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ESTIMATION OF AIRBORNE SALT LEVEL FOR BRIDGE CONSTRUCTION

MAKOTO OHYA[1], MASAMICH TAKEBE[1], NOZOMU HIROSE[1], SHOTA AJIKI[2], and TOSHIHIKO ASO[3]

[1]*Dept of Civil and Environmental Engineering, National Institute of Technology, Matsue College, Matsue, Japan*
[2]*Center to Support Practical Education, National Institute of Technology, Matsue College, Matsue, Japan*
[3]*Graduate School of Sciences and Technology for Innovation, Yamaguchi University, Ube, Japan*

In the construction for steel bridges, it is important to accurately evaluate the environmental characteristics of the local region. It is well-known that the salt accumulation affects the corrosion of steel bridges. In order to evaluate the corrosion durability for a bridge, the airborne salt level is investigated monthly for a year prior to construction of the bridge. It is acknowledged that the airborne salt level varies seasonally, and thus it is possible that the one-year monitoring result does not necessarily represent long-term annual conditions for the airborne salt level. These climate changes make it difficult for the engineer to evaluate the corrosion durability for the steel bridges over a period of 100 years. In this study, the authors invested efforts to develop a procedure of estimating the airborne salt level based on available meteorological information. The estimation results showed reasonable agreement with the measured airborne salt level. It is confirmed that the proposed concise evaluation procedure based on only wind direction and speed information is useful as a method for estimating the airborne salt level.

Keywords: Weathering steel bridge, Corrosion environment, Meteorological data, Wind-force energy.

1 INTRODUCTION

In recent year, the share of application of weathering steel in Japanese bridge construction has been ever rising (Japan Society of Steel Construction 2006). However, it is realized that bridges composed of weathering steel can be subjected to unexpected degradation in areas with severe corrosion conditions such as a coastal zone with a high level of airborne salt particles. Thus, on considering application of weathering steel components for bridge construction, it is desirable to evaluate the corrosiveness of the atmospheric environment of the bridge construction carefully. There are several procedures for atmospheric corrosion environment proposed for this purpose (Japan Society of Steel Construction 2009). Common practice for this purpose nowadays is to undertake one-year monitoring of the airborne salt level *C* at the site of bridge construction. For evaluation of *C*, collected salt particles were dissolved in ion exchange water, and the amount of Cl^- was analyzed by ion chromatography. As the airborne salt level *C*, the measured Cl^- level convert to the NaCl equivalent (Japan Road Association 2014). It is acknowledged that the airborne salt level varies seasonally; showing considerable fluctuation of climatic conditions, and thus it is possible that the one-year monitoring result does not necessarily represent long-term annual conditions for the airborne salt level. In practice, long-term monitoring of the airborne salt level at a specific spot is not at all easy. Therefore, it is desirable to evaluate the severity of the atmospheric corrosion conditions pragmatically by means of available climatic data or numerical simulation. In Japan, the Meteorological Agency (JMA) provides real-time climatic data through the AMeDAS (Automated Meteorological Data Acquisition System) service at about 1300 monitoring spots distributed over Japan (Japan Meteorological Agency 2016). In AMeDAS, a compiled climatic data set over more than the past 50 years in Japan is made available over the internet. From this perspective, the authors invested efforts to develop a procedure of estimating the airborne salt particles level based on available meteorological information.

In this study, we focus on the relations between the airborne salt level and wind. First, we analyzed wind direction and speed data provided by the Matsue Meteorological Observatory to estimate the airborne salt level and compared with the monitoring data for the airborne salt level over 6 years at Bridge A (Figure 1) in order to evaluate the estimation precision of the proposed method. Secondly, the applicability of the proposed estimating procedure was tested for the more extensive area of Sanin District covering Shimane Prefecture as well as Tottori Prefecture. For the purpose of evaluating the atmospheric corrosion environment for weathering steel bridge construction, 2-year monitoring for the airborne salt level was carried out at several spots in Sanin District jointly between National Institute of Technology, Matsue College and Yamaguchi University. The acquired monitoring results are compared with the estimation results using the AMeDAS data to verify the validity of the proposed estimation equation taking wind direction and wind speed as the representative climatic parameters.

2 ESTIMATING AIRBORNE SALT LEVEL FROM METEOROLOGICAL WIND DIRECTION AND SPEED DATA

Most of the airborne salts arising from the sea are carried by wind. Tanaka *et al*. (1996) and Shinohara (2001) assumed that the wind-energy factor is proportional to the square of wind speed and to air de sity in their reviews of correlation between airborne salt level and direction. Referring to the definition of kinetic energy of a wind power station, the authors proposed wind-energy factor P_D [W/day] (Ohya *et al*. 2013) expressed as follows, Eq. (1):

$$P_D[\mathrm{W/day}] = \sum\nolimits_D \frac{1}{2}\rho(VB)^3 AT \tag{1}$$

where ρ [kg/m^3] refers to the air density (about 1.2kg/m^3), V [m/s] is the hourly average wind speed, B is the wind velocity component normal to the gauze surface, A is unit area [1m^2], and D is day [1 day]. The expression for B is, Eq. (2):

$$B = \cos\Theta \ \ (|\Theta| < 90^\circ)\ ,\ \ B = 0\ (|\Theta| > 90^\circ) \tag{2}$$

where Θ refers to the angle of the most frequent wind direction to the normal to the gauze surface during the observation period.

3 FIELD SURVEY FOR AIRBORNE SALT PARTICLE LEVEL AND WIND-FORCE ENERGY COEFFICIENT

The authors carried out 6-years field monitoring spot (Bridge A) and 2-years field monitoring for the airborne salt level at several locations (from Bridge B to E) in Sanin District using the dry gauze method. Five monitoring spots are shown in Figure 1 and Table 1. Airborne salt particles were collected monthly by dry gauze (10cm times 10cm) set at the girder bottom (see. Figure 2). From available AMeDAS data at the nearby sites, the wind-force energy coefficient was calculated. The distances between the monitoring spot and the nearest AMeDAS data acquisition spot are given in Table 1.

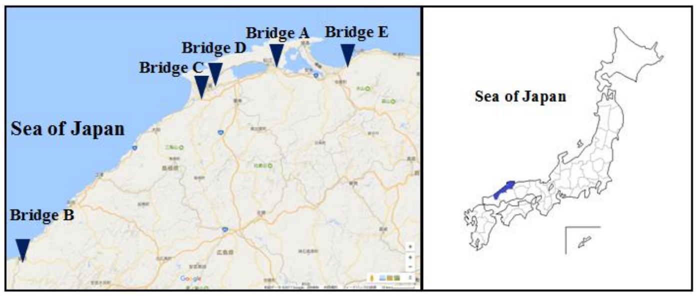


Figure 1. Location of study sites.

Table 1. Observing periods of airborne salt and neighborhood meteorological weathering stations.

Target Bridge	Latitude	Longitude	Observing periods of airborne salt	AMeDAS station(distance)
Bridge A	N 35°27′53.6″	E 133°5′36.9″	2009.12.14 – ongoing	Matsue (about 2.5km)
Bridge B	N 34°39′37.6″	E 131°48′40.0″	2007.2.7 - 2009.2.6	Takatsu (about 3km)
Bridge C	N 35°21′2.7″	E 132°43′29.3″	2006.12.21 - 2008.12.19	Izumo (about 2km)
Bridge D	N 35°22′30.0″	E 132°46′30.7″	2007.1.15 - 2008.12.29	Izumo (about 7km)
Bridge E	N 35°28′11.1″	E 133°26′58.6″	2006.12.19 - 2008.12.22	Shiotsu (about 10km)

Figure 2. Installed location of gauze sheet at bridge E.

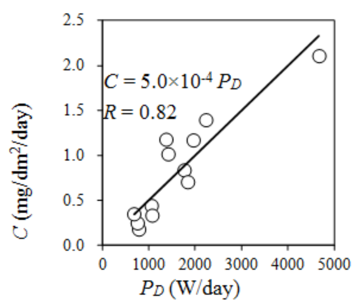


Figure 3. Relations between airborne salt level C and wind-force energy coefficients P_D in 2010.

3.1 Applicability of the Estimation Procedure

For the analysis, meteorological data regarding wind direction and speed made available from the Matsue Meteorological Observatory were used. In Figure 3, the measured monthly airborne salt level C at Bridge A under girder are compared with P_D calculated by Eq. (1) using the meteorological data during 2010. It is seen clearly that a significant positive correlation existed between *C* and P_D. In fact, the plot of *C* vs. P_D in Figure 3 yielded the correlation crossing the origin with correlation factor $R = 0.82$. Measurement results of monthly airborne salt level at Bridge A using the dry gauze method over 6-years between January 2010 and December 2015 are compared with the estimated values *C* by means of climatic data (only wind direction and speed) reported from the Matsue Meteorological Observatory in Figure 4. It is seen in Figure 4 that the estimation results for *C* rationally simulated the detected seasonal trends of increasing *C* on transition from winter to spring and of decreasing *C* through summer to autumn. The annual average between the monitoring and the estimate is compared in Figure 5. The cause of the detected discrepancy between the estimated monthly *C* and the measured monthly *C* was speculated to have arisen from the fact that the captured sea salt particles by the dry gauze method was not only dependent on wind direction and speed but also on temperature and *RH*.

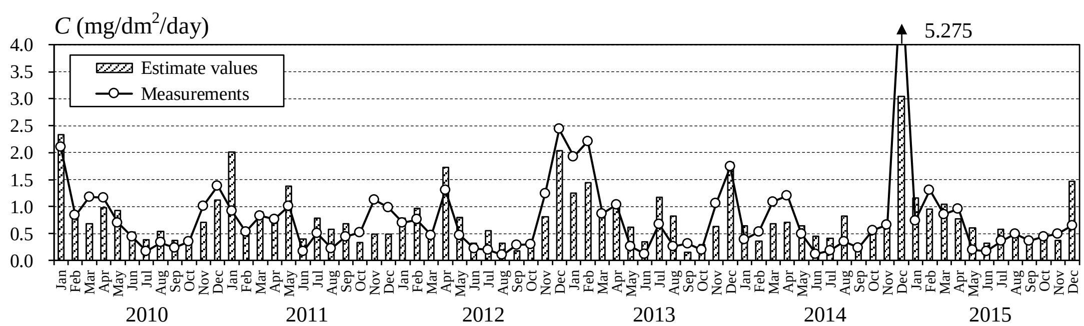


Figure 4. Monthly fluctuation of airborne salt level C estimated by the wind-force energy coefficient and measured by dry gauze method from 2010 to 2015.

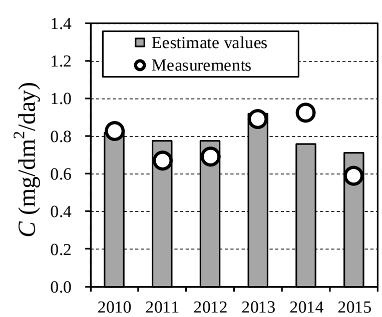


Figure 5. Annual fluctuation of airborne salt level C estimated by the wind force energy coefficient and measured by dry gauze method from 2010 to 2015.

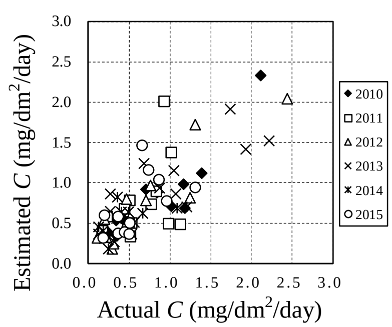


Figure 6. Relations between actual and estimated salt.

Anyway, as seen in Figure 5, the discrepancy between the annual estimated *C* and the annual measured *C* was small, being no greater than 0.1 mdd (mg/dm^2/day), with the single exception of 2014. The correlation between the estimated monthly C and the measured monthly C is plotted in Fig. 6. There are few points showing a significant departure from the general correlation line, as anticipated from Figure 6, but the general correlation looks satisfactory. It is important to demonstrate satisfactory accuracy of the presently proposed simplifying estimation method for monthly *C* as well as for annual *C* from available wind direction and speed information alone.

3.2 Estimation Results for Airborne Salt Level in Sanin Direct

The correlations between the measured airborne salt level *C* (Aso *et al.* 2010) in the first year and P_D calculated from available AMeDAS data are plotted in Figure 7. It is seen in Figure 7 that the correlation between *C* and P_D was positive at all monitoring site, although those have a certain extent of scatter being dependent on the surrounding geographical situation and also on wind conditions. In Figure 7, the linear proportionality expression for *C* as a function of P_D is given with the value of correlation factor *R*. It is seen in Figure 7 that the correlation was highly significant at Bridge C and Bridge D, while it had modest significance at Bridge B and Bridge E probably owing to the difference in geographical conditions between the monitoring spot and AMeDAS data acquisition spot for Bridge B and Bridge E. From the data for monthly *C*, annual *C* was calculated and plotted in Figure 8. Except at monitoring spot Bridge E, where $R = 0.491$ in Figure 7, the error margin between the annual measured *C* and the estimated annual *C* looks quite small in Figure 8, while the error margin was satisfactorily small even at monitoring spot Bridge B with relatively low *R* (= 0.532) in Figure 8. In addition, the seasonal variation pattern appeared to be acceptably well simulated in the monthly estimated airborne salt level at all bridges. These results appeared to suggest that, if *R* for the monthly *C* vs. P_D correlation was no lower than 0.5, the annual airborne salt level *C* might be estimated with satisfactory accuracy.

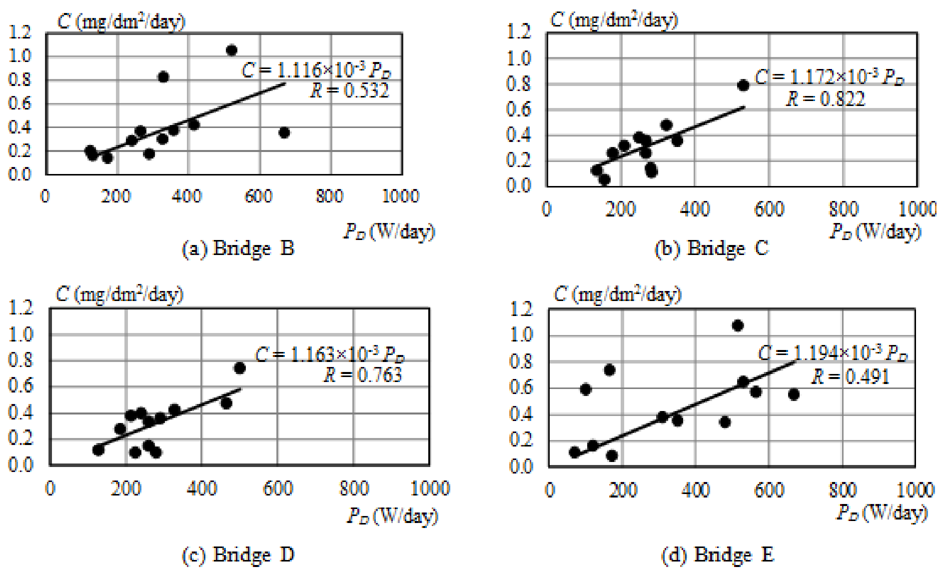
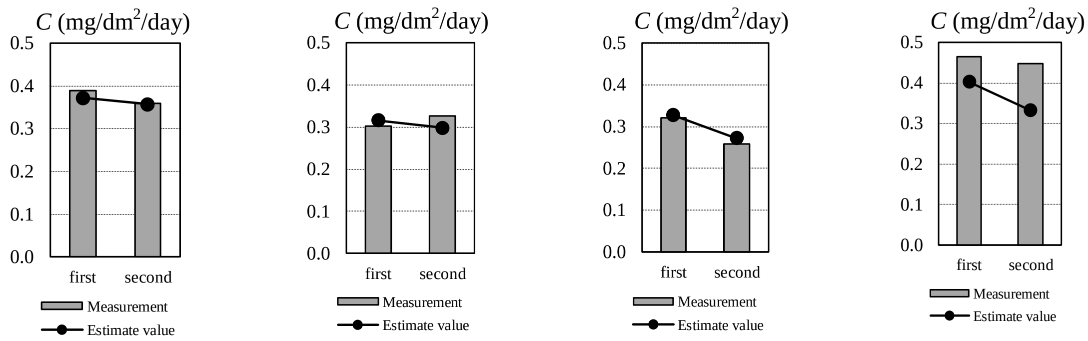


Figure 7. Relations between airborne salt level *C* and wind-force energy coefficient P_D.

4 CONCLUDING REMARKS

The results of this study ensured satisfactory accuracy of the estimation procedure for annual C in terms of wind-force energy coefficient P_D defined as functions of wind speed and wind direction alone acquired from publicly available AMeDAS data provided by JMA, at least for Sanin District. A certain extent of deviation for the estimated annual *C* from the measured annual *C* became detectable for a site at which the value of correlation factor *R* for monthly *C* vs. P_D was lower than 0.5. It is planned to verify the validity of this concise *C* evaluation procedure for other monitoring spots in Japan where AMeDAS data are readily available nearby.



(a) Bridge B (b) Bridge C (c) Bridge D (d) Bridge E

Figure 8. Annual fluctuation of estimated and measured airborne salt level *C*.

Acknowledgments

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