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Effect of Season of Aluminum Panel Anodes on the Cathodic Protection of a Concrete Railway Bridge

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ABSTRACT

Steel reinforcements embedded in concrete have been considered immune to corrosion because of passive film formed on metal surface owing to the strong alkalinity (pH ranging 12.5 to 13.5) of cement. In coastal environments, however, reinforced concrete structures often suffer from severe damage followed by salt corrosion of steel. Cathodic protection is known to be effective in the protection of steel reinforcements regardless of the amount of salt concentration in concrete. We have developed galvanic anode protection system of using aluminum panel, and we applied it to the protection of a railway bridge. In the present report we discuss the effect of temperature on the steel potential (Ec) and steel current density (ic) of aluminum panels in the galvanic-anode protection to a railway bridge after measurements of potential, current density and temperature.

Keywords. Cathodic Protection, Sea-Salt Damage, Galvanic Anode, Depolarization, Reinforced Concrete

INTRODUCTION

Although concrete structures had been believed to be maintenance free, types of degradation and damages have become relevant. Damages by sea salt proceed in several steps 1) corrosion of steel, 2) initiation and propagation of cracks in overlying concrete followed by volume expansion of steel after transformation to rust, and 3) decreased strength of structure owing to the decreased cross-sectional area of steel reinforcement. Cathodic protection (CP) attracted public concern as a countermeasure against salt corrosion that is effective regardless of salt content in concrete. Among various types of CP we employed a galvanic anode system that uses panel of aluminum as anode (it will be referred hereafter as Al-panel). Although a system of zinc panel has a long history in galvanic anode CP we have developed Al-panel as a alternative to Zn-panel (Tanaka 2007) aiming at the reduction of both cost and dead-weight.

In this paper we report application of Al-panel system to the partial protection of railway bridge in actual service. We also discuss the CP performance in terms electrochemical parameters (such as electrode potential of steel, current density on steel surface, and amount of depolarization) and effectiveness in CP as a function of seasonal variation in temperature.

Figure 1. A picture of railway bridge

OUTLINE OF SURVEY

Outline of Railway Bridge. The actual bridge is located alongside the coast of Japan Sea and is exposed to severe salt attack with no shelter that serves as shields against salt particles. **Figure 1.** shows a photo of the bridge under inspection with dimensions shown in **Table 1.** and shape design in **Figure 2.**

Table 1.   Specification of concrete railway bridge

Span	Structure	Width of road [m]	Girder length [m]
A1–P1	RC slab	4.8	6.59
P1–A2	RC slab	4.8	6.59

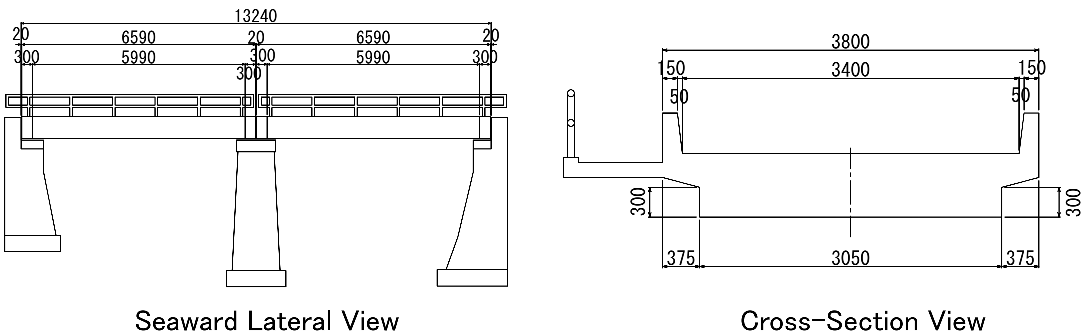

Figure 2. Shape of railway bridge

Install of Aluminum Panel. Prior to Al-panel installation, open circuit potential (OCP) was measured at selected two spans in the bridge. The OCP distribution is shown in **Figure 3.** Correspondingly, trend of corrosion was evaluated with reference to the ASTM criteria shown in **Table 2.** As **Figure .** shows seaward sides were corroded more severely than landward sides. Al-panel coverage was performed only on seaward as **Figure 4.** and **Figure 5.** show. Panels prevented visual view of structure surface when the coverage was complete. Slits, therefore, were placed between individual panels for guaranteeing visual inspection of concrete surface. In each electrochemical measurement, on-potential (Eon), instant-off potential (Eio) and off-potential after 24 hr of switch off (Eoff) of steel were measured using both embedded (MnO_2) and mobile (Ag/AgCl/Sat.KClsoln.:SSE) reference electrodes. A timing control diagram of individual potentials is illustrated in **Figure 6.** base on a guideline of CP management in concrete structure. Generated anode current (approximately equal to protection current) was recorded continuously on a data logger. Values recorded on P1-A2 span will be demonstrated as typical examples, since the data collected on A1-P2 gave similar pattern and tendency. All potential values listed in this paper were converted ones with reference to CSE after temperature compensation.

Table 2. ASTM C 876

Color legends	Criteria [mV vs. CSE]	Remark
	−200 ＜ Ecorr	Greater than 90% probability that no reinforcing steel corrosion
	−350 ＜ Ecorr ≦ −200	Uncertain
	Ecorr ≦ −350	Greater than 90% probability that reinforcing steel corrosion

Ecorr:Open circuit potential of reinforcing steel

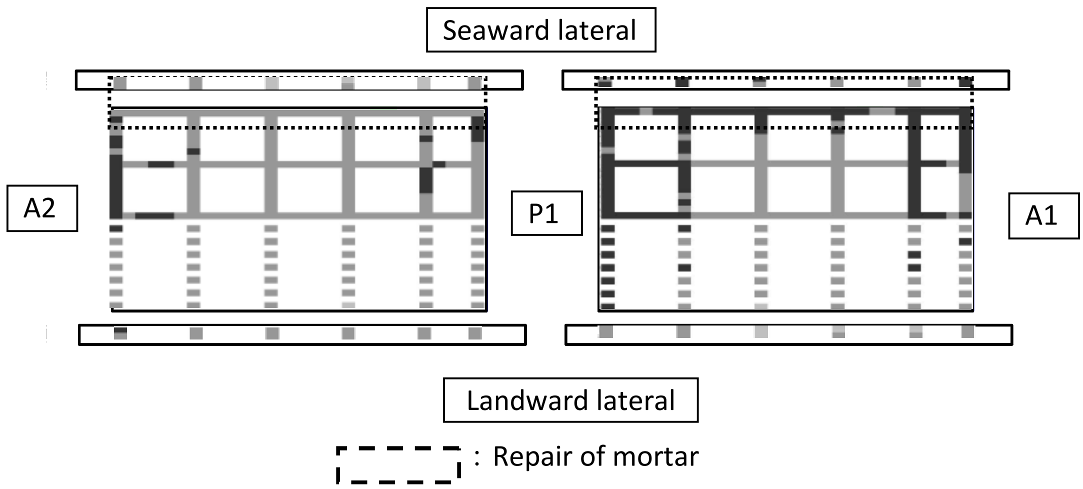

Figure 3. Distribution of open circuit potential evaluated by ASTM876 Development view

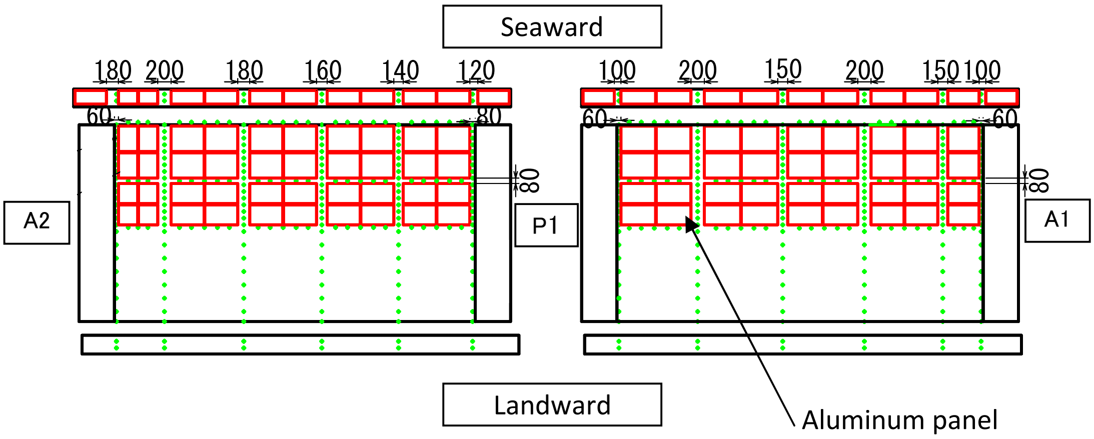

Figure 4. Aluminum panels fitted at railway bridge

Figure 5. A picture of Aluminum panels at railway bridge

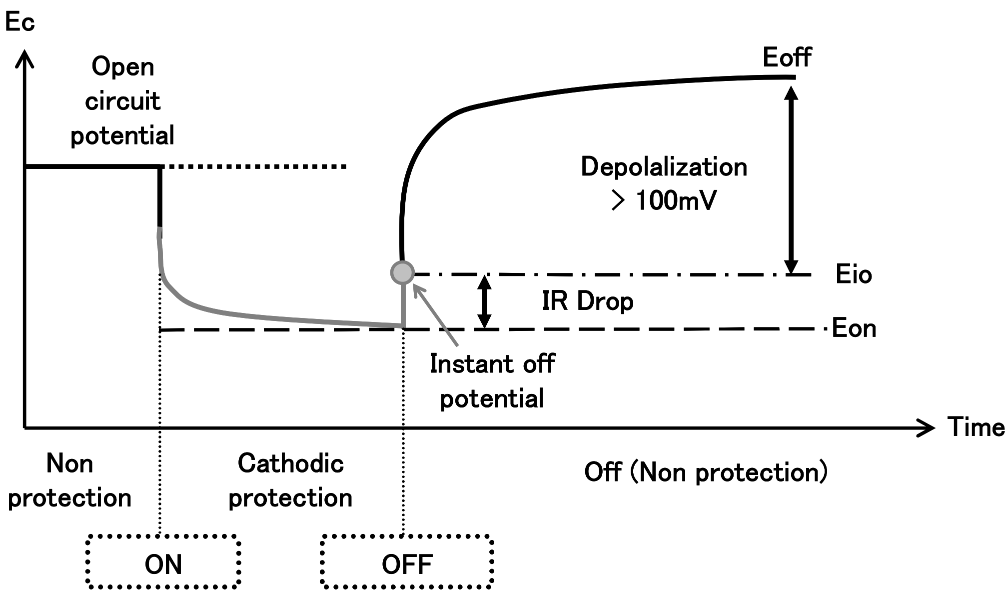

Figure 6. Outline of evaluation method for cathodic protection

ELECTROCHEMICAL SURVEY

Chronic Variation and Temperature Effect of Steel Potential and Cathodic Current Density. Steel potential (*Ec*) and cathodic current density (*ic*) are plotted as functions of time and corresponding temperature in **Figure 7.** Anode current (*Ia*) can be converted by dividing by surface area (*A*) to apparent cathodic current density per unit concrete surface, $ic = Ia/A$, since cathode area is approximately equal to concrete surface area in this panel anode system. Although daily temperature fluctuation gave small influence on both *E*c and *ic* these two parameters showed significant dependency on seasonal variation of temperature. Potential, *Ec,* shifted in the less noble value with rising atmospheric temperature towards summer, and in the nobler value with declining temperature from autumn to winter. Cathodic current density, *ic*, increased with rising atmospheric temperature and decreased with declining temperature. The trend is apparent in the beginning, however, after the lapse of one year or longer the current density decreased gradually converging on a stable value. The minor daily change in atmospheric temperature gave minor effect, presumably, because of the smaller temperature change on steel surface than that in atmosphere owing to concrete coverage.

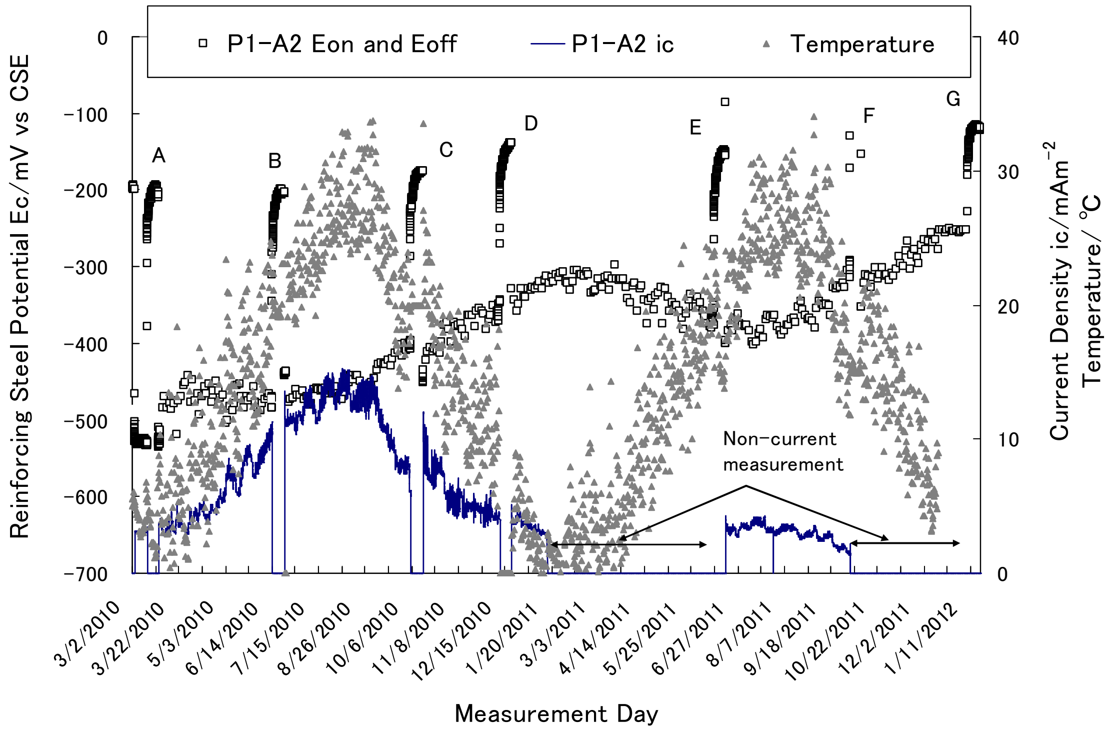

Figure 7. Change in *Ec*, *ic* and temperature with timeEffect of Protection.

Effect of Protection. For the evaluation of protection performance, depolarization measurements were carried out. Results of seven series of measurements are shown in **Figure 8.** All depolarization data showed potential shifts higher than 100 mV (criterion of cathodic protection) indicating that the CP performed properly. Open circuit potential (Eoff) following switch-off of CP current shifted in nobler direction with time, ranging -194, -199, -175, -139, -148, -153, and -117 mV vs. CSE as shown in **Figure 7.** The ennoblement of OCP also suggests the repassivation of steel surface indicative of good CP performance. Furthermore, seasonal variation in the depolarization is thought to be negligible since seemingly no correlation exists between temperature change and depolarization.

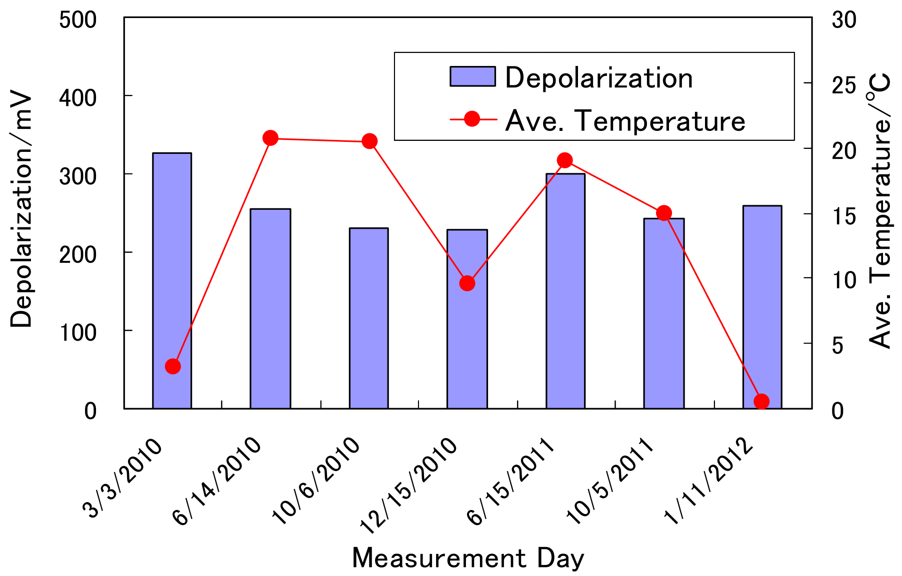

Figure 8. Change in depolarization and temperature with time

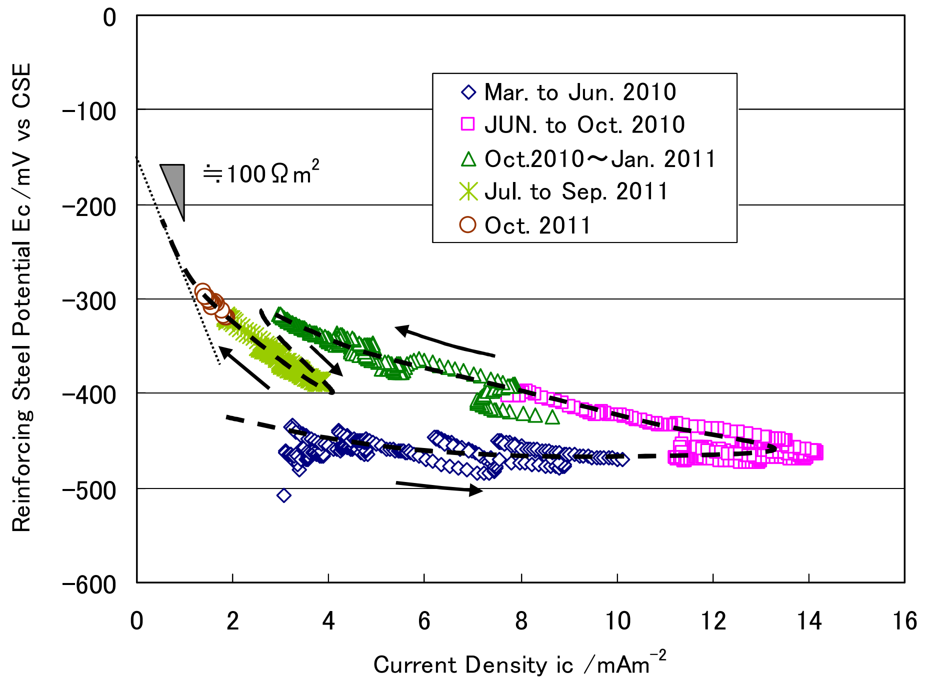

Figure 9. Change in *Ec-ic* prot with time

DISCUSSION

Effect of Atmospheric Temperature on *E*c and *ic* . **Figure 9.** shows the relationship between *E*c and *ic* plotted on *E*c –*i* plane. Arrows in the **Figure7.** indicate the shifts with time. With rising temperature in spring to summer, small potential shift was observed toward less noble direction, while in the case of decreasing atmospheric temperature in autumn to winter opposite trend was obvious: potential ennoblement and decreasing current density.

In one season from winter to summer (February 2011 to June 2011) unexpected failure in current measurement resulted in the lack of data *Ec-ic* data. In the subsequent summer to autumn, however, *ic* and *Ec* shifted respectively toward decreasing and increasing directions on the *Ec-ic* trace curves with the highest polarization.

The curve represents virtually a cathodic polarization curve of steel in concrete, thus indicating that polarization resistance (Rcorr) obtained from the tangent at $ic= 0$, corresponds to inversely proportional to corrosion rate. (In consideration of the Rcorr value) Judging from those data in the series of present measurement that the estimated Rcorr value reached 100 Ωcm^2 and *Eoff* data as well, steel is passivated most possibly. It is thus concluded that the repassivation of steel is complete as the chronic effect of CP.

The above mentioned behavior in E_c and *ic* can be interpreted using both cathodic polarization curves of steel (hereafter by denoted lines *E*c) and anodic polarization curves of Al-panel anodes (hereafter represented by lines $Ea+iR_I$), where R_I indicates cell resistance per unit area and thus iR_1 corresponds to cell voltage. The transition of intersections with time of anode and cathode polarization curves corresponds to drifts in *E*c and *ic.* In the present case$Ea+iR_I$ is predominant factor to changes in *ic* as **Figure 10.** shows. Rising temperature leads to the increase of *ic* and shift of *E*c in less noble direction by decreasing the slope of E_a+iR_I. Declining temperature on the other hand results in the decrease of *ic* and shift of *E*c in nobler direction by increasing the slope of $Ea+iR_I$ line. The chronic shift in *E*c is caused not only by the increase of cathodic polarization but also by the chronic ennoblement of open circuit potential. As is demonstrated in Figure 10, *E*c line shifts from I to II in nobler direction by applying CP. Line $Ea+iR_I$ shifts from (a) to (b) and (c) and with an increase in temperature, and from (c) to (b) and (a) with a decrease in temperature.

From the generalized standpoint of galvanic anode CP it is not preferable that the above mentioned polarization characteristic of $Ea+iR_I$ is controlling *ic*. It is, however, in the case of CP in concrete controlling the change in $Ea+iR_I$ indicates the increase of CP current at nobler OCP of steel (repassivation), which means supply of excessive current.

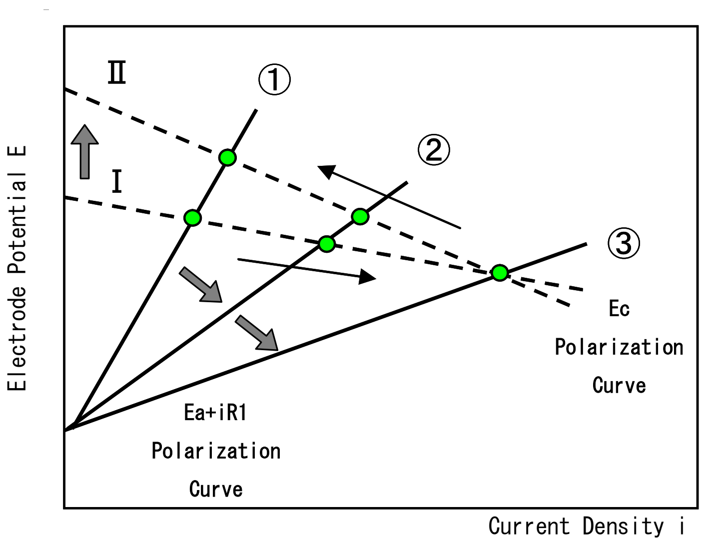

Figure 10. Shift of polarization curve due to the influence of temperature and cathodic protection

In the repassivation process of steel, automatic self-control by the suppression of protection current is a necessary process by polarizing *E*a and thus decreasing *ic*. With this regard the present CP model can be regarded as a system in which current control functions properly.

CONCLUSION

In the CP of steel reinforcement in concrete Al-panel method showed good performance throughout the year even in cool to cold area. Depolarization measurement has proven that this method of CP allows us to discard seasonal fluctuation in electrochemical data when depolarization measurement is carried out at 24 h basis.

Seasonal variation was relevant both in protection current density (*ic*) and potential of steel (*E*c). With rising atmospheric temperature, *ic* increased while *E*c shifted in less noble value, whereas with declining temperature *ic* decreased and *E*c ennobled. Both CP current decrease and steel potential ennoblement continue to proceed in the prolonged CP process finally showing convergence to stable values.

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