A Case Study on the Application of a New Arrangement of Galvanic Anode System on Existing Marine Structure

Thanh Tung Tran
Graduate School of Natural Science and Technology, Kanazawa University, Ishikawa, Japan
Email: tung.tran@stu.kanazawa-u.ac.jp

Tuan Minh Ha
Faculty of Geosciences and Civil Engineering, Kanazawa University, Ishikawa, Japan
Email: tuanha@se.kanazawa-u.ac.jp

Hiroaki Kameda
Kokudo Kaihatsu Center Co. Ltd., Japan
Email: kameda_hiroaki@kokudonet.co.jp

Toshiyuki Aoyama
P.S. Mitsubishi Construction Co., Ltd., Japan
Email: t-aoyama@psmic.co.jp

Kazuyuki Torii and Saiji Fukada
Faculty of Geosciences and Civil Engineering, Kanazawa University, Ishikawa, Japan
Email: torii@se.kanazawa-u.ac.jp; saiji@se.kanazawa-u.ac.jp

***Abstract*—Concrete structures in a marine environment or exposed the salinity are vulnerable due to both physical and chemical deterioration process. A large number of reinforced concrete bridges built during the high economic development period in Japan will be at risk of serious damage caused by salt damage if there are no timely remedial measures. The repair of these structures by conventional methods is costly and difficult in securing traffic regulation. In this study, the authors proposed a new arrangement of galvanic anode system at low cost and convenient in replacement as well as its application to the existing marine structure. Preliminary results from the experiment indicated that this method was effective in corrosion suppression through the recognition of steel depolarization performance. The monitoring of the experiment will be continued with the expectation that the structural longevity will be extended from 20 to 25 years.**

***Index Terms*—Galvanic anode system, Depolarization performance, Salt damage, Corrosion.**

I. Introduction

The experiment carried out on a jetty bridge located in the Hokuriku region - Japan, a narrow band of hilly country and adjacent to the sea, is known for its climate characterized by damp winter and heavy snowfall. For nearly three decades, under the influence of seawater, flying salinity due to wind season as well as the use of anti-freezing agent has caused severe damage to the structure. Physical damage comes from the formation of salt crystallization, which results in volume expansion, salt hydration pressure and salt crystallization pressure, while chemical damage will cause corrosion in the reinforcement, which is the main cause of concrete deterioration. The degradation of concrete negatively affects to structure performance, shown through increasing cracks and deflection, as well as decreasing capacity loading. Furthermore, a report from Rodriguez et al. showed that the beam strength decreased by 23% when a corrosion degree of rebar reached 14% [1]. In additional, Misra and Uomoto noticed that only 2.4% of the reinforcement rusted can cause a degradation by 17% of beam's bearing capacity [2].

Cathodic protection is known as an essential treatment method for salt damage of concrete. The main purpose of this measure is to reduce the rebar corrosion by lowering its potential. This can be done by either connecting steel with an external anode (sacrificial anode), which is usually a higher active metal than the steel, or making it the cathode of an impressed current system.

This study presents a new arrangement of galvanic anode system for repairing salt damage with the advantage of being low cost and replaceable, suppressing steel corrosion and increasing service life that is expected from 20-25 years. The discrete zinc sacrificial anode is

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installed in the drilled holes of the parent concrete, which can be replaced since the amount of zinc is consumed.

The work also included an experiment on the application of the new arrangement galvanic anode system to the real marine structure after the previous study which is mentioned in the reference of [3]. In that research, two series of experimental systems were conducted. Series I was made on specimens of reinforced concrete slabs manufactured in the laboratory, with the aim of assessing the effect of water leakage through the cracks to the current protection distribution, thereby confirming the preference of the galvanic anode system compared to impressed current system. Series II is the implementation of this galvanic anode system to the existing structure, a steel bridge reinforced concrete deck slab that has served 38 years in the snow-cold district, heavily influenced by deicing salt in winter seasons. The results indicated that if the criteria for evaluating depolarization performance is specified at a value of 100 mV, which is usually taken as the standard in cathodic protection, 20%-40% of the measurement points are satisfied [3]. However, if a depolarization amount of 50 mV is considered as effective corrosion suppression, up to 40%-70% of locations have good responses [3].

In this study, the new arrangement of galvanic anode system continued to be applied to a beam of the jetty bridge, which has been located in the marine environment for many years. Preliminary results have shown that the depolarization effect was consistent. The comprehensive evaluation of the effectiveness of this method will be declared after the end of the experiment.

II. Overview of Galvanic Anode System

The system with the main device is the galvanic anode (as shown in Fig. 1 and Fig. 2) consisting of a plurality of 30 mm diameter zinc plates stacked and 125 mm in length. The core is fitted with an M6 bolt for easy installation and replacement. After inserting in the depth of 250 mm drilled hole, a backfill compound will be injected to fix the galvanic anode and more importantly, to provide an environment which is conductive for anode dissolution.

III. Experiment Methods

Fig. 3 describes the installation procedure. The experiment was carried out on a beam segment with a length of 3100 mm and wide of 800 mm as shown in Fig. 4-6. On the lateral sides of the beam (the North and South sides), there were 8 positions for galvanic anode installation, divided into 4 locations for each side. In addition, two locations for drain points, where Polyvinyl chloride (PVC) pull box 100x100x100 mm will be installed, and five locations for titanium wire sensor (WS) Ø3 x L75 mm were also arranged.

In the preparation work, a survey will be conducted with radar machines to detect the positions of the steels, then the appropriate locations will be marked. After that, on the lateral and bottom surface of the beam, 8 drilled holes with 40mm of diameter will be provided for the galvanic anode, 2 drilled holes with 80mm of diameter for drain points (Fig. 7) and 5 drilled holes with 20mm of diameter for titanium wire sensors. A rectangular grid of 100x200 mm was marked as basic for later measurement of potential (Fig. 8).

The reinforcement continuity is checked between two drain points, before connecting galvanic anode with steel through the wires put in cutting grooves of 30mm of wide, which then are covered with final finishing material.

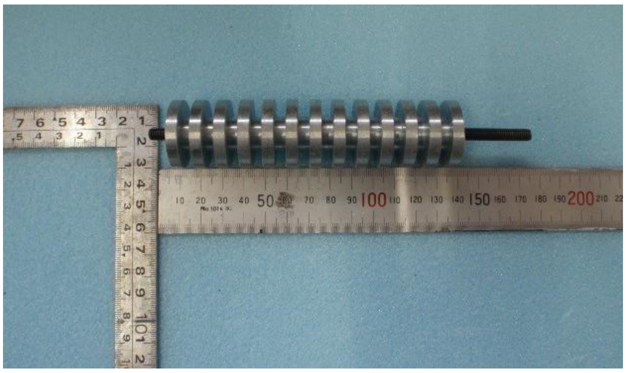

Figure 1. Galvanic anode before installation

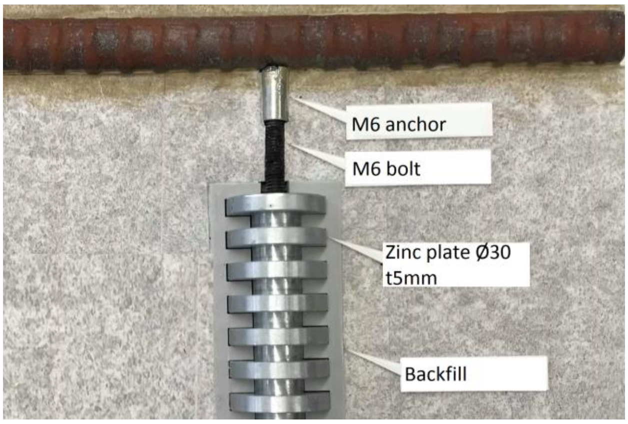

Figure 2. Galvanic anode in the parent concrete

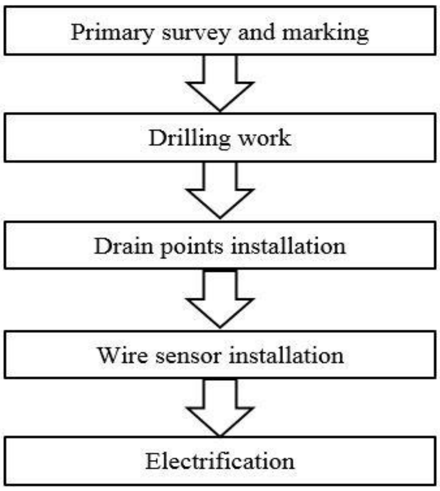

Figure 3. Galvanic anode system construction flow.

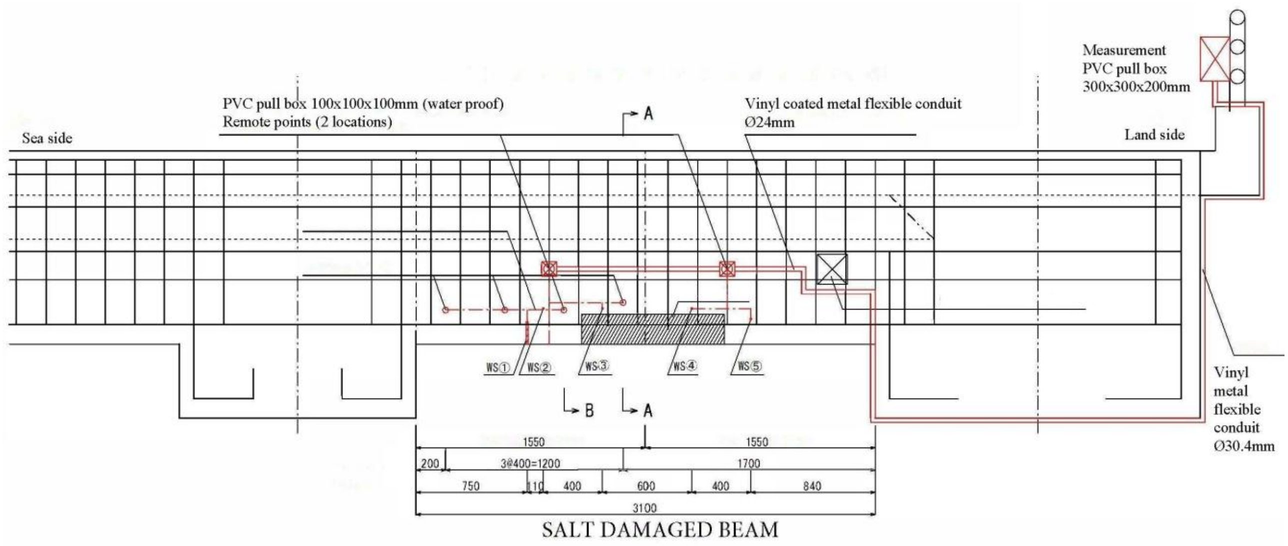

Figure 4. Beam from south side (unit: mm)

Titanium wire sensor (Fig. 9 and Fig. 10) is also set up in 5 positions to separately record the potential of steel. In future, a multi-sensor system will be developed with expectation of providing an automatic measurement and high accuracy.

Finally, a good electrical conduction between anodes and steels is confirmed before the entire system is connected to the measurement box (PVC pull box 300x300x200 mm) along with the data logger installation.

IV. Results and Discussions

A. Chloride Ion Concentration

Chloride ion concentration was measured from concrete cores according to JIS A 1154 (Japanese Industrial Standards). The concrete cores were sliced into a 10 mm-thick layer and classified according to groups of 0-20 mm, 20-40 mm, 40-60 mm, 60-80 mm and 80-100 mm, of which the number is the depth of concrete measured from the concrete surface.

For each of these groups, three samples were taken and tested, the average value was shown in the graph as per Fig. 11.

The chart shows that the highest chloride ion concentration is 9.30 kg/m^3, corresponding to a concrete depth of 20-40 mm, and gradually decreases by the depth of concrete with the lowest value of 4.77 kg/m^3 at a thickness of 80-100 mm.

The results of chloride ion concentration ranged from 4.77 to 9.30 kg/m^3, whereas marginal chloride ion concentration for making corrosion may be set to 1.2 kg/m^3 [4], showed that the concrete located in a very aggressive environment and rebar might be rusted. In fact, based on visual observation in some critical locations after removal of the contaminated concrete, corrosion is revealed.

B. Rest Potential of Steel

Rest potential of steel or corrosion potential is the potential difference between the rebar in the concrete structure and a reference electrode measured at the time of 24 hours after the disconnection of the anode, based on method of half-cell potential measurements [5].

This measurement method (as illustrated in Fig. 8) is usually applied to find the location of the rusted reinforcement in concrete and to evaluate the degree of steel corrosion in the structure, as a basis for the design of the anode installation locations as well as the anode layout.

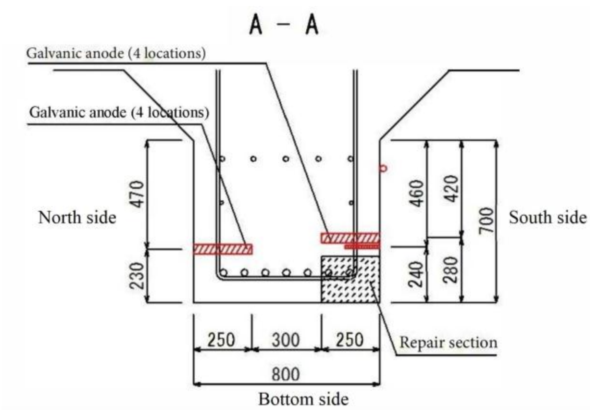

Figure 5. Beam cross section A-A (unit: mm)

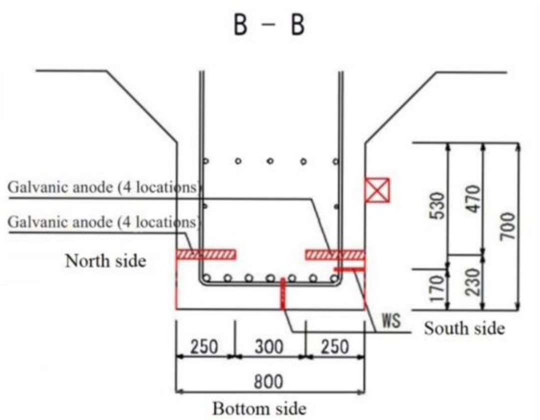

Figure 6. Beam cross section B-B (unit: mm)

In this research the reference electrode of Silver/Silver Chloride (SSE) was used, and the rest potential mapping on the rectangular grid 100x200mm after measurement was obtained as per Fig. 12.

The probability of steel corrosion is evaluated according to the rest potential which is calculated based on ASTM standard [6] and the potential conversion between SSE and Copper-copper sulfate half-cell described in reference of [7]. Finally it is summarized as followings:

- If the potentials over an area are more positive than -80 mV SSE, there is greater than 90% probability that no reinforcing steel corrosion is occurring in that area at the time of measurement.
- If potentials over an area are in the range of -230 to -80 mV SSE, corrosion activity of the reinforcing steel in that area is uncertain.
- If potentials over an area are more negative than -230 mV SSE, there is a greater than 90% probability that reinforcing steel corrosion is occurring in that area at the time of measurement.

Fig. 12 shows that exception of the points could not be measured (the cells without value), most of the potential values are less than -230 mV SSE, which is considered as a limitation for assessing the rustiness of steel. Therefore, it can be inferred that the corrosion phenomenon in the concrete beam has started and tended to thrive in the salty environment with high levels of chlorine ion concentration as mentioned above.

C. *Depolarization Performance*

To assess the corrosion suppression effect, in this experiment, the concept of depolarization performance was introduced as a criterion for evaluation. It is based on depolarization amount of steel, determined by the difference between the instant-off potential of the rebar and its potential after 24h following disconnection of anode. The depolarization difference between the 24 hours off potentials is described in Fig. 13.

It can easily be seen that, except for galvanic anode locations, the steel depolarization amount has been observed at all locations, which demonstrates the depolarization effect was consistent.

The value of the depolarization amount is categorized in different colors, in that the value of 100mV is considered as depolarization performance criterion routinely applied to galvanic anode systems [3]. According to this criterion, 12% of the total results are meeting the requirement. If a value of 50mV is considered as the parameter to evaluate, up to 50% of measured data is satisfied.

On the other hand, it seems that the amount of depolarization at a point depends on the distance from that point to the location of the galvanic anode. In fact, the results in Fig. 13 show that, for the values in the last 5 columns on the right, corresponding the measurement points with the distance to the nearest galvanic anode of 300 to 1100 mm, the depolarization performance significantly reduced when compared to the remaining locations, where the distance to the nearest galvanic anode is only 100mm.

Figure 7. Drain point

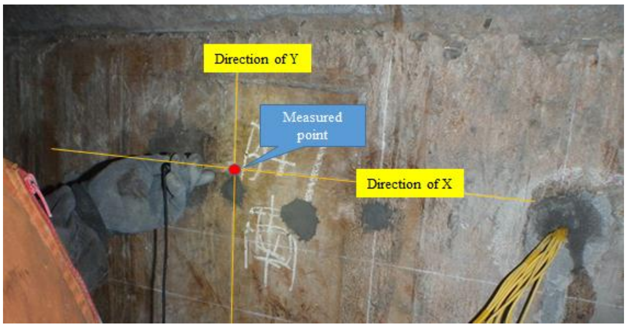

Figure 8. Rectangular grid 100x200mm

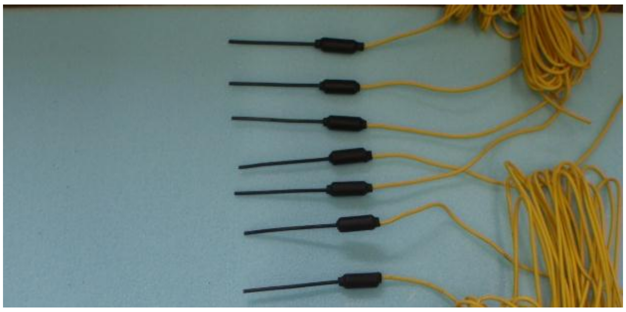

Figure 9. Titanium wire sensor

Figure 10. Wire sensor after installation

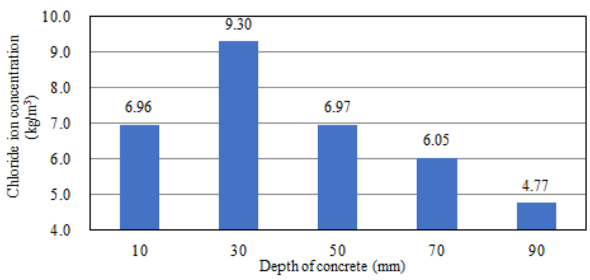

Figure 11. Chloride ion concentration

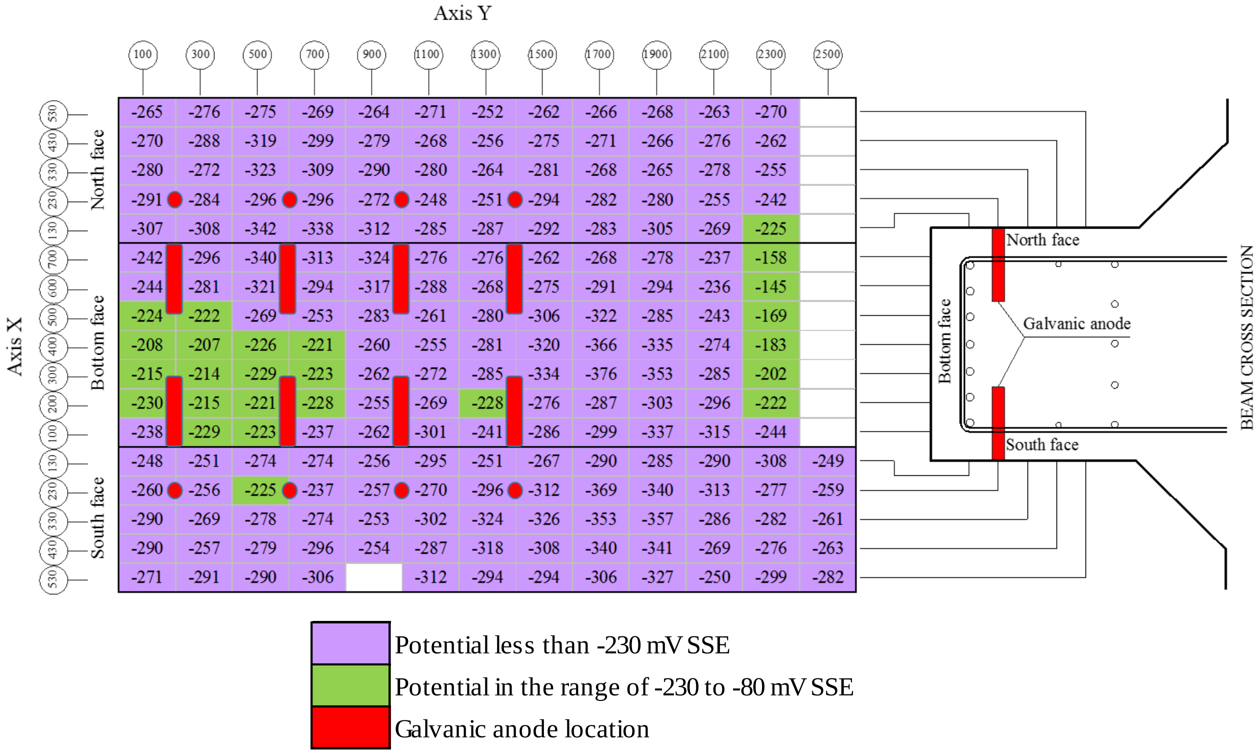

Figure 12. Rest potential mapping

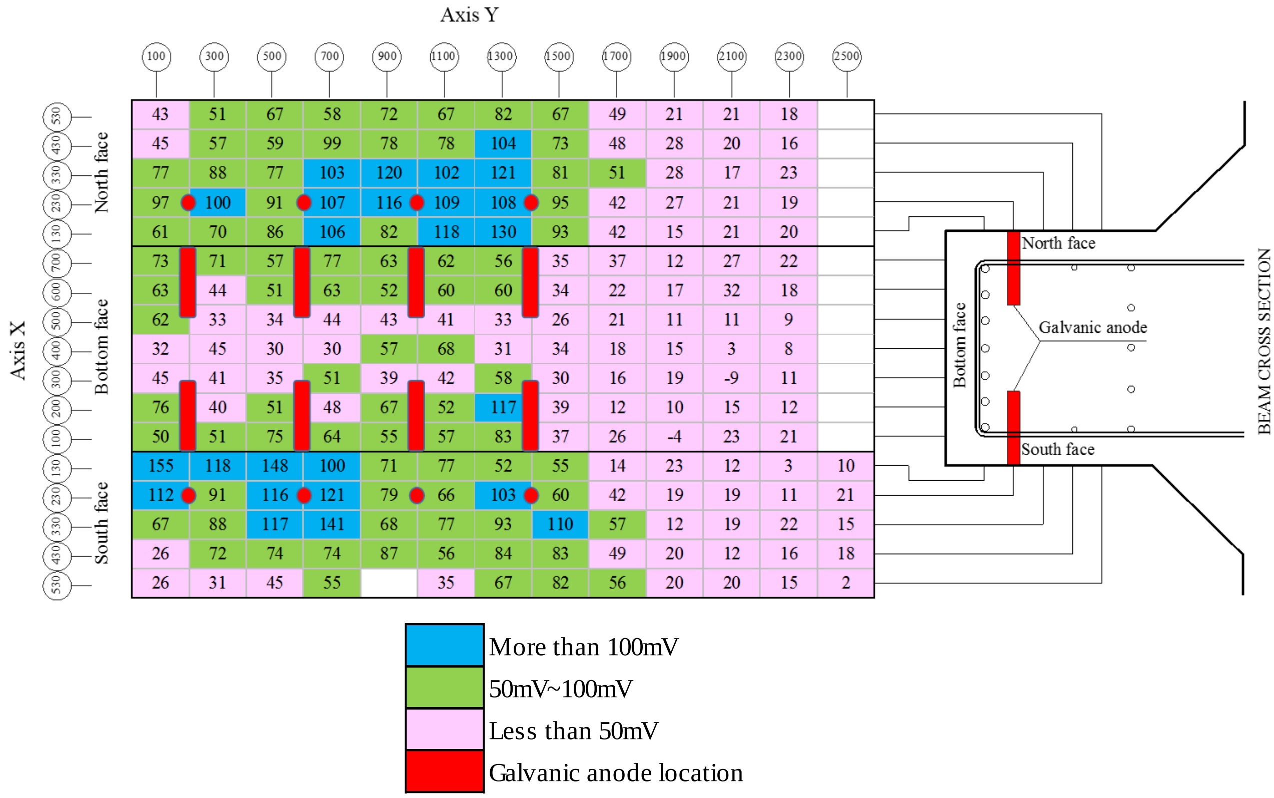

Figure 13. Depolarization performance mapping

V. Conclusions

This paper introduces a new arrangement galvanic anode system and its application on the real marine structure for the purpose of anti-corrosion. Based on the results of this study, the following conclusions are given:

1. The authors confirm that this new arrangement galvanic anode system is effective in corrosion suppression of the reinforced concrete structure and the implementation on the existing ones for corrosion

mitigation is possible. However, in order to deeply assess the performance degree of anti-corrosion, the monitoring will be maintained to determine the long term effect.

2. Depolarization performance depends on the distance from the steel to the galvanic anode. The closer to the anode, the higher the depolarization effect. The research on the maximum distance affected by galvanic anode should be proceeded to determine the location of galvanic anode installation as well as galvanic anode density.
3. The wire sensor system needs to be improved so that the potential of rebar can be measured automatically and simultaneously across the entire surface of the structure, reducing the time and increasing the accuracy of measurement.
4. Finally, the influence of the steel density and the depth of drilled hole for anode installation should be investigated in the near future, which might significantly affect steel depolarization amount as well as corrosion mitigation effectiveness.

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Thanh Tung Tran
Affiliation:
Master student, Division of Environmental Design, Graduated School of Natural Science and Technology, Kanazawa University, Ishikawa, Japan
Brief career:
2009 Faculty of Civil Engineering, University of Transport and Communications, Hanoi, Vietnam (Bachelor of Civil Engineering).

Tuan Minh Ha
Affiliation: Postdoctoral researcher, Faculty of Geosciences and Civil Engineering, Kanazawa University, Japan
Brief career:
2014 Faculty of Civil Engineering, Ho Chi Minh City University of Technology, Viet Nam (Bachelor of Civil engineering).
2016 Graduate school of Natural Science and Technology, Kanazawa University, Japan (Master of Engineering).
2018 Graduate school of Natural Science and Technology, Kanazawa University, Japan (Doctor of Engineering).
2018 Postdoctoral researcher, Faculty of Geosciences and Civil Engineering, Kanazawa University, Japan

Hiroaki Kameda
Affiliation: Kokudo Kaihatsu Center Co., Ltd, Japan.
Address: Komatsu city, Ishikawa, Japan.
Brief career:
2001/03 Department of Civil Engineering, Faculty of Engineering, Kanazawa University, Japan (Bachelor of Civil Engineering).
2004/04 Kokudo Kaihatsu Center Co.
Academic Societies & Scientific Organizations:
Japan Society of Civil Engineers (JSCE)
Japan Concrete Institute (JCI)

Toshiyuki Aoyama
Affiliation: Senior Researcher, P.S.Mitsubishi Construction Co.,Ltd.,
Address: Harumi Center Bldg.3F,2-5-24, Harumi, Chuo-ku, Tokyo, Japan
Brief career:
1998 Department of Civil Engineering, Nagaoka University of Technology, Japan (Master of Engineering).
2010 The Graduate School of Science and Engineering, Waseda University, Japan (Doctor of Engineering).
Academic Societies & Scientific Organizations:
Japan Society of Civil Engineers (JSCE)
Japan Concrete Institute (JCI)

Kazuyuki Torii
Affiliation: Professor, Dr.Eng., Faculty of Geosciences and Civil Engineering, Kanazawa University.
Address: Kakuma-machi, Kanazawa city, Ishikawa, Japan.
Brief career:
1978 Completed Master's degree, Graduate School of Kanazawa University.
1986 Completed Doctor's degree, Graduate School of Kyoto University.
1996 Professor, Department of Civil Engineering, Kanazawa University, Japan.
Academic Societies & Scientific Organizations:
Japan Society of Civil Engineers (JSCE)
Japan Concrete Institute (JCI)
Japan Society of Materials Science (JSMS)

Saiji Fukada
Affiliation: Professor, Dr.Eng., Faculty of Geosciences and Civil Engineering, Kanazawa University, Japan.
Brief career:
1999 Completed Doctor's degree, Graduate School of Natural Science and Technology, Kanazawa University, Japan
2017 Professor, Faculty of Geosciences and Civil Engineering, Kanazawa University,
Japan Academic Societies & Scientific Organizations:
Japan Society of Civil Engineers (JSCE)
Japan Concrete Institute (JCI)