the progress of corrosion, necessitating urgent repair works. To decide the suitable method and timing of preventive repair against steel bar corrosion, it is necessary to know when the corrosion starts inside of concrete nondestructively. Electrochemical measurement have been used to estimate the presence of steel bar corrosion, especially half-cell potential measurement is believed to be practical and useful (Samples and Ramirez, 2000).

In this study, to establish a nondestructive monitoring method of steel bar corrosion in port concrete structures damaged by chloride attack, half-cell potentials of steel bars in concrete had been monitored for 10 years at a superstructure of open-type wharf.

OUTLINE OF CORROSION MONITORING

Target Structure. Corrosion monitoring of steel bars in concrete was conducted at a superstructure of open-type wharf in a Japanese port. The open-type wharf (water depth = -

12m) consists of steel pipe plies and reinforced concrete superstructures, as shown in Figure 2. The open-type wharf was about 25 years old at the commencement of corrosion monitoring. Based on the result of visual observation to surface appearance of the superstructures, a relatively sound beam was selected for the corrosion monitoring. The cross section of the beam was 0.8m by 1.0m. The clearance between the bottom surface of the beam and H.W.L. was about 0.5m. According to Maintenance Manual of Port Facilities in Japan (Port and Airport Research Institute, 2007), the deterioration level was judged as "d" at the commencement of the corrosion monitoring. It means that no symptom of deterioration and deformation is observed at the surface of the beam.

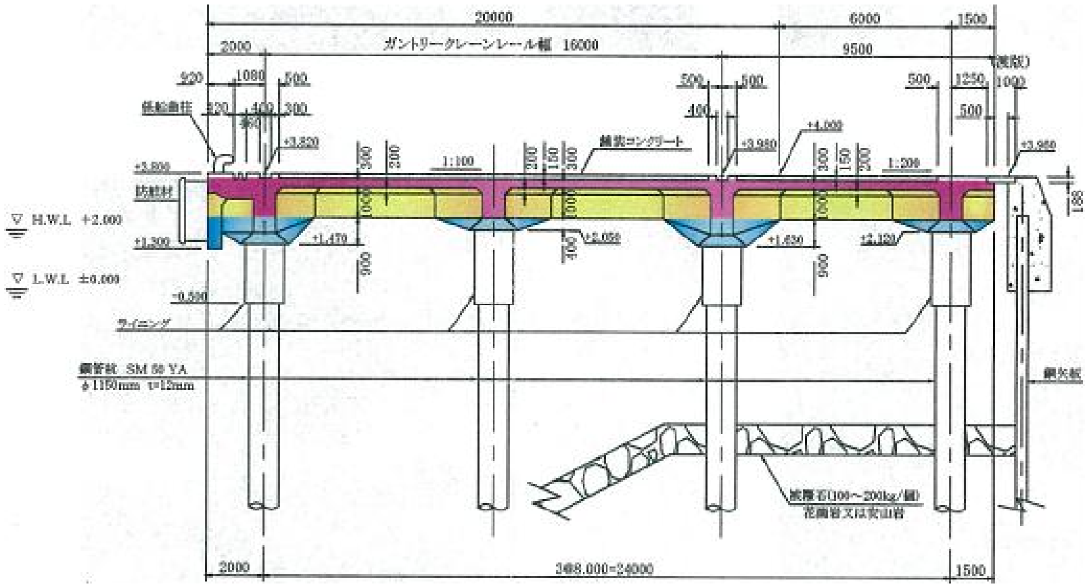


Figure 2. Cross-sectional view of target structure

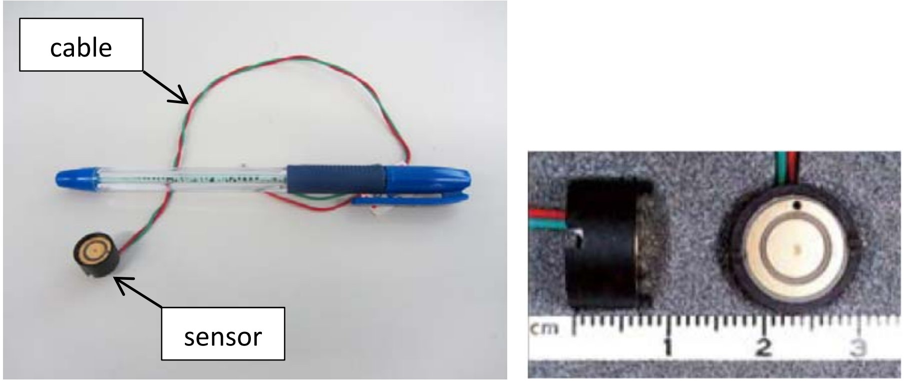


Figure 3. Sensor for corrosion monitoring

Sensor Installation. Figure 3 is the outside appearance of the sensor used for corrosion monitoring. In the figure, a ball-point pen is also included for reference of size. As indicated Figure 4, sensors were embedded in concrete to measure half-cell potentials of a steel bar in concrete. The sensor was 13mm in diameter and 7mm in height, similar to the size of aggregate. It enabled us to install the sensor as close to the bar as possible, and to mitigate the influence of sensor installation on deterioration process as much as possible (Nagayama, et al., 1996). The reference electrode of the sensor was made of gold film, which is considerably durable under severe conditions such as marine environments. The diameter of the reference electrode was 4mm.

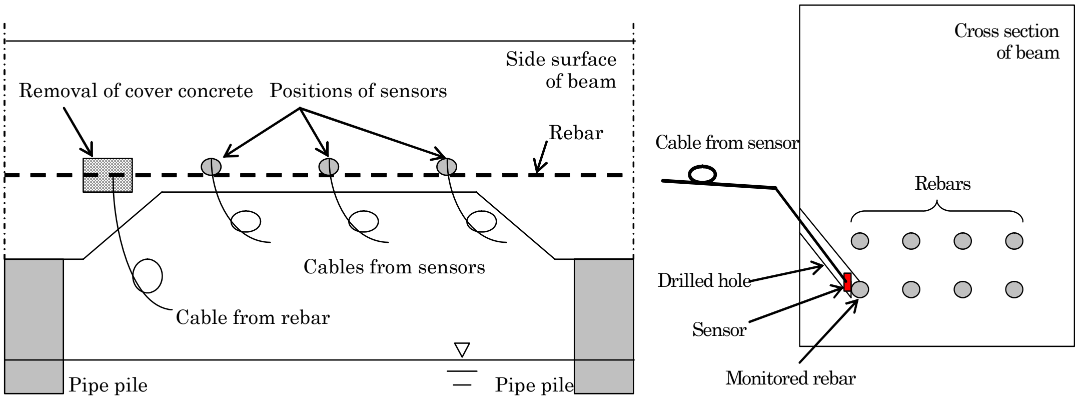
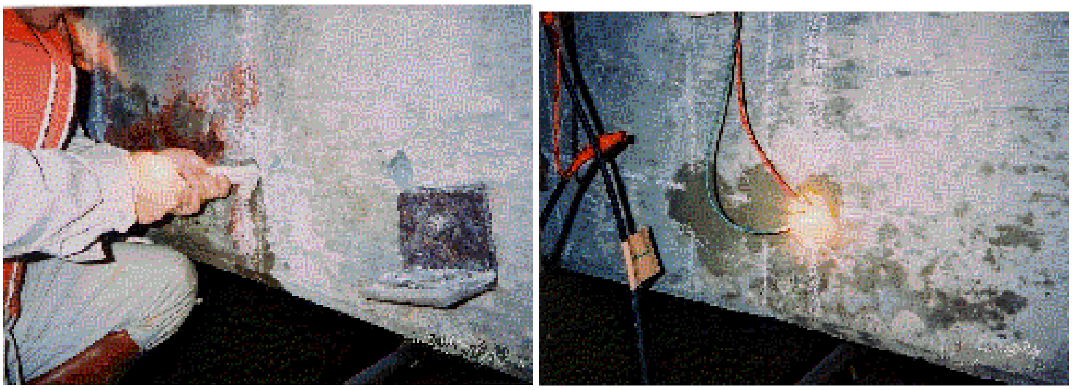


Figure 4. Outline of sensor installation

(a) Before installation

(b) Cable for electric short-circuit



(c) Pushing the sensor into the hole

(d) Completion of installation

Figure 5. Procedure of sensor installation

At 3 points on a side surface of the beam, drilling was made up to the vicinity of the measured steel bar. The diameter of drilled holes was 24mm. After fresh mortar was poured into the hole by the depth of about 20mm, the sensor was pushed into the fresh mortar so that the distance between the sensor and steel bar was about 10mm. Then, the rest of drilled hole was fulfilled with non-shrinkage mortar. Besides, a cable for electric short-circuit was directly connected with the measured steel bar after removing a part of concrete cover. Figure 5 illustrates a series of work for sensor installation.

Procedure of Corrosion Monitoring. The cables from the sensors and the steel bar were extended up to the apron, and put into a cable box. At the measurement, half-cell potentials were measured by a portable voltmeter after connecting the cables. By doing so, there is no need to attach the sensor to the concrete surface, omitting temporary scaffolds under the superstructure and works on boats.

As seen in Figure 5(b), it was confirmed that no corrosion was observed in the measured steel bar at the position of cable connection when removing the cover concrete. The cover depth of steel bar was about 130mm. The chloride ion concentration of concrete in the vicinity of the steel bar was 0.47kg/m^3, which was measured by concrete powder obtained at drilling for the sensor installation. From this fact, it was estimated that corrosion of steel bars in this beam would be initiated in the near future, although the symptom of deterioration was not observed at the time.

RESULTS AND DISCUSSION

Change in Half-Cell Potential. Figure 6 shows the change in half-cell potentials measured for 10 years from the commencement of corrosion monitoring. The values of half-cell potentials in the figure were converted into the values against saturated copper sulphate electrode. No.1 to 3 in the figure indicate the positions of half-cell potential measurement; No.1 is sea-side, No.3 is land-side, and No.2 is in between. At the beginning of monitoring, half-cell potentials of the steel bar ranged between -150mV and -20mV, showing the possibility that no corrosion occurred in the steel bar according to the ASTM criteria (American Society for Testing and Materials, 1977). This agreed with the fact revealed at removal of the concrete cover, mentioned above.

However, about 5 years (about 1800 days) after the commencement of corrosion monitoring, half-cell potentials measured at No.1 shifted toward negative direction. According to the ASTM criteria, it was not clear if the corrosion started in the steel bar, while the trend of measured half-cell potentials was apparently different from those measured at other points, even considering scatters of measured half-cell potentials with time. It is well known that such a drop in measured potentials was observed in experiments where steel bar corrosion was artificially accelerated in room (Islam and Sugiyama, 2009).

To investigate the reason for this change in the measured half-cell potentials at No.1, visual observation was carried out to the bottom surface of the beam. It was when about 2400 days passed after the corrosion monitoring started. For the visual observation, temporary scaffolds were placed under the superstructure. As a result, rust stain was observed at the bottom surface of the beam near the measuring point of No.1, as shown in Figure 7. It was considered that the change in half-cell potentials at No.1 was caused by steel bar corrosion, showing effectiveness of corrosion monitoring of steel bars in concrete by continuous measurement of half-cell potentials.

The visual observation revealed that the steel bars inside concrete of the target structure would be corroded to some extent, necessitating suitable repair to the superstructure. Consequently, the structure was repaired by cross-sectional restoration method after the contaminated concrete was removed. The concrete near the measuring position No.1 was removed for this repair, resulting in termination of corrosion monitoring at No.1. Corrosion monitoring at both No.2 and No.3 was continued even after the repair work. As seen in Figure 6, the half-cell potentials measured at No.2 and No.3 were consistent with the values before the repair work. This means that the repair work was done effectively without poor construction. It can be said that corrosion monitoring by measuring half-cell potentials of steel bars in concrete is also promising for one of construction control methods for repair work against steel bar corrosion.

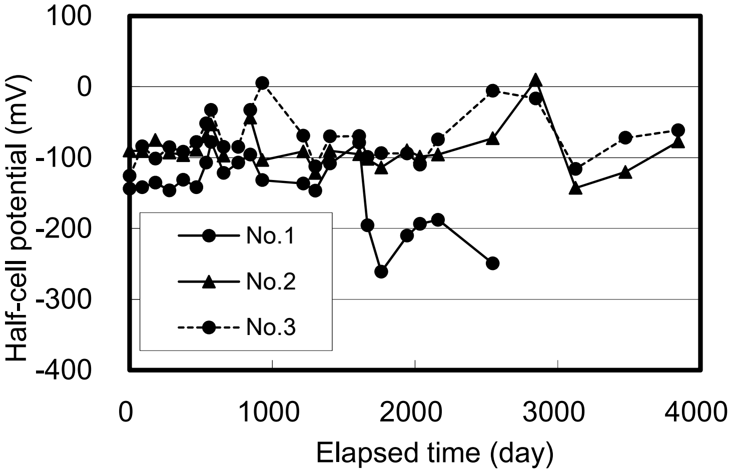


Figure 6. Result of half-cell potential measurement

Figure 7. Bottom surface of beam near No.1

Scatter of Measured Values. As seen in Figure 6, it was found that measured values of half-cell potentials scattered more or less. One of the reasons for the scatter was considered the influence of temperature on half-cell potentials of steel bars in concrete. Although temperature in air is not exactly the same as temperature inside concrete, the influence of temperature in air on measured half-cell potentials was investigated. Figure 8 shows the relationship between temperature in air and half-cell potentials measured at No.2, while the measured values at this point were relatively stable. From this, it was found that the higher the temperature in air, the smaller the measured half-cell potential. A solid line in the figure is the regression line of measured data. The slope of this line was -1.2mV/degree C, similar to the value obtained from the laboratory test (Matsuoka, 2005).

Furthermore, the range of half-cell potentials for the same temperature in air was about 50mV. It was considered that the range of 50mV was smaller than the scatter observed at the corrosion monitoring as shown in Figure 6. Therefore, it seemed that other factors than temperature existed, necessitating further researches on this matter to establish the corrosion monitoring by half-cell potential measurement.

Within the range of this study, the scatter of measured half-cell potentials lied between 50mV and 100mV. In judging corrosion initiation of steel bars in concrete based on results of half-cell potential measurement, the range of this scatter should be carefully taken into account.

Judgment Criteria for Corrosion Initiation. Comparing the measured half-cell potentials with the actual state of steel bar corrosion, it was consequently confirmed that the ASTM criteria was practically valid and useful. According to the past research, the ASTM criteria is not always valid for judgment of initiation of steel bar corrosion in port concrete structures where concrete cover is relatively large and chloride ion concentration is considerably high. In this study, since the sensor was placed very close to the measured steel bar, the influence of cover concrete on half-cell potentials seemed small, being negligible. It was concluded that, in case of corrosion monitoring on superstructure of open-type wharf, the sensor for measuring half-cell potentials should be placed as close to steel bars as possible, as conducted in this study.

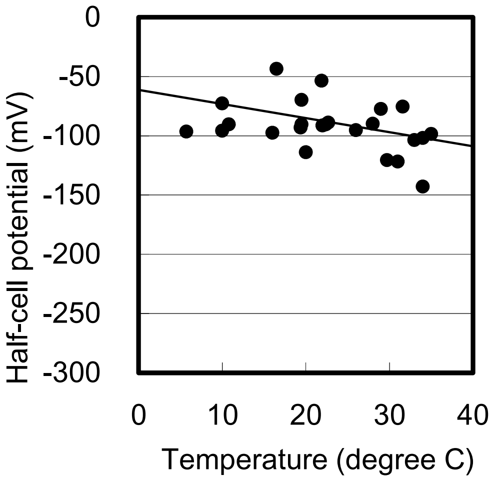


Figure 8. Influence of temperature on half-cell potentials

CONCLUSIONS

This paper described the result of corrosion monitoring on an existing port concrete structure. In the test, half-cell potentials of a steel bar in concrete had been monitored for 10 years at a superstructure of open-type wharf in a Japanese port. The measured potentials dropped below the threshold value proposed by the ASTM criteria 5 years after the commencement of monitoring, expecting the initiation of corrosion. To confirm this expectation, visual observation was conducted to the bottom surface of the superstructure. As a result, rust stain was observed close to the measuring point where the half-cell potentials were shifted. It means that measurement of half-cell potentials of steel bars in concrete is effective for corrosion monitoring of port concrete structures. However, there existed many kinds of factors which caused measurement errors, such as temperature. The influence of these factors on measured data and the threshold of judgment of corrosion initiation should be further investigated.

At the moment, laboratory tests are being conducted to propose suitable threshold values of half-cell potentials for corrosion monitoring of port concrete structures. In the examination, specific conditions of port concrete structures are considered such as cover thickness, humid condition of concrete, chloride ion content. Also, an appropriate arrangement of sensors embedded in port concrete structures is investigated using the obtained data through probabilistic approach.

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REFERENCES

American Society for Testing and Materials. (1977). "*Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete*", ASTM C876-09

Islam, G. M. S. and Sugiyama, T, (2009). "Corrosion Monitoring Rebars in Concrete under Accelerated Chloride Environment", *Proceedings of 4th International Conference on Construction Materials*, pp.255-262

Matsuoka, K. (2005). "*A study on quantitative corrosion evaluation of steel bars in RC structures by polarization resistance method*", PhD Thesis submitted to Osaka University, in Japanese

Nagayama, M., Tamura, H. and Shimozawa, K. (1996). "Rebar corrosion test method using both a corrosion current meter and embedded minisensors", *Proceedings of the Japan Concrete Institute, Vol.18, No.1*, 807-812, in Japanese

Port and Airport Research Institute. (2007). "*Maintenance Manual of Port Facilities in Japan*", Coastal Development Institute of Technology, in Japanese

Samples. L. M. and Ramirez, J. A, (2000). "Field Investigations of Concrete Bridge Decks in Indiana: Part I: New Construction & Initial Field Investigation of Existing Bridge Decks", *Concrete International, Vol.22, No.2*, pp.53-56