Measurement of Airborne Chloride Particle Sizes Distribution for Infrastructures Maintenance

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ABTRACT:Maintenance of deteriorated infrastructures subjected to chloride attack had become a challenging task. It is going to be more serious problem in near future in which budget and resource are decreasing. One of the critical issues is quantification of the airborne chloride amount coming to the structures. Currently available models to predict the airborne chloride are very weak and had no improvement since a few decades. The most possible reason is having no measurement data available that can offer necessary information to construct a more sophisticated prediction model. Traditional measurement data of airborne chloride for infrastructures maintenance was in terms of the total amount of chloride without particles size information. It was commonly measured by interval of months, which results in large dependency on the site characteristics. Consequently, it is rather difficult to apply the measured data from one location to another. It also implies that it is very tough to construct a good prediction model that can give an amount of airborne chloride under arbitrary time and given topology.

This paper proposes a new airborne chloride measurement method that is able to capture particles size distributions of sea salt aerosol (SSA) in a target space by only within a several ten seconds. Measuring in such a very short period enable the modeler to link the weather, wave characteristics and surrounding topology with the measured data, and in addition, knowing the particle sizes distribution is an innovative and indispensible information, which are very important matters for constructing a robust and sophisticated prediction model for a purpose of a better infrastructures maintenance.

KEYWORDS:Chloride attack, concrete, measurement, Airborne Chloride

1. INTRODUCTION

In the viewpoint of infrastructure maintenance under airborne chloride laden environment, it is the most important to know how much the sea salt aerosol particles (SSA) reached the structure. SSA contains about 1.9% of chloride (by mass) that will be accumulated on the surface of infrastructure, diffused and accelerates the corrosion process of the steel components.

On-site measurement of SSA particles at the target structure by capturing by gauze or solid plate is the most traditional way to estimate amount of incoming Chloride, figure 1. Since the measurement is usually conducted for months or a year, the result of on-site measurement is strongly depending on the climate and topologycharacteristics of the site. Hence measuring for long duration will average out the wave, weather conditions, and wind routes, which accumulatively associate the measurement result with the site characteristics. For this reason, it is difficult to apply the result obtained from one location to another different location unless well knowing the correspondence between those two.

Annual chloride amount investigation at 266

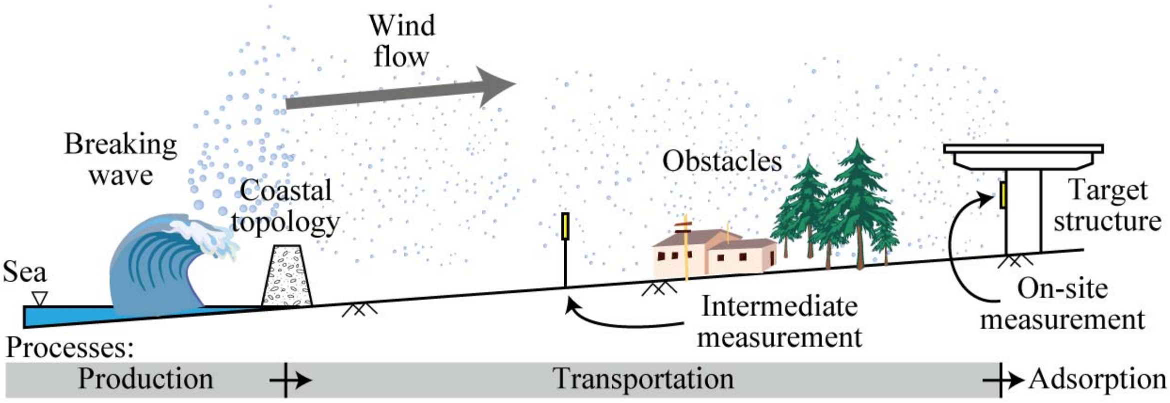

Figure 1: Airborne Chloride measurement for infrastructures maintenance

locations all over Japan during year 1985-1993 is well-known research outcome done by Public Works Research Institute of Japan (PWRI). The investigation has been carried out by their own method that capture the SSA on stainless plate installed in a small shed and collects for result monthly.SSA particles that reached the target structure resulted from three sequential processes: SSA production, transportation, and surface adsorption, for the prediction, it is pointless to relate the measured result (the last surface adsorption process) with the site characteristics without quantifying the previous two processes.

In infrastructures maintenance in which budget, time and human resource are limited, to obtain airborne chloride amount at every infrastructure having a potential to be attacked by Chloride is not a wise solution.The amount of airborne chloride at the target structure can be calculated by a proper physical modeling to link those three processes together, Kokubo 2009. However, the most important thing is to know the starting process, the SSA particles production process, which is mainly depending on weather, wave conditions, and coastal topology.

SSA contains various sizes of particle ranged from several ten micrometers to thousand micrometers, Stanislaw 2007. Each individual particle size has different physical characteristics, which differently affects the transportation process by wind. Smaller particle is able to suspend in the air longer than the larger one, which results in a longer horizontal flying distance. Consequently, it is essential to know the SSA particle sizes distribution from the measured data in order to verify the transportation process modeling.

This paper proposes a new measurement method to capture SSA with particle sizes distribution by performing an intermediate measurement near coastal line that able to link the measurement result with the environmental conditions, figure 1. The measured result is then be used as a starting point to calculate the amount of airborne chloride at any location and time for a purpose of infrastructure maintenance.

2. CONCEPT

The concept of measuring SSA particles is to capture various sizes of SSA particles on the water-sensitive paper (WSP, by Syngenta corp.) while keeping the size distribution information as it is. When amoving SSA particle on the wind flowcollide the WSP, it leaves a stain on the paper, which can be measured and converted to diameter of the real particle. Those stains are and then counted for size distribution by digital image processing. However, due to fiber grain and limitation of chemically coated film of the WSP, SSA particles smaller than 20 micrometer cannot well make stains on the paper surface.

A basic measurement configuration is shown in figure 2. A measurement pole attached with several

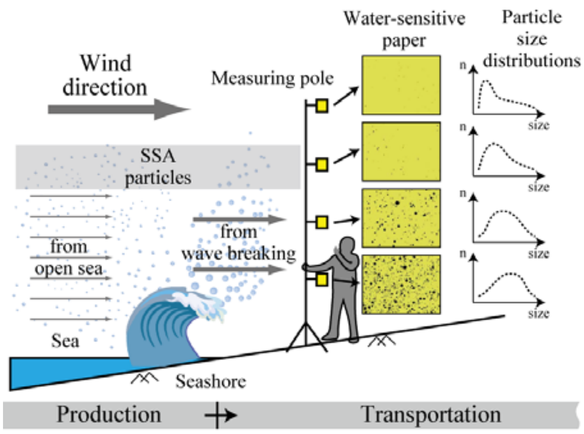

Figure 2: Concept of measuring SSA particles distribution using WSP

WSPs at different elevation is placed at some distance inland away from the seashore to capture the SSA particles. It should be noted that this configuration is not a direct measurement of the production process, but it is somewhere in the transportation process. If there is no obstacle in between the particles production point and the measurement point, a lamina wind flow in transportation process can be assumed. As a result, by introducing the information of particle sizes distribution analyzed from the WSPs, the measured particle distributions can be converted back to those of the production point by considering only free-fall effect of the SSA particles in transportation process.

Several measurement poles (or a single) are placed at some distance away from the seashore line. Placing at longer distance results in reduction of the particles captured on the WSPs. This reduction is caused by particles dropping by gravity, blocking by either terrain or obstacle. On the other hand, measuring at too close to the seashore where waves are breaking may results in interference with sea wave splash that immediately falls down and has no effect on airborne particles formation. SSA particles that just formed by wave breaking action, take some distance to ride on the wind to be uniformly dispersed in the air space. Stronger wind condition needs longer distance. We assumed that the safe distance from the seashore line is equal to distance that wind traveled in one second.

The estimation method proposed in this paper aimed to obtain the SSA particles size distributions at the production process with correspondence to the relation on weather, wave conditions, coastal and surrounding topologies by performing measurement in very short duration. The duration setting is flexible, which could range from several ten seconds to several minutes depending on how dense the SSA particles concentration on the WSP and steadiness of environmental conditions at the measurement location. During such short measurement duration, the time-varying weather and wave conditions can be linked with the measured data as well as the topologies, which can satisfy the condition to construct the generalized prediction model.

During the measurement period, wind direction should be rather constant to ensure that origin of the SSA is not changed. The WSP is set to face normal to the wind direction, while the direction can be set (rotate) correspondingly by the measurer.

After the measurement, WSP will be digitalize into bitmap file to be ready to be processed by image processing software (for counting particles and analyze its sizes).

3. PROCEDURES

Since, for example, the coming wave height during a few minutes may be in half or as twice, for measuring in such a very short duration, recordingthe conditions of surrounding environment at every instant is important. Figure 3 shows the experiment field in which using two measuring poles at front and back line (A and B), for example, at sand beach. Surround condition measurement line is set up nearby in the same orientation for measuring relative real-time wave height and wave count by using VDO camera. Horizontal and vertical distances among breaking wave, the measure pole, the VDO camera will be measured and calculated for relative wave height by using a simple trigonometry (small angle approximation). Wind speed and wind direction are measured by digital anemometer attached at the top of measuring pole.

During measurement standby, WSP faces (58mm×38mm) are turned so that its backs against the wind direction until beginning of the measurement. The corresponding pole measurer turns the pole to face WSP against the wind to start to catch the SSA particles. After proper amount of SSA particles are captured, the measurer turn the pole backward and flip the pole down slowly for WSP collection.

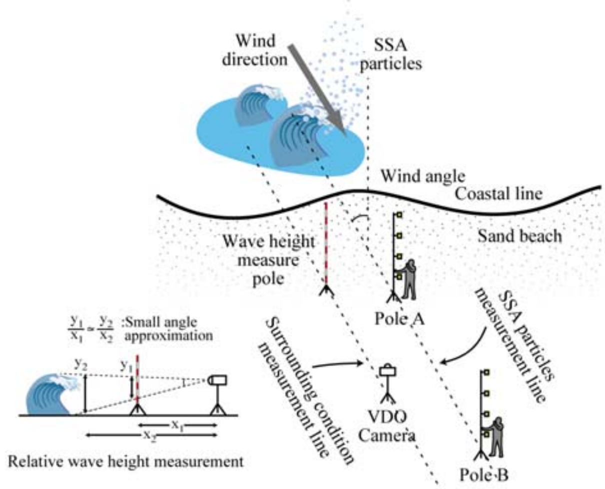

Figure 3: Measurement site

Since the WSP is very sensitive against moisture, it needs to be kept in dry box until getting dried. The WSP is then sealed by thin film laminator to prevent further accidentally staining.Ten times optically magnified WSP photos (6 sampling points per one WSP) is taken by stereo microscope equipped with 2.0M pixels CCD camera. Each digitalized photo is then analyzed for particles number and sizes distribution by digital image processing software named Winroof (Mitanicorp). The final result is the form of SSA particle sizes distribution.

4. RESULTS AND DISCUSSION

In this paper we selected measurement point at Maehama, Kochi prefecture, Japan. During summer, wind flows strongly from the south that locates Pacific Ocean, figure 4. Two measurements at different coastal conditions, sand beach and behindtetrapod are selected to illustrate the measurement results as shown in figure 5. The figures show the stained WSP at those two locations at different heights (1 - 4 meters) with pole A and B (front and back).

Figure 4: Location of measurement

Average wind speed during measurement for sand beach and tetrapod are 6.7 m/sec and 5.4 m/s, respectively. Wind direction was almost come from the south that normal to the coastal line all the measurement period. Average wave heights (at wave breaking point) are 1.6 meters and 1.5 meters, measurement durations are 50 sec and 25 sec, respectively. Measurement duration behind tetrapod is less than half of that of sand beach since SSA particles were captured on WSP faster. If SSA particles are captured too many (with some overlap), there will be difficulties in particles counting procedures.

For sand beach, pole A and B are located away from coastal line about 30 and 45 meters, respectively. On the other hand, for tetrapod, sea water splash with effect of wind has effect on longer distance inland. The measurement location had to be located at more distances, 60 and 75 meters respectively for pole A and B.

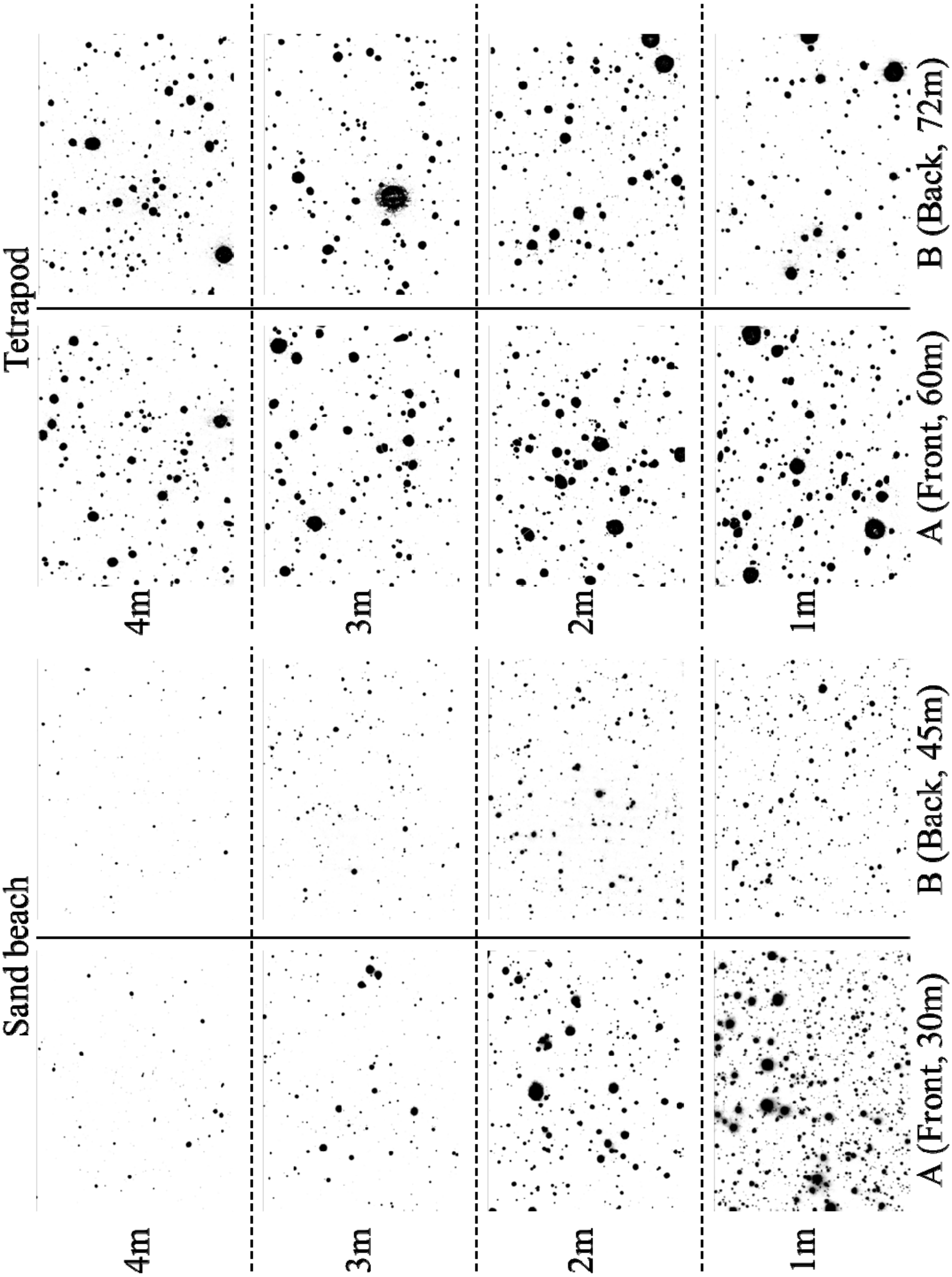

Figure 5: Stained WSP (sampling size: 12.8mm×9.6mm)

SSA particles distribution for sand beach, see figure 5 (left), is straightforward. The higher elevation increases, the lesser number of particles reduce. In addition, when distance from coastal line goes longer, some (large) particles drop vertically due to gravity while smaller particles can travel in more distance with less elevation drop.

On the other hand, for the tetrapod side, larger particles are generated due to the wave smashing at the tetrapod and rise to higher elevation than only wave breaking at sand beach. These large particles raisedup more than 10 meters. While measuring at 4 meters height could not capture such a high vertical distribution.

Figure 6 shows distribution of different SSA particle sizes at each elevation. For sand beach,

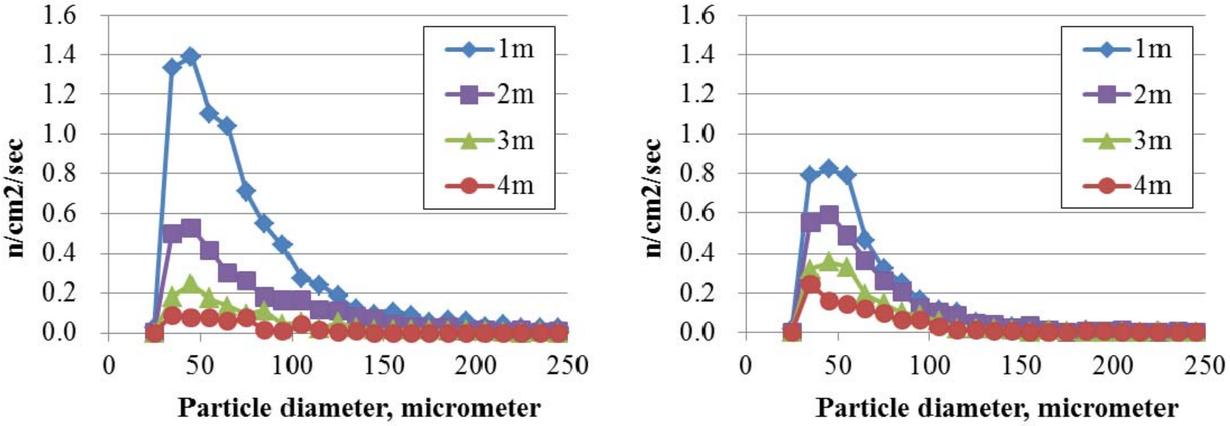

Figure 6: Particle size distribution at different elevations (sand beach).

Left: pole A (30m), right: pole B(45m)

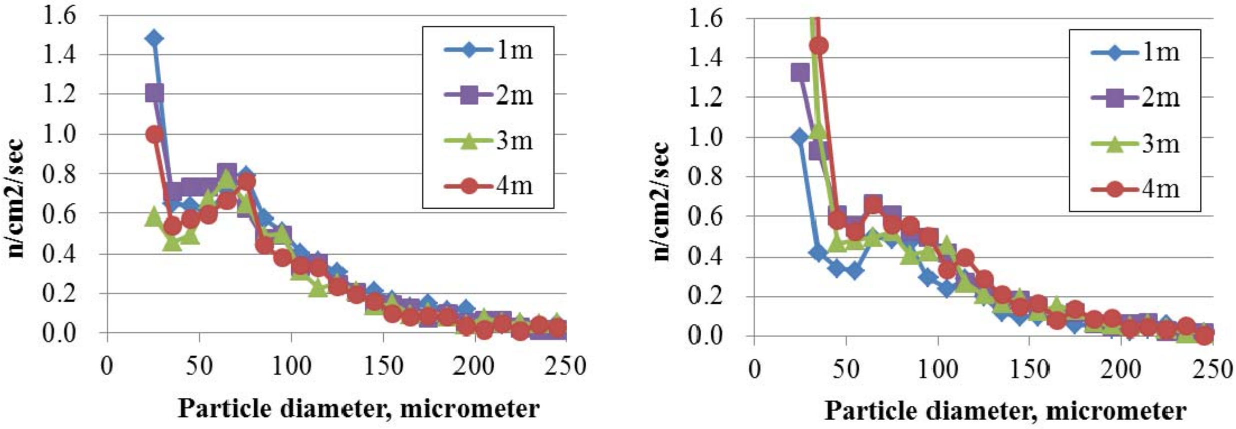

Figure 7: Particle size distribution at different elevations (tetrapod).

Left: pole A (60m), right: pole B(72m)

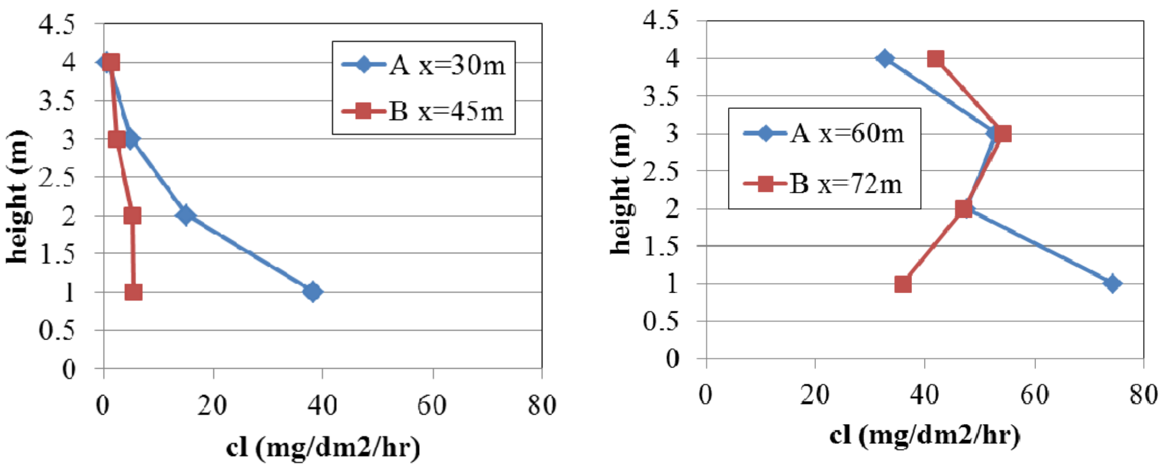

Figure 8: Airborne chloride flux at different elevations. Left: sand beach, right: tetrapod

particles having size around 50 micrometer are dominant and reduced at higher elevation. When comparing between pole A (coastal distance is 30 meters) and pole B (45 meters), at pole B where is further, has a slight increase in small SSA particles while slight decrease in larger particles (>100 micrometers). It should be noted that larger particle contains more chloride than smaller one. When amount of chloride (flux) is plotted against height, it can be shown in figure 8 (left). It is clear that there is lower chloride amount at higher elevation and also at longer distance.

On the other hand, figure 7 shows the same distribution for tetrapod. There are two peeks of dominant diameter, 25 and 75 micrometers. However, such a small 25 micrometers particle has much lesser amount of chloride contained, on 75 micrometers diameter is considered as predominant diameter for tetrapod, which is larger than that of the case of seabeach. From the diameter distribution, it seems that there is no much different between different at each elevation. However, after calculated for amount of chloride, figure 8 (right), higher chloride amount has tendency to present at lower elevation due to effect of larger SSA particles. These large particles (150-200 micrometers) drop rather faster than smaller one resulting in retaining smaller particles in the air longer to reach further distance.

5. CONCLUSIONS

This paper purpose a new method to estimate amount of airborne chloride with SSA particle sizes distribution. The information containing particle sizes is important for verify the airborne chloride prediction model.

SSA particles are captured on the water-sensitive paper (WSP) and leave colorized stains on the paper surface. Employing this method, small particles size up to about 20 micrometers can be captured with in several tem seconds. Such short measurement duration, it can be assumed that the weather and wave conditions are unchanged. As a result, it is at ease to relate ambient and coastal conditions to the measurement results. This is a necessary condition to verify the prediction model with the results.

With adequate case studies and results verification, this new approach will become a very useful in airborne chloride prediction in infrastructure maintenance in future.

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