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Prediction of Adhesion Behavior of Sea-Salt Particles on Bridge Girders

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Abstract

It is important to estimate corrosion environment of steel bridges for a proper corrosion prevention and maintenance program. The critical factors of corrosion are temperature, humidity and various dusts on the surfaces. Among them, the adhered sea-salt particulate matter (SSPM) is most important and therefore airborne SSPM near a bridge site must be considered in its design. To prevent degradation of protective paint, forced wash out of adhered SSPM has been tried in some bridges. In order to make a proper plan of wash out, it is better to know adhesion behaviors of SSPM to bridge girders, which in turn depend mainly on the amount of airborne sea salt particles and wind on a bridge site. The objective of this manuscript is to pursue numerical method to simulate the adhesion behavior of salt particles oriented from ocean. To this end, adhesion behaviors of salt particles on bridge girders are estimated using CFD analysis. By the use of these basic behaviors with other data such as wind velocity, amount of airborne SSPM, total amount of adhesion of sea salt particles are numerically predicted. The comparisons between the numerical and observed results showed that the numerical analysis can reproduce essential behaviors of airborne SSPM.

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Keywords: Maintenance of steel bridges; Corrosion protection; adhesion of SSPM.

1. Introduction

Corrosion protection and fatigue control have been one of main issues in bridge maintenance programs in developed countries. In fact, some bridges in coastal area suffer serious corrosion damage (Figs. 1). In view of corrosion prevention, proper selection of materials is important in the planning and proper anti-corrosion maintenance program play a key role during a service period. The governing factors of corrosion are the time of wet (TOW) that depends on temperature, humidity and various dusts on bridge surfaces. Among them, the adhered sea salt particulate matter (SSPM) is most important in coastal region.
of Japan. Recently, forced wash out of adhered sea salt has been experimentally performed in some bridges in Japan to improve the durability of anti corrosion paint (Miyamoto et al, 2009). For an effective conduction bridge washing, it is necessary to know adhesion characteristics of airborne SSPM on bridge girders. Even if amount of airborne SSPM near a bridge site is given, adhesion of them on a bridge surface is another problem. As air flow around bridge girders is very complex, amount of adhesion can be highly non-uniform (Obata et al, 2008). The objective of this work is to propose a numerical method to predict the adhesion behavior of SSPM on a bridge surface using computational fluid mechanics (CFD). The numerical results are compared in situ observation results and discussed.

![Figure 1: Corrosion of steel bridges](image)

2. OBSERVATION OF ADHERED SSPM

2.1. Location and instruments

The authors have been collecting corrosion environment data at the Mikuni bridge (Fig. 2) near the coast of Sea of Japan since Dec. 2008. Observed data are temperature, humidity, wind velocity, wind direction, airborne SSPM and adhered SSPM using atmospheric corrosion monitor (ACM) sensors. The Mikuni bridge is an eight spanned continuous box-girder bridge that is located from about 3.5 km from the nearest coastline. Wind data is acquired by an ultrasonic windometer every 1 second. The density of airborne SSPM is estimated by trap tanks (Mori et al, 1985) set along the bridge. The tanks are set up in the downstream and the other is upstream direction (Fig. 2). Adhered SSPM on bridge girders is monitored indirectly by using ACM sensors that probe micro current accompanied by electro-chemical reaction, i.e., corrosion. The quantity of SSPM adhesion can be estimated by amount of corrosion currency and relative humidity in a given period. The locations of ACM and thermo-humidity sensors are illustrated in Figs.2 and 3.

2.2. Results

The main observed results are summarized in Figs. 4 and 5. Figure 4 shows the amount of airborne SSPM captured by the trap tanks every 2 months. The unit used to represent the amount of airborne sea salt particles is mdd, which stands for \((mg/dm^2/day)\). It is interesting to note that much more SSPM is sometimes detected in the upstream side instead of downstream side. Figures 5 illustrate the examples of relation between corrosion current and relative humidity in June, 2010. The curves in these figures represent estimated amount of adhered sea salt by (Motoda et al, 1994). These suggest that more sea salt...
is adhered on the lower surface of the box girders. The estimated SSPM adhered in the bay region between two girders are less than those of other parts.

Figure 2: Set up of sensors

Figure 3: Location of sensors

Figure 4: Airborne SSPM
3. ANALYSIS of ADHESION OF SEA SALT PARTICLES

3.1 Outline of analysis

In order to estimate the adhesion of airborne SSPM on a bridge surface, a numerical analysis must consider (a) amount of airborne SSPM at a given site and wind data, (b) behavior of adhesion of SSPM on a solid surface, and (c) detach and wash away of adhered SSPM. These analyses use multi phase fluid dynamics but each representative length scale is quite different. When the distribution of airborne SSPM at a site is known, fluid dynamic analysis can be performed with a proper boundary and initial condition to examine adhesion behaviors of sea salt particles. Detach of adhered particles poses another complex problem but cannot be ignored to discuss corrosion behavior of girders. In this work, our efforts are focused on the analysis (b).
Standard k-e model is used to express a turbulent flow. Regarding adhesion of particles to a solid wall, strictly speaking, it depends not only on collision of particles but also electrostatic or intermolecular force between a particle and a wall. A sort of chemical and physical reaction also involves on a solid surface. In this work, instead of pursuing detailed adhesion behaviors that require much more theoretical and experimental works, we simply assume that a particle is captured forever once it collides with a surface.

Numerical analyses are performed using general purpose computational fluid dynamics program, STAR-CD Ver. 4.08(Computational Dynamics, 2008) with customized subroutines for our particular purposes, i.e., introduction of suspended micro particles and their adhesion to fixed solid surfaces. Figure 6 shows the region of analysis that is based on the cross section of the Mikuni bridge. Only one layer of cells along the plane perpendicular to a bridge axis is set for the sake of numerical efficiency. The initial and boundary conditions are as follows. Inbound stream is uniform along AD and the outlet boundary is set along BC. CD is a frictionless boundary while the ground surface AB is modeled as a non-slip boundary. All the bridge surfaces are modeled as fixed non-slip boundaries. Each case is an 80 seconds non steady state air flow analysis. After initial 20 seconds, 5 units per meter of particles representing SSPM are injected uniformly from the boundary AD every one second. The other major conditions of analysis are given in Table 1. The size of particle is determined according to ocean origin sea salt particle. Temperature and humidity has negligible effects on the results. Artificial sinusoidal velocity change with
5 seconds period is introduced as its existence has critical effects in adhesion behaviors (Obata et al., 2008).

![Graph showing adhered seasalt](image)

Figure 7: Estimation and observed adhered SSPM between 3/2010 and 6/2010.

Table 2: Numbers of adhered particles

<table>
<thead>
<tr>
<th>Averaged Wind Speed (m/s)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A  B  C  D  E  F</td>
</tr>
<tr>
<td>1.00</td>
<td>7  0  3  2  6  2</td>
</tr>
<tr>
<td>2.00</td>
<td>6  1  3  4  12  7</td>
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<tr>
<td>3.00</td>
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<tr>
<td>4.00</td>
<td>6  1  3  3  18  9</td>
</tr>
<tr>
<td>5.00</td>
<td>8  1  6  0  22  11</td>
</tr>
<tr>
<td>6.00</td>
<td>11 0  4  1  19  8</td>
</tr>
<tr>
<td>7.00</td>
<td>12 0  2  1  22  10</td>
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<td>11 0  5  0  22  5</td>
</tr>
<tr>
<td>9.00</td>
<td>10 0  2  1  27  12</td>
</tr>
<tr>
<td>10.00</td>
<td>18 1  2  2  15  15</td>
</tr>
</tbody>
</table>

3.2 Results

The numerical results are summarized by the numbers of particle unit adhered in each part of girders in Table 2. The largest numbers are underlined in this table. Airborne particles are most likely to adhere on the lower surface followed by the web of a girder box in the upstream side. The location of most adhesion is independent of incoming wind velocity.
These results give only a tendency of adhesion in very short time period. In order to estimate the adhesion of sea salt particles in long period, the amount of airborne SSPM at the bridge site and wind history must also be taken into account. In that case, a short time analysis by CFD serves as a sort of Green’s function. Total amount of adhesion ($S$) in a given period between $T_1$ and $T_2$ and location will be estimated by in the following form of integration

$$S = \int_{T_1}^{T_2} m(v(t)) f(t) dt$$

where $m$ is mass of adhered sea salt during a unit time with unit mass of sea salt per volume at time $t$. $v$ and $f$ are wind velocity and mass of airborne sea salt respectively.

Figure 7(a) shows the results based on Eq. (1) between March and June of 2010. In this case, $m(v)$ is numerically deduced from Table 2 as a function of wind speed. $f$ is given as the two months averaged values in Fig. 4. As for wind velocity, in situ observed values are used. As is seen in this figure, the contribution of wind from upstream side is equally important even when the amount of SSPM in the wind from upstream side is only a half that from downstream side. The predominant direction during this period is South or South East, that is, upstream side. The estimated amount of adhered SSPM by ACM sensors are given in Fig. 7(b). These estimations are based on relative humidity and corrosion current diagrams (Figs. 5). The distribution of adhered SSPM is very similar to the numerical results. Density of adhered sea salt is the highest in the lower faces of box girders. The second highest location is outside web (A or D in Fig. 7(b)) both in numerical simulation and observation. At least, the proposed method can be a useful numerical tool to estimate adhesion of SSPM on bridge girders.

4. CONCLUSION

A simple framework is proposed to estimate adhesion behaviors to bridge girders numerically. It adopts two step approaches. One is a local analysis using a CFD with the Lagrangian type of modeling of airborne micro particles for basic cases. The other is numerical integration of adhered sea salts based on the basic cases and observed mass of airborne sea salts and wind in a given period. The results of the proposed method show a good coincidence with the observed results of adhered SSPM on bridge surfaces. As the present method ignores the effect of wash out of adhered particles by rains, these results must be understood with some reservations. However, these results will give valuable basic information for a proper plan of wash out of bridge girders. It should be emphasized that wind velocity and amount of airborne SSPM can also be reasonably estimated on the basis of rapidly developing meteorological analysis (WRF, 2010). With such powerful numerical tools, the simulation of sea salt adhesion can fully be performed numerically. The detailed results will be reported elsewhere.

5. ACKNOWLEDGEMENTS

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REFERENCES

