CALCULATION MODEL OF AIRBORNE CHLORIDE ION FOR BRIDGE MANAGEMENT SYSTEMS

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ABSTRACT**:** It is necessary to improve efficiency of the management system for the civil infrastructures. Because of the problems on aging of structures, reducing cost of maintenance and technicians, are now becoming critical. The authors considered an improvement of cost estimation system for the management of infrastructures. As a result, we found that it is indispensible to ensure high accuracy of the deterioration prediction model. Especially, we focus on chloride attack, it is rather the critical factor affecting its overall service life of the concrete structures. However, there is lack of efficient model that able to provide an accurate input data concerning airborne chloride and ions adhesion on the surface, for the deterioration prediction of individual structure. So, it is now difficult to obtain a good accuracy of the chloride attack prediction. From this research background, this paper aimed to concentrate on establishing calculation model for airborne chloride ion concentration at arbitrary time and location, the model especially focus on seawater aerosol production process.

KEYWORDS: maintenance management system, deterioration prediction, chloride attack, seawater aerosol, production process, costal condition

1. INTRODUCTION

The problems on aging of structures, reducing cost of maintenance and technicians, are now becoming critical. So, it is necessary to improve efficiency of the management system for the civil infrastructures. The authors considered total management system of infrastructures, especially concrete bridges [1] [2]. In reference [1], we proposed a cost estimation method in case of chloride attack occur. It was considered an improvement of deterioration prediction by probability for some deterioration factors. And future cost estimation was calculated by using this results. After that, we have been considered about the probability of deterioration function and investigation of structures to improve the accuracy of deterioration prediction [3]. However, these attempts have not brought about fundamental improvement for the deterioration prediction. From this consideration, we found that it is indispensible to ensure high accuracy of the deterioration prediction model. Figure 1 shows one of computational results of chloride attack deterioration and maintenance cost prediction for the reinforced

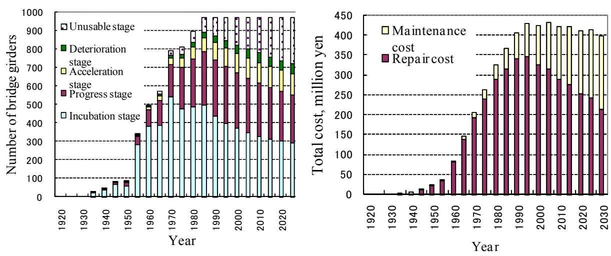


Figure 1 Example of the results of the deterioration (left) and the maintenance cost (right) prediction

concrete bridge girders.

Chloride attack is one of the critical deterioration for the concrete structures affecting its overall service life. Prediction model for the chloride attack consisting of chloride ion penetration, reinforcement corrosion, concrete cracking, at present have fairly good accuracy in an acceptable level. However, there is lack of efficient model that able to provide an accurate input data concerning airborne chloride and ions adhesion on the surface, for the deterioration prediction of individual structure. For this reason, it is now in the condition that difficult to obtain a good accuracy of the chloride attack prediction.

From this research background, this paper aimed to concentrate on establishing calculation model for the amount of airborne chloride ion at arbitrary time and location.

2. CALCULATION MODEL OF AIRBORNE CHLORIDE ION

Calculation model for airborne chloride ion prediction consists of three processes; seawater aerosol production process, translation process, and adhesion process [4].

2.1 Place of seawater aerosol production

Seawater aerosol that contains the chloride ion is produced by the turbulence of sea surface. A typical sea surface turbulence is in the form of waves breaking. From this reason, seawater aerosol is produced when wave breaking is occurred. Therefore, we can assume that the wave breaking point is located at the place of seawater aerosol production.

In this paper, we treat the differences between the open sea and the seashore as two types of place of seawater aerosol production. The reason why distinguishing into two types is wave breaking mechanisms is clearly different, and to adopt an expedient for some influences of distance from seawater aerosol production place to target point on the land. As a mechanism of wave breaking, the waves breaking on the open sea is occurred as a result of limit of wave development by the wind, while the waves breaking at the seashore is occurred by shoaling and hit costal rocks, and other obstacles on the shoreline. For this reason, the place of seawater aerosol production on the open sea is distributed widely on the sea surface, while the place of seawater aerosol production at the seashore is a line along the seashore.

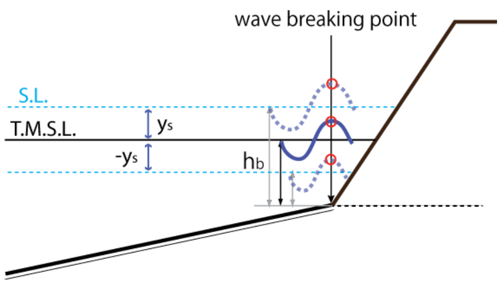
2.2 Initial point of seawater aerosol production

In this section, we define the initial point where seawater aerosol produced for each type of place of production place.

2.2.1 Initial point of seawater aerosol production for the seashore

Waves breaking position and breaking condition of the waves approaching the seashore is much influenced by coastal condition. Especially, the wave breaker or coastal rocks that act as obstacle objects have large effect on the aerosol production. For examples, when a typhoon and a periodic wind approached, high waves, which hit on costal obstacle, shoot off a large amount of seawater aerosols. But, if such high waves enter a sand beach, there are less seawater aerosol produced than that of the obstacle. From this fact, it is necessary to distinguish between the existing of some obstacles (called obstacle coast) and beach (called beach coast) as places of seawater aerosol production at the seashore.

Initial point of seawater aerosol production for the obstacle coast is defined at the crest of wave on the vertical line where the sea bed intersects with the slope of obstacle (Figure 2). Wave height at this



point is calculated by Aida's formulas [5].

Figure 2 Diagram of tidal influence for initial point of seawater aerosol production at the obstacle coast

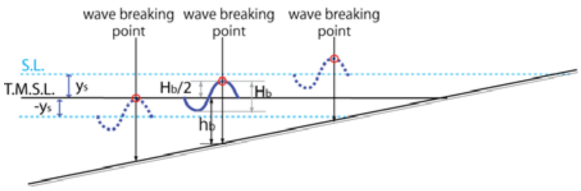


Figure 3 Diagram of tidal influence for initial point of seawater aerosol production at the beach coast

2.2.2 Initial point of seawater aerosol production on the open sea

The waves breaking on the open sea occur when the wind blew for a long period and which come from a constant direction. The area of seawater aerosol production is the wind blew extent. In this paper, the produced seawater aerosol is assumed to be a steady state at some sea condition (wave height, period, wind velocity and direction). The initial point of seawater aerosol is assumed the point, which on seashore and sea surface level.

2.2.3 Tidal influence on initial point of seawater aerosol production

Tidal level fluctuation around Japan coasts varies from several ten centimeters to several meters. If the sea level changed several meters, the wave breaking point and the relationship with obstacles location also change greatly. From this reason, tidal level fluctuation influence has on the production process of seawater aerosol at the seashore. In this paper, influence of tide is considered as shown in Figure 2 and 3.Tokyo bay Mean Sea Level (T.M.S.L.) or local Mean Sea Level (M.S.L.) is defined as the standard sea level, and the difference between the current sea level and the standard sea level is defined as $\pm y_s$.

2.3 Model of seawater aerosol production

Seawater production process is explained in the following. First, the seawater aerosol production at the initial point is assumed to occur at the same time as the wave breaking process. Seawater aerosol is assumed to distribute vertically along the vertical line passing through the initial point of seawater aerosol production.

2.3.1 Total number of produced seawater aerosol

θ_{total}(aerosol/m^3/sec) is defined as the total number of produced seawater aerosol in unit volume of air per unit of time (density). It is assumed to be a function of the height of breaking wave, as

$$\theta_{total} = \delta \cdot \theta_0 \cdot f(H_b) \cdot (1/T) \qquad (1)$$

Where δ is the coefficient on the place of seawater aerosol production, θ_0 is the referent number of produced seawater aerosol (aerosol/m^3), $f(H_b)$ is a function of breaking wave height H_b, $f(H_b) = C \cdot H_b$ in this paper, we assumed as $C = 1$. T is wave period (sec).

2.3.2 Seawater aerosol size distribution

The size of seawater aerosol, which is produced at the same time as the wave breaking, is non uniform. The horizontal transport process depends on the aerosol sizes, shooting height, and wind effect. It is, therefore, indispensable to assume the size distribution of produced seawater aerosol at the initial point.

In this paper, the size distribution of seawater aerosol produced at the initial point is assumed to follow an exponential function as shown in Equation (2). However, the distribution is referred to wind-tank experiment by Koga et al [6].

$$f(d) = \frac{1}{d_a} \exp\left(-\frac{1}{d_a} \cdot d\right) \quad (2)$$

Where d is the diameter of seawater aerosol (m), d_a is the average diameter of seawater aerosol (m) $f(d) = \lambda \exp(-\lambda \cdot d)$ is the probability density function as $\frac{1}{d_a} = \lambda$ in Equation (2). An average of the probability density function is $1/\lambda = d_a$, the definition of average diameter d_a is then reasonable. The size distribution of seawater aerosol can be decided by only one parameter d_a. $\theta_{d_i-total}$ is the total number of produced seawater aerosol density of diameter d_i (aerosol/m^3/sec), it is calculated by integrating the density function in the range of Δd as shown in Equation (3).

$$\theta_{d_i-total} = \theta_{total} \cdot \int_{d=d_i-\frac{\Delta d}{2}}^{d=d_i+\frac{\Delta d}{2}} \frac{1}{d_a} \exp\left(-\frac{1}{d_a} \cdot d\right) dd \quad (3)$$

2.3.3 Vertical distribution of seawater aerosol at the initial point

It is assumed that the seawater aerosol produced at initial point is distributed on vertical direction. Equation (4) shows the vertical distribution function of seawater aerosol. θ_{d_i,z_j} (aerosol/m^3/sec), the seawater aerosol number density of diameter d_i and at height z_j, can be calculated by Equation (5).

$$f(z) = \frac{1}{z_a} \exp\left(-\frac{1}{z_a} \cdot z\right) \quad (4)$$

$$\theta_{d_i.z_j} = \theta_{d_i-total} \cdot \int_{z=z_j-\frac{\Delta z}{2}}^{z=z_j+\frac{\Delta z}{2}} \frac{1}{z_a} \exp\left(-\frac{1}{z_a} \cdot z\right) dz \quad (5)$$

Where z_a represents an average height of vertical distribution of seawater aerosol (m). z is the height from initial point (m).

The vertical distribution of seawater aerosol is assumed that as the wave height is higher, the higher the vertical distribution can form. Consequently, z_a can be expressed function of height of wave breaking as shown in Equation (6).

$$z_a = \varepsilon \cdot H \quad (6)$$

Where ε is the coefficient for the vertical seawater aerosol distribution, H is wave height, which is equal to observed significant wave height for the open sea case, and equal to the height of breaking wave for the seashore case. The reason why the vertical distribution of seawater aerosol is an exponential form (Equation (4)) is that, the vertical distribution of chloride concentration from actual measurement shows tendency of exponential distribution. From this reason, many researchers treat the vertical distribution of the amount of chloride or aerosol number as exponential function [7] [8].

2.4 Model for sea salt aerosol transportation

We assume that the seawater aerosol transportation is the process of moving to target point along with wind while falling by gravity. The vertical distribution of wind velocity is assumed as constant during seawater aerosol transportation.

x is the distance from initial point to target point on the land. U is the wind velocity. So, the transportation time of seawater aerosol to the target calculated by x/U. w_{d_i} is falling velocity d_i seawater aerosol of diameter, then seawater aerosol falls by the height of $w_{d_i} \cdot (x/U)$ while transport ting. Consequently, the seawater aerosol number density of diameter d_i at height z_j and translation distance x (aerosol/m^3/sec), which reach on target point can be calculated by Equation (7).

$$\theta_{d_i,z_j,x} = \theta_{d_i-total} \cdot \int_{z=z_j-\frac{\Delta z}{2}}^{z=z_j+\frac{\Delta z}{2}} \frac{1}{z_a} \exp\left[-\frac{1}{z_a}\left\{z_j + w_{d_i}\left(\frac{x}{U}\right)\right\}\right] dz \quad (7)$$

Where z_j is the height from level of initial point to that of target point (m), w_{d_i} is the terminal velocity seawater aerosol of diameter d_i (m/s).

Terminal velocity is constant under the condition that forces acting on the aerosol are balanced. The terminal velocity is calculated by Equation (8), assuming that the seawater aerosol is a perfect sphere. In this paper, it considers that the terminal velocity equal the free fall velocity, because the time required to reach constant velocity is sufficiently short.

$$w_{d_i} = \left\{\frac{4gd_i}{3C_D} \cdot \frac{(\rho_p - \rho_{air})}{\rho_{air}}\right\}^{\frac{1}{2}} \quad (8)$$

Where g is the acceleration of gravity (m/sec^2), d_i is the seawater aerosol diameter (m), μ is the dynamic viscosity of air (kg/m/sec), ρ_p is density of seawater (kg/m^3), ρ_{air} is density of air (kg/m^3), C_D is drag coefficient.

$$C_D = 24/\mathrm{Re} \qquad (\mathrm{Re} < 1) \quad (9)$$

$$C_D = \left(0.55 + 4.8/\sqrt{\mathrm{Re}}\right)^2 \quad (1 < Re < 10^4) \quad (10)$$

Re is Reynolds number.

$$\mathrm{Re} = \frac{(w_{d_i} \cdot d_i)}{(\mu/\rho_{air})} \quad (11)$$

2.5 Model of seawater aerosol adhesion

The adhesion process of seawater aerosol is the process that the air containing aerosol hit on the structure surface. In this paper, it is considered that the amount of adhered seawater aerosol on the surface is the flux of seawater aerosol that pass through the structure surface. Therefore, the chloride ion flux is considered as the amount of adhesive chloride ion. The chloride ion flux is calculated by the seawater aerosol number density multiplied by the wind velocity.

2.5.1 Conversion from the seawater aerosol number density to chloride ion flux

In order to calculate an amount of adhesive chloride ion, the seawater aerosol number density is converted to the amount of chloride ion. M_{d_i}, the amount of chloride ion (kg) included in one seawater aerosol is calculated by Equation (12).

$$M_{d_i} = V_{d_i} \cdot \rho_p \cdot (\mathrm{Cl}/100) \quad (12)$$

Where V_{d_i} is the volume of seawater aerosol, which diameter is d_i ($V_{d_i} = \frac{\pi d_i^3}{6}$, m^3), ρ_p is the density of the seawater (kg/m^3), Cl is the concentration of chloride ion included in seawater (1.9% by weight).

$M_{d_i,z_j,x}$ (kg/m^3/sec), the amount of chloride ion included in the diameter d_i aerosol, at the target point can be calculated by Equation (13). And, the flux of the chloride ion, $F_{d_i,z_j,x}$ (kg/m^2/sec), is calculated from the $M_{d_i,z_j,x}$ multiplied by wind velocity, as shown in Equation (14). Finally, the total flux of chloride ion $F_{z_j,x}$ (kg/m^2/sec), which is the flux passing through the target surface, is calculated by summing the whole aerosol as shown in Equation (15).

$$M_{d_i,z_j,x} = \theta_{d_i,z_j,x} \times M_{d_i} \quad (13)$$

$$F_{d_i,z_j,x} = M_{d_i,z_j,x} \times U \quad (14)$$

$$F_{z_j,x} = \sum F_{d_i,z_j,x} \quad (15)$$

There is one limitation in the above model. The amount of chloride ion, which is calculated by Equation (14), is proportional to the wind velocity. However, when the seawater aerosol can not be in steady state in the air, the relationship of Equation (14) could be broken. In fact, it seems that the seawater aerosol is produced at the moment of wave breaking. So, when the wind velocity is too high, the production of seawater aerosol could not be completed in time and the amount of to be translated aerosol will exceed the amount of produced aerosol. That is, when the wind velocity is too high, the amount of airborne chloride ion may be overestimated in this model. From this reason, there are some solution such as decreasing the amount of translated airborne chloride ion with a function of the wind velocity. However, it is still a limitation to be improved in the future.

2.5.2 Correction of chloride ion flux

The total flux of the chloride ion $F_{z_j,x}$ calculated in Equation (15) is in case of the wind direction is normal to the target surface. When the wind direction is deviated from the normal direction, $F_{z_j,x}$

needs to be corrected. The corrected total flux of chloride ion $F_{z_j,x}'$ can be calculated by Equation (16), when the wind direction is deviated θ degree from the normal direction to the surface.

$$F_{z_j,x}' = F_{z_j,x} \times \cos\theta \quad (16)$$

2.6 Assumption on coefficients and constants

It is necessary to give the coefficients and the constants to be suitable in practice in the proposed calculation model. Each of these numbers need to be determined based on individual experiments to study each numbers. In this paper, however, the numbers are decided by reverse analysis against the past researches.

2.6.1 Outline of referred measurements

Two measurement results, which are different in coastal conditions, are adopted. One is measurements behind shore protection by Hashida et al [9] and Matsunaga et al [10], and the other is on the sand beach by Murakami et al [11].

The detail of the measurements is shown in Table 1 and 2. The amount of chloride ion is converted for verification from the amount of chloride denoted in the reference papers. The cross section of the shore protection for measurements of Hashida et al and Matsunaga et al is assumed as in the Figure 4.

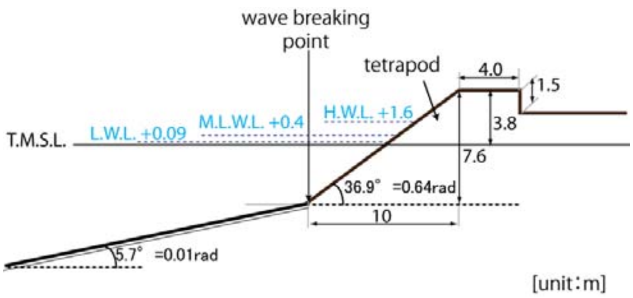


Figure 4 Cross section of shore protection

2.6.2 Coefficients and constants

The coefficients and constants in the proposed model are shown in Table 3.

Table 1 Measurement conditions of reference [9] and [10]

Measurements data and time	Wind velo-city (m/s)	Wind directi on	Wave height (m)	Wave period (sec)	Average tide level (m)
1998/11/20, 17:30-	5.49	57	0.79	5.0	+0.45
1998/12/8, 14:00-	7.94	52	1.29	6.0	+0.39
1998/12/9, 15:30-	5.79	47	1.29	6.4	+0.42
1999/1/7, 17:30-	12.5	53	2.43	6.9	+0.32
1999/1/8, 8:30-	12.1	53	2.28	6.7	+0.18
2000/1/20, 16:30-	9.54	45	1.76	6.4	+0.26
1998/12/10, 7:30-	4.85	51	0.68	4.6	unknown
1999/1/7, 14:30-	13.10	56	2.39	6.9	unknown

Table 2 Measurement conditions of reference [11]

Measurements data and time	Wind velo-city (m/s)	Wind directi on	Wave height (m)	Wave period (sec)	Average tide level (m)
1992/12/22, 11:00-	3.3	66	1.34	6.0	unknown
1993/11/6, 9:00-	2.5	22	0.52	7.5	unknown

Table 3 Coefficients and constants for the proposed model

		on seashore		on open sea
		obstacle	beach	
d_a (μm)		350	20	8
δ		1	10	400
θ_0 (aerosol/m^3/sec)		2.0×10^4		
ε	$d \geq d_a$	2	2.5	40
	$d < d_a$	10		

2.6.2.1 The average diameter of seawater aerosol d_a

The average diameter of seawater aerosol d_a, which is calculated from Equation (2), for obstacle coast is assumed as 350μm, 20μm for beach coast, and 8μm for the open sea.

There are two mechanisms of the seawater aerosol in the production process; one is produced when the bubble on the sea surface is breaking, and another is produced by the splash of wave breaking. The diameter of the seawater aerosol, which is produced by the bubble breaking mechanisms, seems from several μm to several hundred of μm [12]. While the diameter of the seawater aerosol, which produced by the splashing, is up to several thousands of μm. It is comparatively big and visible with human eyes [6].

The assumed average size of seawater aerosol is shown in Table1. Because, the seawater aerosol distribution produced at the open sea, which is reached on the land, is smaller than that of the seawater aerosol produced at the seashore.

2.6.2.2 The coefficient about aerosol production place δ and the referent number of produced seawater aerosol θ_0

The standard number of produced seawater aerosol is assumed as constant, $\theta_0 = 2.0 \times 10^4$ (aerosol/m^3). The total number of aerosol is decided by the coefficient about production place δ. It is assumed that $\delta = 1$ for the obstacle beach, $\delta = 7$ for the sand beach, and $\delta = 400$ for the open sea as shown in Table 3. The coefficient δ is in inverse proportion to the average diameter of seawater aerosol. The smaller the diameter of seawater aerosol, the larger number of aerosol produced.

2.6.2.3 The coefficient for the vertical seawater aerosol distribution ε

It is assumed that the seawater aerosol shoot into the sky by the wave breaking energy. The vertical distribution is expressed in Equation (4), which is controlled by the average height z_a. z_a is calculated by Equation (6), which is a function of consisted by wave height and the coefficient ε. The produced particles on the open sea are accumulated vertically according to the fetch (the distance of wind blow) based on Toba's theory [12]. However, in this paper, it is assumed that the coefficient $\varepsilon = 40$, which is function of only wave height. It seems that the seawater aerosol produced in the seashore is lifted higher as it is smaller. The coefficient ε is assumed $\varepsilon = 2.5$ for the sand beach, and $\varepsilon = 2$ for the obstacle beach when $d \geq d_a$, and $\varepsilon = 10$ when $d < d_a$. The reason why the coefficient ε of the obstacle beach is different from the diameter of seawater aerosol is that, the diameter of aerosol produced at the obstacle beach is distributed in wide range. If the coefficient ε is constant in this wide range aerosol diameters, the coefficient will be unreasonably. So, the coefficient ε is divided into two steps by the average diameter of seawater aerosols.

2.6.3 Result of fitting model parameters

Figure 5 and Figure 6 show the result of applying the above coefficients and constants to the proposed model. Figure 5 shows the results for the case of behind the obstacle coast. The difference in measurement results and calculation results is ranged from 10 times to 50 times as shown in Figure 5. The accuracy of the result measured just behind the obstacle is seemed to come from the especially poor. The reason is seemed to come from the wind turbulent. Figure 6 is the results for the sand beach. The difference of measurement and calculation results is ranged from several times, however, there are small number of measurements data when compared with Figure 5, and the wind velocity and the wave height is small and in narrow range in the time for the measurements.

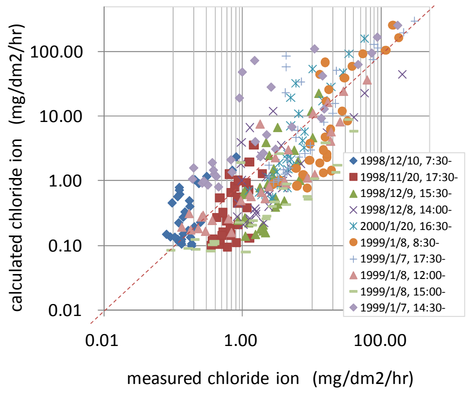


Figure 5 Result of fitting parameters for reference [9], [10]

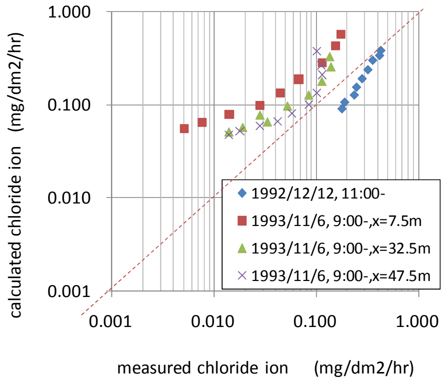


Figure 6 Result of fitting parameters for reference [11]

3. VERIFICATION

This chapter verifies the proposed model with coefficients and constants by using measurement results that one of the author had measured for airborne seawater aerosol at seashore of Izumo city [13].

3.1 Outline of measurement

Airborne seawater aerosol is measured at two types of coast, one is beach coast and another is obstacle coast, as shown in Figure 7, of the seashore of Izumo city, Shimane prefecture. Figure 8 shows experiment configuration and collection paper. Drops of seawater aerosol on collected paper were counted and analyzed particles diameter by the water-sensitive paper analyzer “MY A NODE”. Wind and wave conditions are shown in Table 4. From No.1 to No.6 are measured at 60m from behind tetrapod, the other cases are measured at 20m from sand beach seashore. The wind velocity is measured at the measurement place, and wind direction always blew from east during measurement period. The wave data is observed at Kyoga-misaki at Kyoto prefecture by Japan Meteorological Agency. Tide level shown is based on mean sea level at 22cm.

(a)Sand beach (beach coast) (b) Tetrapod (obstacle coast)

Figure 7 Configuration of measurement place

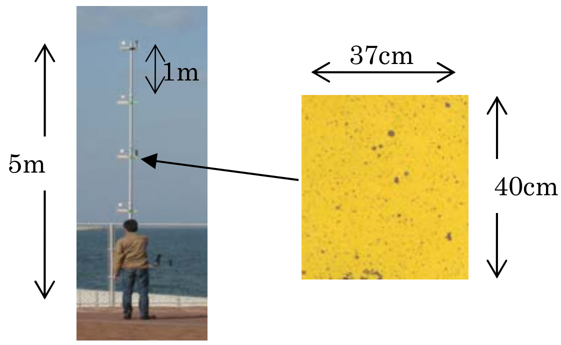


Figure 8 Configuration of measurement implement (Left) and aerosol collection paper (Right)

Table 4 Measurements conditions

No	Data 2009/1/11 at time	Time Period (min)	Wind velo-city (m/s)	Wave height (m)	Wave period (sec)	Tide level (cm)
1	11:20-	5.00	10.4	3.2	8.6	-7.03
2	11:40-	5.00	9.2	3.6	9.0	-5.54
3	13:30-	3.66	10.2	3.1	9.0	-4.91
4	11:55-	5.00	8.4	3.6	9.0	-4.43
5	12:10-	5.00	8.0	3.6	9.0	-3.50
6	13:45-	5.00	5.9	3.0	8.8	-3.10
7	12:45-	3.33	9.5	3.1	9.0	-3.00
8	13:00-	5.00	8.5	3.1	9.0	-2.90
9	13:15-	5.00	8.9	3.1	9.0	-2.80

3.2 Calculation condition

Figure 9 shows assumed cross section to calculate case No.1 to No.6, measurements for obstacle coast. Sea bed slope is assumed as 1/50.

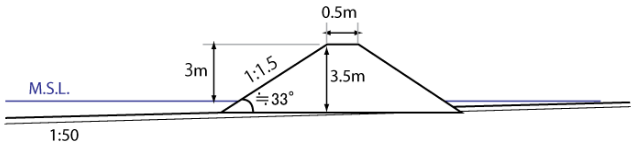


Figure 9 Image of measurement implement and aerosol collection paper

3.3 Results of verification

Figure 10 shows the relationships between the measured chloride ion and calculated chloride ion. The calculated chloride ion is higher than measured chloride ion as a total tendency. The reason is that, it is seemed to be influenced by the cross section between shore protection (Figure 4) and tetrapod (Figure 9). However, the calculated results are shown within an order of measured results, and it is seemed nearly good tendency.

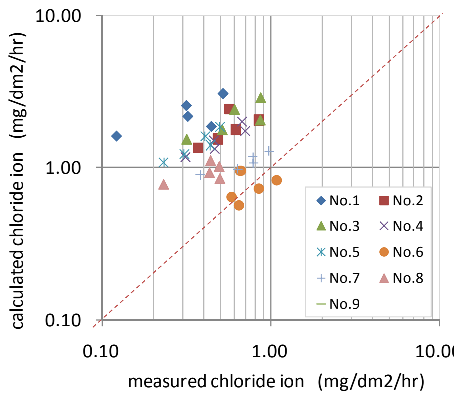
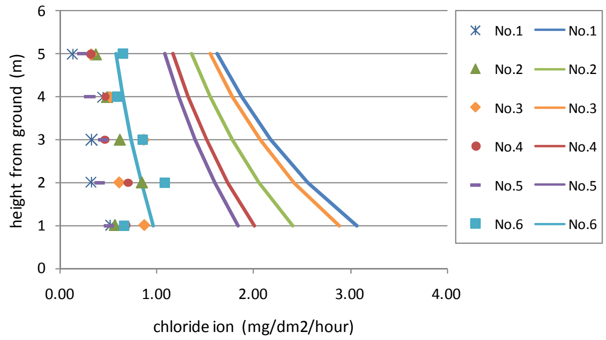


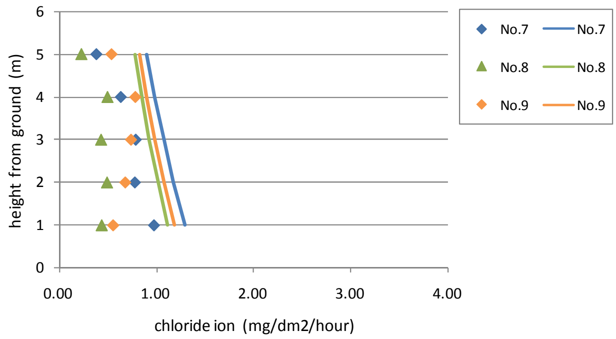
Figure 10 Relationships between measured and calculated chloride ion

Figure 11 shows the vertical relationships between the measured chloride ion (dot) and calculated chloride ion (line). From this Figure, it seems that calculations result for behind tetrapod is overestimated compared to that of the sand beach.

In case of obstacle coast (upper figure), calculated ions are several times larger except of the case No.6. Because the wind velocity in case No.6 is low compared with another case, see in Table 4. Actually, the wind velocity is measured by visual reading with 30 seconds interval. It seems that the accuracy of wind velocity influences the calculated results.



(a) Measurement case No.1 to No.6, behind tetrapod



(b) Measurement case No.7 to No.9, sand beach

Figure 11 Vertical relationships between measured (dot) and calculated (line) chloride ion

4. CONCLUSIONS

4.1 Calculation model for the amount of airborne chloride ion

The calculation model for the amount of airborne chloride ion prediction at arbitrary time and location is proposed. The model consists of three processes; seawater aerosol production process, transportation process, and adhesion process.

The aerosol production is assumed by following processes. First, an initial point of aerosol production is classified by three types according to the production place. And the produced aerosol number density at initial point is decided according to the condition of the production place and wave height. Then, the size distribution and the vertical distribution of seawater aerosol at the initial point can be assumed as the exponential function. In the aerosol transportation process it is assumed that the horizontal movement is caused by wind and vertical movement by gravitational. The adhesion process is considered that the amount of adhered seawater aerosol equal the flux of seawater aerosol passing through the structure surface.

4.2 Verification of proposed model

The proposed model involved coefficients and constants were verified by measurement results of seawater airborne chloride at Izumo city. The calculated chloride ion is higher than measured chloride ion as a total tendency. The reason is that, it can be assumed to be influenced by the cross section and accuracy of wave and wind data. However, the calculated results are shown within an order of measured results.

Consequently, it seems that the proposed model can be used as the calculation model for the amount of airborne chloride ion to predict the chloride attack. However, additional consideration on deciding coefficients and constants is necessary for improving the model in future.

4.3 Data of weather, wave and geographical environment

The accuracy of input data, which are weather and geographical conditions, have much influence on the accuracy of the proposed model. For this reason, it is indispensable to collect and prepare the input data to support for the structures of all over the country for carrying on the propose model.

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