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On the Determination of the Required Current Density for Designing the Galvanic Cathodic Protection of Steel Structures in Marine Environment

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PThe steel structures installed in marine environment have experienced severe corrosion problems. Consequently, those structures should be protected with appropriate methods. Cathodic protection (CP) is one of the most widely adopted corrosion control techniques in such an environment. For the proper protection of the CP system, an adequate current density should be supplied to the protected surface of steel structures. The CP technique is subdivided into two kinds, i.e. the impressed current method and the galvanic (sacrificial anode) one. The required current density for the former CP system is regulated automatically by the rectifier, which rolls as a power supplier. The second one, however, cannot be regulated automatically, because this system has no automatic function. The optimum required current density for this system, therefore, should be determined when it is designed.

Several recent investigations reported that the life of sacrificial anodes was shortened significantly. It is not clearly revealed why the life of the sacrificial anodes was shortened, however, it is assumed that the environmental conditions were changed, and the geographic parameters were not fully considered from the design stage of steel structures.

This study was focused on the determination of the optimum required current density of CP for steel structures in natural seawater. Steel plate samples applied CP in seawater with several different locations were tested to determine the optimum current density for a CP design. To establish the better test method several power supplying techniques were attempted in this study. The test period for each sample was from 7 to 60 days according to the test situation. Potential and current density were measured during the test period. The final current density was evaluated through the extrapolation from this short-term test results.

Keywords *: cathodic protection, current density, steel structure, marine environment.*

1. Introduction

Cathodic protection (CP) has been developed in many fields since it was adopted as a protection technique to the hulls of naval ships by Humphrey Davy in 1824 and now it becomes one of the most widely used corrosion protection method.[1),2)] The CP system has been recognized as the most effective and technically appropriate corrosion prevention methodology for steel structures in marine environment. Consider iron corroding in a natural electrolyte solution. The respective anode and cathode reactions are

$$Fe \rightarrow Fe^{2+} + 2e^- \quad (1)$$

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \quad (2)$$

Cathodic polarization reduces the rate of the half-cell reaction (1) with an excess of electrons, which also increases the rate of oxygen reduction and OH^- production by reaction (2).[1)]

There are two kinds of method for cathodic protection. One is the sacrificial anode method and the other is the impressed current one. In the former, the metal called as a sacrificial anode, with more active potential, connects to the protected structures electrically. The structures with a noble potential in galvanic couple are cathodically protected, while the active metals are anodically dissolved. In the latter method a rectifier supplies impressed current for cathodic polarization by converting from AC power to DC instead of galvanic metals. In Korea, the sacrificial anode method is preferred to adopt in marine environment, since this technique does not need much maintenance work. The complicated impressed current equipments are needed periodical maintenance works during an operation, because once, it is out of order, it is difficult to repair quickly and to keep in a good condition.[3] Though sacrificial anode method is needed to change anodes periodically, it is mainly used in Korea, because once anodes are installed to steel structures, less work is needed for the life time of the anodes. The anode life is around 10-20 years.

Designs of both the impressed current and the sacrificial anode systems have some common steps, as follows.[1,4,6]; 1) calculation of exposed area of structures to the environment, 2) determination of polarized potential, 3) current demand, 4) calculation of the amount of anode consumption, 5) number of anodes and their distribution, 6) anode resistance, 7) design output current. Recently, it was reported that the life of sacrificial anodes was significantly shortened than that of original designed anodes due to the relevant factors as follows; quality of anode material, flow velocity due to the geological aspect, temperature and dissolved oxygen of seawater on the location of installation.

Among the above steps, one of the most important factors for CP design is the optimum required current density.[7,8] Therefore, this study was focused on the determination of optimum required current density for CP of steel structures in marine environment. To decide the optimum required current density, potentiostatic and galvanostatic methods were attempted, and those experiments have been carried out at several different locations.

2. Experimental

In this study to determine the required current density for cathodic protection, a power supply was used. The potential of CP for steel structures in seawater is -780mV with the seawater silver-silver chloride electrode (SSCE).[7),9)]

The current density, which can keep the CP potential, therefore, is called the required current density. There are two methods to determine the required current density; galvanostatic and potentiostatic.

Galvanostatic method is that optional current density is forced to approach to -780 mV/SSCE from the beginning of experiment. Potentiostatic one is that the protection potential (-780 mV/SSCE) is forced and the final current density is determined when it approaches to a stable value. Practically -800 mV/SSCE, instead of -780 mV/SSCE, was given to compensate for field errors in a real environment. The experiments by both galvanostatic and potentiostatic methods were carried out at several different locations to decide the optimum required current density.

3. Results and discussion

3.1 Experiment No. 1

3.1.1 Experimental method

A steel plate type of specimens was selected for a galvanosatatic test, as indicated in Fig. 1 Cathode with exposed area of 0.162 cm^2, was a steel plate of 30 cm × 30 cm × 2 mm. Anode was a steel plate of 12 cm × 12 cm × 1 mm. The seawater silver-silver chloride electrode (SSCE) was used as a reference. Supplied current was adjusted by a variable resistor to control protection potential of -800 mV/SSCE.

3.1.2 Results

Fig. 2 shows the variation of potential and current density with time as the result of experiment No. 1.

The potential and the current density were controlled to keep -800mV/SSCE, 100 mA/m^2 respectively. The current density was increased several times because initial potential was -700 mV/SSCE, however, it was difficult to control the potential and the current density due to variable weather conditions. Although the potential approached around -800 mV/SSCE after 20 days, it increased over -800 mV/SSCE again. Whenever the potential increased, it was controlled to keep -800 mV/SSCE. However, the weather was so rough at that time and it was failed to get a potential of -800 mV/SSCE.

The anticipated causes of failure were that the specimen's size was relatively small to get a stable current density, and the surface of specimen was not enough to polarize cathodically due to the change of sea weather resulted in the unstable frame of test device. It was difficult to establish the relationship between the variation of current density and the time under galvanostatic condition. Therefore, it was concluded that the control of appropriate current density was impossible, and to overcome these pro-

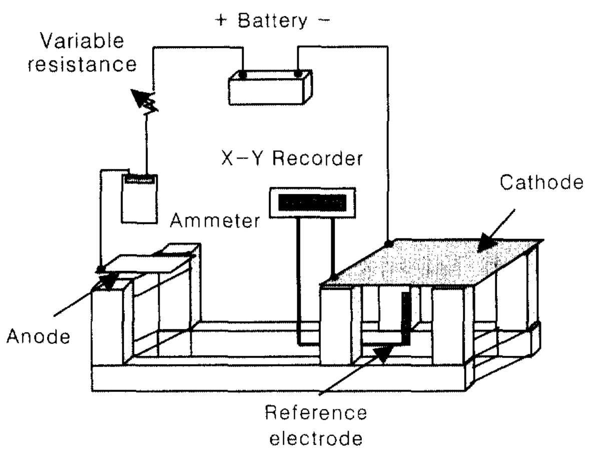

Fig. 1. Schematic view of the specimen.

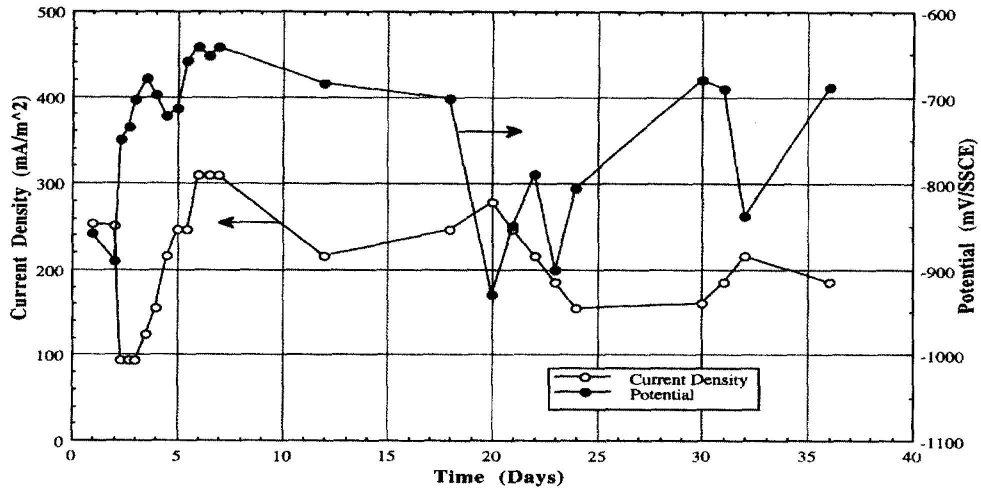

Fig. 2. Variation of potential and current density with time.

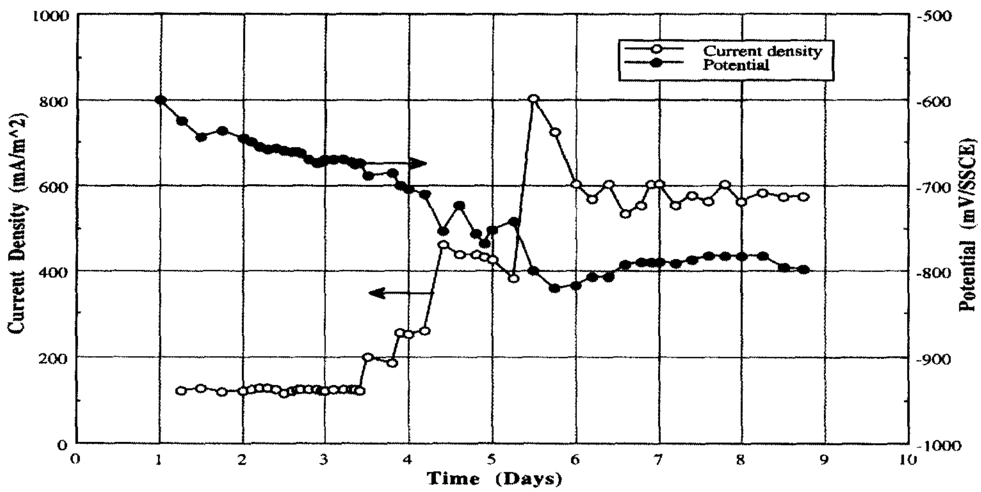

Fig. 3. Variation of potential and current density with time.

blems, specimen's size should be big enough to get a stable cathodic polarization. It was assumed that the potentios tatic method is practically better than the galvanostatic method.

3.2 Experiment No. 2

3.2.1 Experimental method

In this experiment, the specimen size of 100 cm × 100 cm × 2 mm was used to reduce the influence of specimen's size. Exposed area of specimen was 1.99 m^2, and anode was 13.2 cm × 13.6 cm × 2 mm. The distance between anode and cathode was 200 cm to prevent the possible current concentration to a specific spot. It was a high velocity location at a cooling water outlet of power plant in this experimental place, and the flow velocity ranged 0.24-1.05 m/sec. In addition, the difference between high and low tides was very large. Galvanostatic method was adopted at the beginning of test, however, it was switched to potentiostatic method after 5 days.

3.2.2 Results

Fig. 3 shows the variation of potential and current density with time as the result of Experiment No. 2. The current density was 120 mA/m^2 at the beginning of the test. The polarization, i.e. the change of potential was very slow, therefore, the current was increased at Day 4. And power supply was also exchanged from battery (12 V) type to rectifier (220 V). After power supply was changed to rectifier, potential value reached to -800 mV, however, the current density increased suddenly to 800 mA/m^2, and stabilized to around 600 mA/m^2. After that, it did not come down to under 600 mA/m^2. In general, the required current

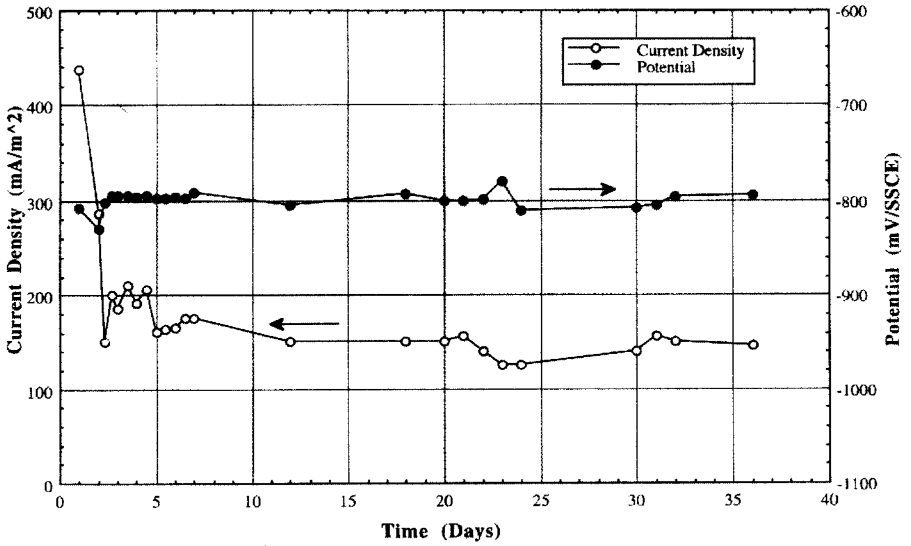

Fig. 4. Variation of potential and current density with time.

density for designing steel structures in seawater is 100 mA/m^2. Through all things considered, it was assumed that the specimen in this test had not reached a stable polarization due to a disturbance of specimen's surface by the current adjustment and the power supplier change, and also high velocity flowing to one direction caused specimen to interrupt cathodic polarization. From this experiment, at the high current density ranged 600-800 mA/m^2, it could be assumed that the current density was considerably influenced by the velocity of seawater.

3.3 Experiment No. 3

3.3.1 Experimental method

Potentiostatic method was adopted in this experiment 1No. 3 with the same size of specimen, and current was given by a rectifier for 10A. The weather was moderate during the test.

3.3.2 Results

Fig. 4 shows variation of potential and current density with time as the results of experiment No. 3 with potentiostatic method for 36 days. -800 mV/SSCE was kept very well during the most of test period. Current density was over 400 mA/m^2 at the beginning of the test, after 2 days, however, down to around 200 mA/m^2. In addition, it was decreased, and kept range of 130-150 mA/m^2. Through this experiments it was revealed that the influence of flow velocity was dominant in previous experiments, however, environmental factors such as weather, flow velocity, were minimal. Through the stable data, it could be assumed that the variation of current density was substantial change of environment by tide and current of seawater. Although variation of current density was large during first 2 days, it was reduced and stabilized with time.

3.4 Experiment No. 4

3.4.1 Experimental method

The size of specimen was changed from 100 cm × 100 cm × 2 mm to 70 cm × 70 cm × 2 mm as indicated in Fig. 5. This size was easy for handling and installing the specimen in the field. The area of expose to seawater was 1 m^2. The rectifier, as a power supplier with a capacity of 3A, was manufactured for this experiment, and a supplying current could be controlled with both automatically and manually. This rectifier, shown in Fig. 6, had an excellence in the adjustment of potential and the stability of power supply.

3.4.2 Results.

The variation of potential and current density with time

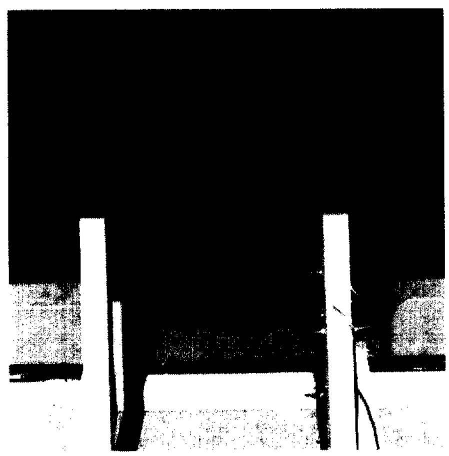

Fig. 5. The specimen for cathode.

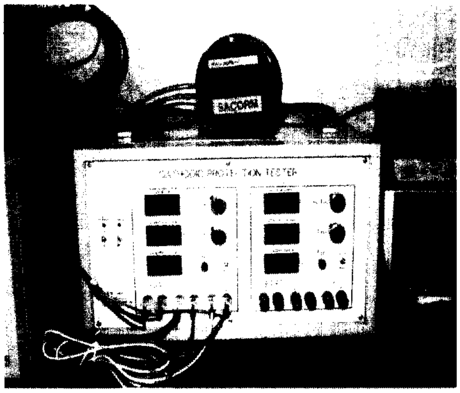

Fig. 6. Power supply (3A).

is shown in Fig. 7. The protection potential was kept well with an error of less than (1 mV at -800 mV/SSCE by using the new manufactured rectifier. Current density increased over 400 mA/m^2 at the beginning of the test, however, as time passed, it reduced and approached around 200 mA/m^2 after 17 days. It decreased continuously, and after 30 days, it approached to 150 mA/m^2. Though there were some variations of current density after 30 days, it seemed to be stabilization. There were sometimes rough weathers during the test, and velocity of seawater was a little higher than the other locations. As all things are considered, it could be assumed that this variation of current density was substantial with these marine environmental conditions.

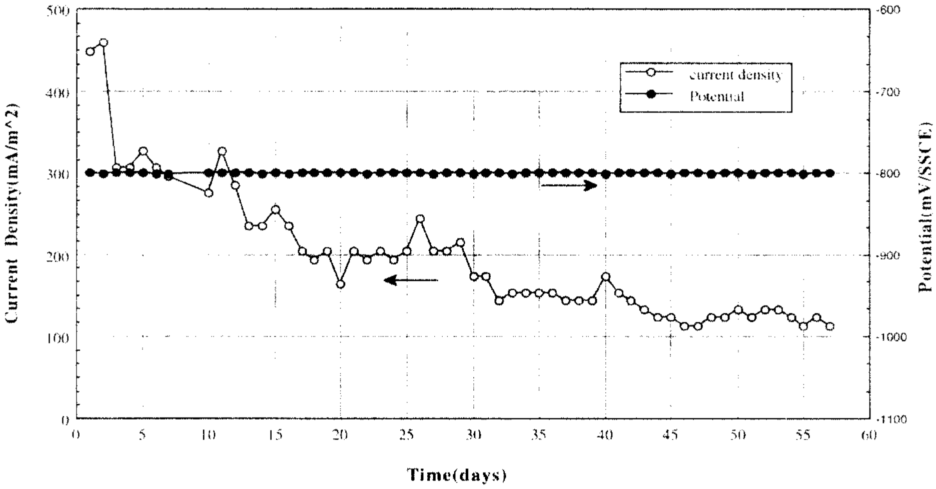

Fig. 7. Variation of potential and current density with time.

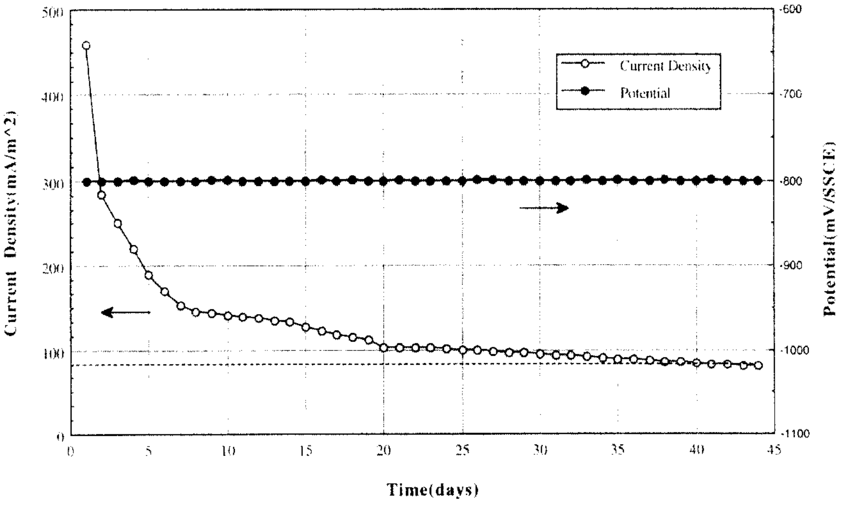

Fig. 8. Variation of potential and current density with time.

3.5 Experiment No. 5

3.5.1 Experimental method

The same size of specimen and rectifier with Experiment No. 4 was adopted in Experiment No. 5. Test method was also potentiostatic.

3.5.2 Results

Fig. 8 shows the variation of potential and current density with time as the result of Experiment No. 5 by potentiostatic method for 44 days. -800 mV/SSCE was kept all during the test with an error of less than (1 mV. The variation of current density decreased from the 460 mA/m^2 at the first day to the 100 mA/m^2 at the 20th day, and reached around 80 mA/m^2 after 44 days.

And the current density was stabilized after 30 days. This location was surrounded with islands, so the influence of flow velocity was much less than the other places, and moderated weather also helped the low current density as well.

4. Conclusions

In this study, it could be obtained through several different field experiments as follows;

1) Corrosion & protection conditions of steel structures have been influenced by various marine environmental factors, such as flow velocity, and weather conditions. When steel structures under marine environment are designed, therefore, various protection conditions should be reflected in accordance with the marine environments.

2) The direct field measurement is necessary for deter mining the required current density involved the environmental factors.

3) Potentiostatic measuring method for determining the required current density is more useful than the galvanostatic one.

4) Period of experiment to determine the required current density is needed at least 1 month.

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