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Estimation of Consumption of a Sacrificial Anode from Cathode Potential in a Seawater Environment

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Abstract

Sacrificial anodes are widely used for cathodic protection of steel structures in seawater environments. The anode must be replaced before being depleted, and the main objective of this study is to investigate the practical applicability of this method of estimating anode consumption.

The field test facility used in the present was a steel pipe pile structure at Yamanouchi Wharf in Yokohama Port, Japan. The consumption of the anode was estimated from the resistivity of seawater and the potential of the steel pipe pile. This estimated anode consumption is the same as that obtained from the protective current generated from the anode, which is given by the voltage drop across the shunt resistance. This result demonstrates that the amount of consumption of the anode can be estimated based upon potential and resistivity survey data.

Keywords: steel structure, cathodic protection, corrosion, anode consumption

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Introduction

Steel pipe and sheet piles have been used as structural materials for port and harbor structures since the 1920's in Japan. Sacrificial anodes are widely used for cathodic protection of steel structures in seawater environments[1]. Since anodes are consumed over time, they should be replaced before being depleted. Therefore, estimating the consumption of the anode is important.

There are two methods by which to estimate the consumption of the anode: a method based on the weight loss of the anode and a method based on the protective current generated by the anode. Both of these methods are costly.

A linear relationship between the protective current generated by the anode and the potential of the cathode (steel) has been demonstrated in sacrificial anode cathodic protection systems in neutral seawater environments[2]. Utilizing this relationship, the consumption of an anode could be estimated based on the potential of steel, which can easily be measured. The present paper discusses the practical applicability of this method of estimating anode consumption.

Experimental

The field test facility used in the present study is a steel pipe pile structure at Yamanouchi Wharf in Yokohama Port, Japan. A field test was conducted at this research facility for approximately five months, between September 10, 2004 and February 15, 2005. Figure 1 is a schematic diagram of the steel pipe pile. The steel pipe pile is constructed of JIS SSK 490 steel and is 900 mm in diameter, 34,500 m long and 14 mm thick.

A sacrificial Al-Zn-In anode, shown in Fig. 2, was welded to the steel pipe pile at a depth of -3,400 mm. The connection of the steel pipe pile and the sacrificial anode included a 0.01 Ω shunt resistor, which facilitated the determination of the protective current based on the voltage drop across this resistor. The potential of the steel pipe pile was measured using a silver - silver chloride (Ag/AgCl) seawater electrode, which was installed at depths of -2,400 mm and -4,000 mm. The voltage drop across the shunt resistor and the potential of the steel pipe pile were monitored in 10-minute intervals using a data acquisition system.

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Results and Discussion

Theoretical relationship between protective current and potential of cathode

The difference between the potential of the steel pipe pile and the sacrificial anode is given theoretically as follows:

$$E_c - E_a = I \cdot R \qquad (1),$$

where E_c (mV) is the potential of the steel pipe pile (hereinafter referred to as the cathode potential), E_a (mV) is the potential of the sacrificial anode (hereinafter referred to as the anode potential), $\boldsymbol{I}$ (mA) is the protective current generated from the sacrificial anode, and R (Ω) is the total resistance of seawater in the space where the current flows.

As shown in Fig. 3, R can be expressed as:

$$R = R_a + R_b + R_c \qquad (2),$$

where R_a, R_b and R_c (Ω) are the resistance of seawater in the space where the current flows in the neighborhood of the anode, the bulk and the steel pipe pile (cathode), respectively.

Here, R_a is much higher than R_b and R_c, so that R_b and R_c are considered to be negligible. Therefore, the protective current $\boldsymbol{I}$ can be obtained as:

$$I = \frac{E_c - E_a}{R_a} \qquad (3),$$

and R_a is experimentally given as:

$$R_a = \frac{\rho}{2\pi L}\left\{2.3\log_{10}\left(\frac{4L}{r}\right) - 1\right\} \qquad (4),$$

where ρ (Ω cm) is the resistivity of seawater, L (cm) is the length of the anode, r (cm) is the radius of the anode $[r = C/2\pi]$, and C (cm) is the circumference of the anode.

The length of the anode L is 85 cm and the equivalent radius of the anode r is 7 cm. The anode potential is -1,111 mV, which is obtained by the method of sacrificial anode testing regulated by JSCE[3)]. The sacrificial anode is not polarized, so that the anode potential can be assumed to be constant. Therefore, the protective current $\boldsymbol{I}$ can be obtained as:

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$$I = \frac{E_c + 1111}{0.0054 \cdot \rho} \qquad (5).$$

Estimation of the consumption of the anode

The cathode potentials at the depths of −2,400 m and −4,000 m are shown in Fig. 4. Both of these potentials become increasingly negative with time and are in agreement, indicating that the cathode potential does not depend on the measurement point. The resistivities of sea water, shown in Table 1, change seasonally by approximately ±10%. The average of resistivity is 26.7 Ω cm. The protective current can be estimated from the cathode potential and the resistivity using Equation (5). The estimated protective currents and those obtained from the voltage drop across the shunt resistance (hereinafter referred to as the directly measured protective current) are shown in Fig. (5). The estimated values and the directly measured values are in good agreement. The protective current of the existing structure can be obtained based on potential and resistivity survey data.

The anode consumption can be given by dividing the integrated electricity quantities by the anode capacity, as shown below:

$$W = \frac{Q_i \left(= \sum I \cdot \Delta t\right)}{q_{ac}} \qquad (6),$$

where W (kg) is the anode consumption, Q_i (c) is the integrated quantities of electricity, and q_{ac} (c kg^{-1}) is the anode capacity.

The anode consumption calculated from the estimated protective current (W_e) and that calculated from the directly measured protective current (W_d) are shown in Table 2. W_e is approximately 94% of W_d. The anode consumption can be estimated from the cathode potential and the resistivity of seawater.

Conclusion

In the present study, the practical applicability of the estimation method of the anode consumption has been investigated. The anode consumption can be estimated based on the potential of steel (cathode potential) and the resistivity of seawater. However, the test duration of the present study was very short. The long-term anode consumption should be estimated after consideration of

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decreases in the length L of the anode and the radius r of the anode in Equation (4).

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Table1 Resistivity of seawater

Date	10, Sep.	4, Oct.	4,Nov.	10,Dec.	11,Jan.	15,Feb.
Resistivity of seawater (Ω cm)	24.3	26.0	26.4	27.2	27.2	29.0

Table2 Anode consumption (W_e) estimated from the protective current and anode consumption (W_d) calculated from the directly measured protective current

W_e	W_d
3.36 kg	3.58 kg

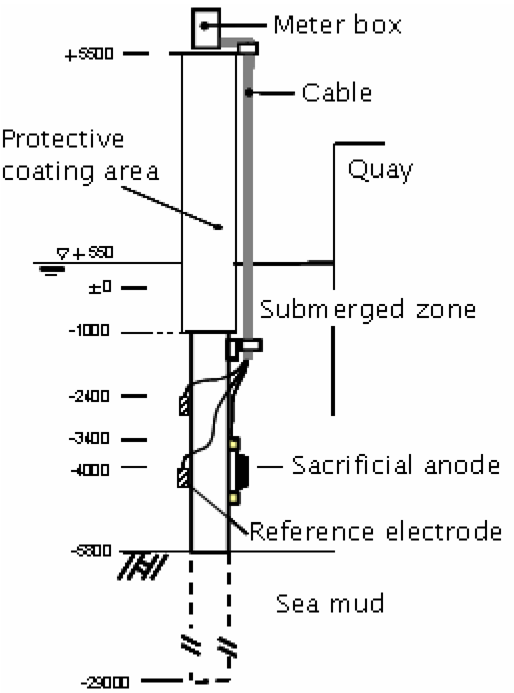

Fig. 1 Schematic diagram of the steel pipe pile.

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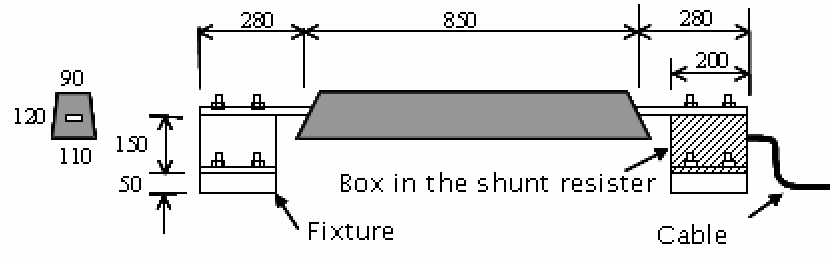

Fig. 2 Schematic diagram of the anode.

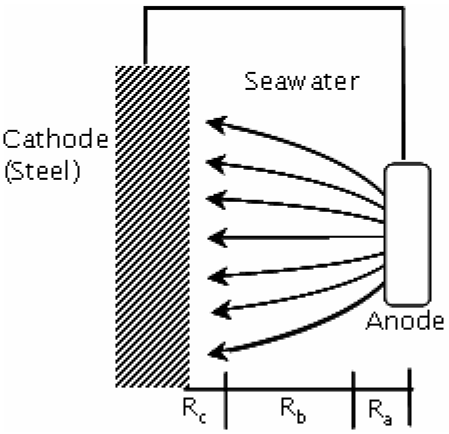

Fig. 3 Schematic diagram of the distribution of the seawater resistance.

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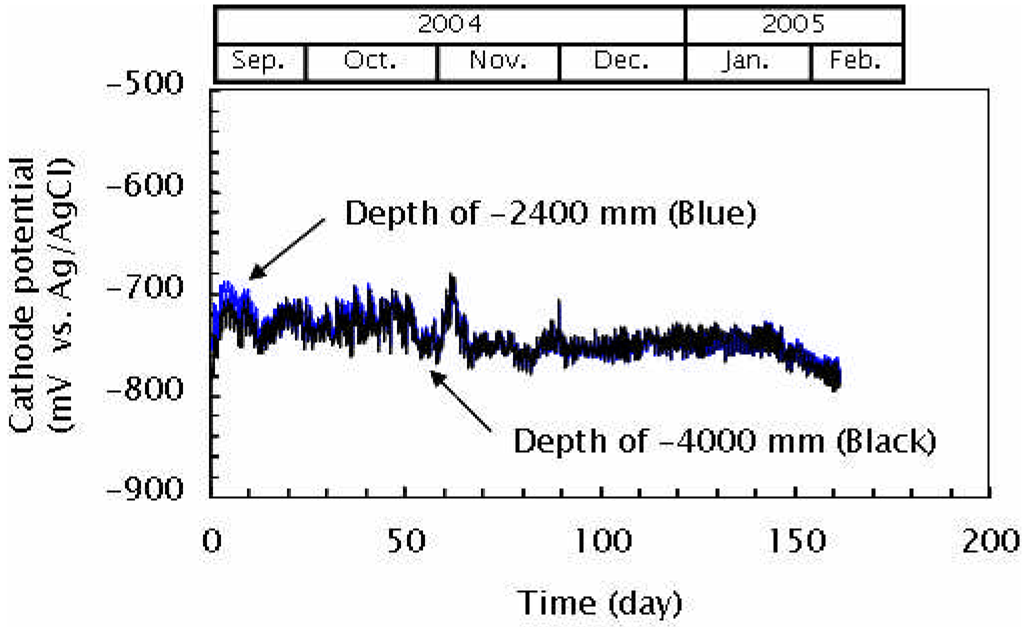

Fig. 4 Variation of cathode potentials (Potential of the steel pipe pile) with time.

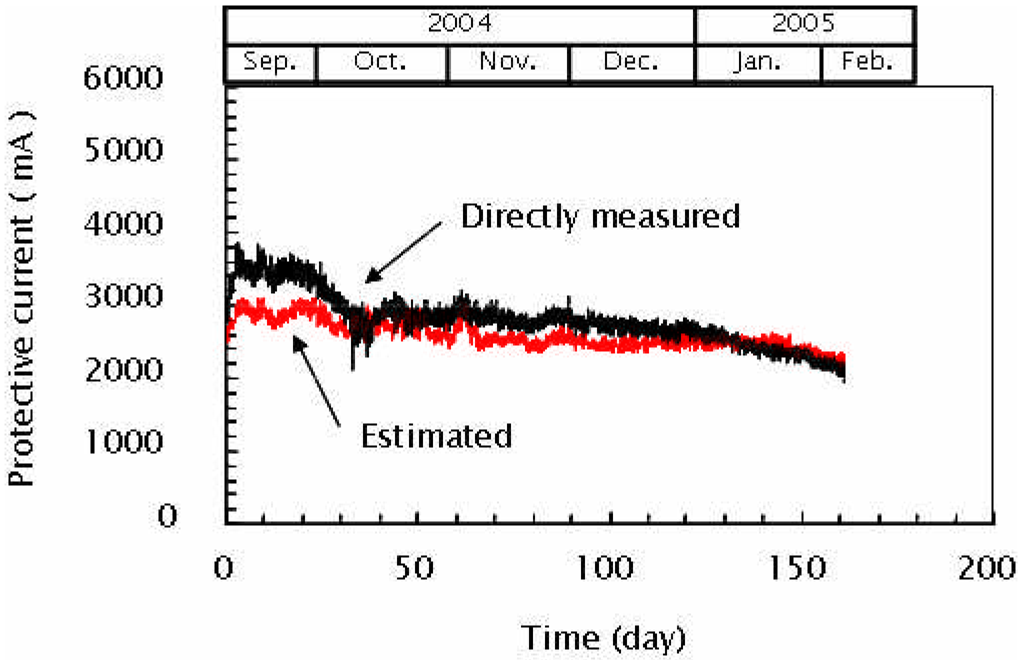

Fig. 5 Variation of protective currents with time.

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