An Investigation of Sea Spray Icing and Deicing on Membrane Structures

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Abstract— **Reduced visibility due to sea-spray ice accretion is a major problem for the operation of lighthouses in northern harbors. To address this problem we designed membrane structures that wrap a small lighthouse. The wet growth of spray ice was investigated through cold laboratory experiments. Small water particles with a diameter of approximately 0.1 mm were flowed to the test fabrics, and the icing occurred on the windward side of the fabrics. The experiments were performed using several materials. The ice-accreted fabrics were vibrated and we observed the state of exfoliation of ice and the structural features of sea spray icing. The field test was carried out at the west coast of Hokkaido, Japan. Two dummy lighthouses were set up on a breakwater. Several types of membrane were tested for wrapping the dummy lighthouses during the winter season. A spacing device was installed on the dummy lighthouse and the space of the membrane so that the membrane fluttered in the wind. Hydrophilic coating material and water-repellent coating material were noticeably different in both the icing growth process and the deicing condition. There was a difference in the generated vibration by the form of the spacer, and it caused the difference in the deicing.**

I. INTRODUCTION

THE northern part of the Sea of Japan is famous for being a marine disaster zone because of spray icing. Figure 1 is a photograph of the sea spray ice accreted on a small lighthouse in Atsuta harbor, located on the west coast of Hokkaido, Japan. Reduced visibility due to sea spray ice accretion is a major problem in the operation of lighthouses in northern harbors.

A conventional lighthouse that was sufficiently high (approximately 10 m) to prevent reduction in visibility due to spray icing was used in Hokkaido, Japan until recently. Now-a-day, the conventional lighthouses are being replaced by economically smaller lighthouse made of FRP (fiber reinforced plastic) or steel. Measure to counter anti-icing and deicing are necessary for small lighthouses. In general, deicing is still a manual operation that uses a hammer. In order to address this problem, we designed membrane structures to cover small lighthouses. The membrane structure was composed of a chemical cloth and a spongy spacer.

Accretion of ice and snow forms a visco-elastic material, and the failure pattern in realizing this was found to depend on the strain rate. Since ice is expected to exfoliate easily from the cloth due to fluttering, etc., the membrane undergoes rapid distortion.

Several recent studies have investigated the physical properties of sea spray ice. Ono [1] measured the weights of ice and brine, as well as the density, salinity, and growth rate of spray ice on a ship. He also measured the cross section of the accreted ice structure. Makkonen [2] developed a wet growth model of atmospheric icing on an ice structure. Lozowski et al. [3] simulated marine ice accretion. Ryerson and Gow [4] studied the microstructural features of spray ice on a ship and confirmed the channelized network of brine. Icing tests using canvas cloth were carried out in a laboratory experiment [5]. The cloths were coated with polypropylene, vinylidene fluoride, vinyl chloride, and silicone. However, these cloths were not used practially in the deicing of the lighthouse.

In this research, the features of icing on the fabrics and the deicing condition were checked by cold experiments conducted in the laboratory and field.

Fig. 1. Sea spray icing on a small lighthouse.

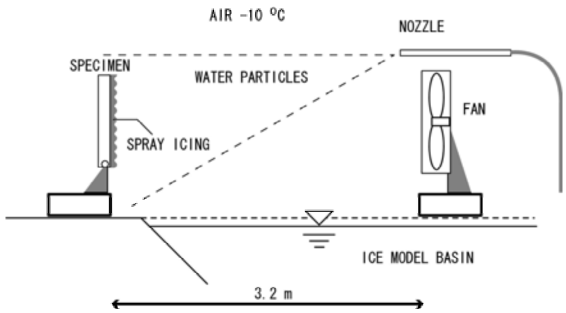

Fig. 2. Apparatus on an ice model basin.

II. Laboratory experiment for ice accretion

A. Experiment using salt water

The wet growth of spray ice was investigated through laboratory experiments. The experimental apparatus 1 was set up in an ice model basin, which was 35 m long and 6 m wide, at the National Marine Research Institute. A schematic view of the apparatus is shown in Figure 2. The air temperature in the cold room was maintained at approximately –10 ºC. Small water droplets with a diameter of approximately 0.1 mm were supplied by dual spray nozzles and were flowed to a film specimen. The specimens used are shown in Table 1. During the experiments, the wind speed was 2–3 m/s and the salinity of the supplied water was approximately 35‰. The experiments were performed using several materials. When the ice-accreted films were vibrated, the state of exfoliation of ice was observed and the structural features of sea-spray icing were revealed.

Table 1
Test specimen.

	Material
A	Silicon heat-resisting cloth
B	Fluoro ethylane plastics
C	Polyester coated with vinyl chloride
D	Fiber reinforced plastic composites
E	Waterproof nylon cloth
F	Polyester coated with polyurethane

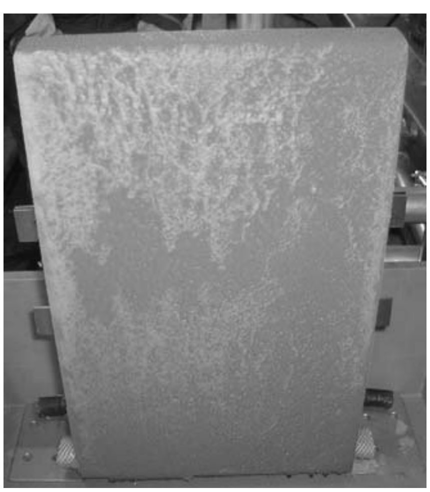

Fig. 3. Spray icing on polyester coated with vinyl chloride.

In the laboratory experiments, wet growth of icing occurred on every test fabrics, although the icing growth process and the deicing condition were different for each test fabrics. Figure 3 shows the ice accretion that is reproduced on a film specimen made of polyester coated with vinyl chloride. The icing had occurred at the windward side of the film. There were remarkable irregularities on the outer surface, and channelized network of brine were confirmed in the accreted ice. On the other hand, Figure 4 shows the icing on a belt made of a fiber-reinforced plastic composite. In this case, water drops of uniform thickness had grown on the surface of the polyethylene belt, and ice of uniform thickness had grown. Figure 5 shows the results of film vibration test, where the specimen was vibrated at 3.57 Hz, and the state of exfoliation of ice was observed. The ice exfoliated easily with every test cloths, although the deicing of the waterproof hydrophile material was easier because of the thin ice accretion and its uniform thickness.

Fig. 4. Spray icing on fiber reinforced plastic belt.

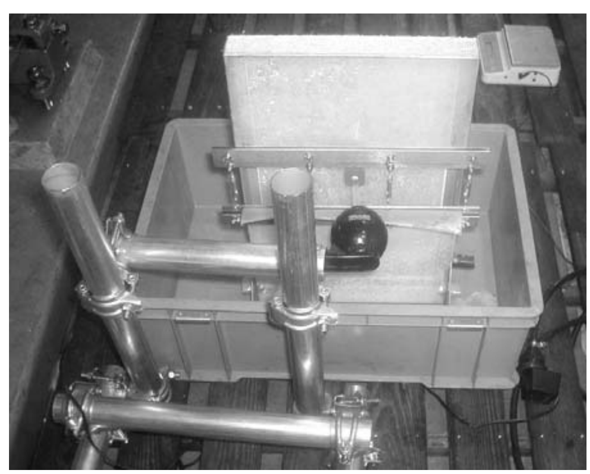

Fig. 5. Vibration test of ice accreted film specimen.

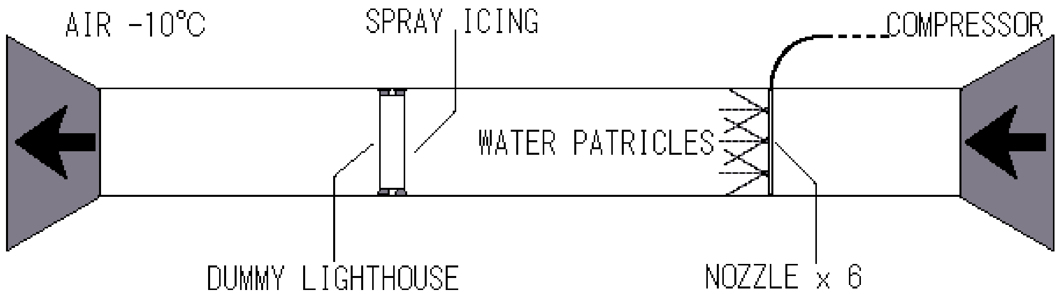

Fig. 6. Schematic view of wind tunnel test.

B. Wind tunnel experiment

Since the experimental wind speed condition was unstable in the above apparatus, apparatus 2 was set up in order to conduct the experiments under strong wind conditions. A schematic view of apparatus 2 used for the experiment is shown in Figure 6. The experiments were performed in a cold wind tunnel, a closed circuit wind tunnel located in the Cryospheric Environment Simulator (CES) at the National Research Institute for Earth Science and Disaster Prevention. The working section is 1 m × 1 m, and a maximum length of 14 m is available depending on the experimental requirements. The air temperature in the cold room was maintained at approximatery –10 ºC. Small water particles with a diameter of approximatery 0.1 mm were supplied by 6 spray nozzles and were flowed to a dummy small lighthouse. Non-saline water was used. The body of the dummy lighthouse was made of steel pipes with dimensions of 30 cm diameter and 80 cm length. The wind speed was 10–20 m/s during the experiments, and the wet growth of icing occurred on the windward side of the film. The experiments were performed using various fabrics.

A spacing device was installed between the dummy lighthouse and the fabric, so that the membrane fluttered in the wind. The spacer was made of the spongy material. Figure 7 shows the membrane structure made of the waterproof nylon cloth and a spiral-shaped spacer.

Fig. 7. Spray icing on waterproof nylon cloth with spiral-shaped spacer.

In the nylon cloth model, exfoliation occurred due to the vibration generated by a strong wind. This exfoliation did not occur with other cloth models. This might imply that deicing was effective because the nylon cloth was flexible and icing was thin and uniform.

A difference was noted in the vibrations generated due to the variations in the type of spacer used and this led to differences in the deicing. The spiral-shape spacer propagated the vibration primarily to the larger area and stimulated deicing.

III. Field Test

The field test was carried out at Hamamasu harbor, located on the west coast of Hokkaido. Two dummy lighthouses were set up on a breakwater extending from the north to the south. Several types of membrane models were tested for wrapping the dummy lighthouses during the winter season. A spacing device was installed between the dummy lighthouse and the membrane (Figure 8). A northwesterly wind generated a icing spray on the sea-facing side of the harbor, and the spray drifted intermittently toward the lighthouse. Ice accretion on the wrapped lighthouse was recorded by the monitoring system.

Figure 8 FRP lighthouse wrapped by membrane structure.

Figure 9 shows the ice accretion on the dummy lighthouse without the membrane. The icing grew on the windward side of the lighthouse. A horizontal cross section of the ice accretion shows the presence of growth rings. Presence of brine was detected in it and the salinity of the samples was 7 ‰. Althouth the steel pile dummy lighthouse although was coated with a water-repellent coating of fluorine, ice accretion occurred most frequently on it. On the other hand, heavy icing on the membrane was rare. Figure 10 shows the ice accretion on the same dummy lighthouse where the membrane was wrapped around the bottom half. This figure appears to be clear that the membrane structure controls the growth of icing. In the case where the membrane was coated with thick icing, the cloth could not undergo fluttering or distortion and deicing was difficult.

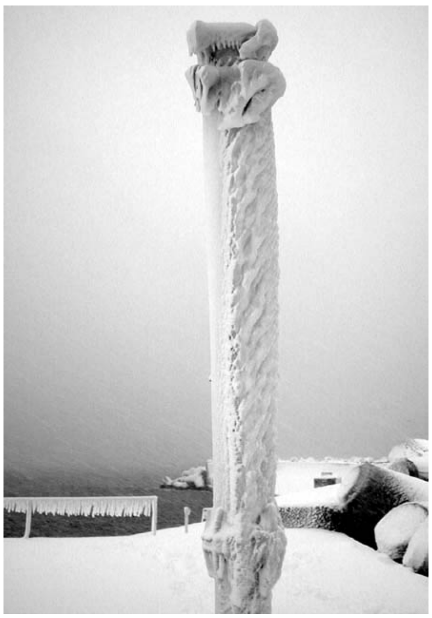

Fig. 9. Sea spray icing on steel dummy lighthouse.

Fig. 10. Anti-icing effect of membrane structure.

IV. Conclusions

Investigations of ice accretion on a membrane structure were performed using laboratory experiments and field observation. The membrane structure was made of a chemical cloth and spongy spacer.

Wet growth of icing occurred on every test fabric in laboratory experiments, although the icing growth process and the deicing condition were different in the test fabrics. In the water-repellent coating cloth, water droplets froze before draining out and there were remarkable irregularities on the outer surface.

Deicing was easily performed by vibrating the membrane. The waterproof nylon cloth was effective in deicing because it was flexible and had thin and uniform icing. The vibration generated was dependent on the type of spacer used by the form of the spacer, and this let to the difference in the deicing.

The field test was carried out using two dummy lighthouses set up on the breakwater at Hamamasu harbor. A spacing device was installed on the dummy lighthouse and the space of the membrane. Ice accretion often occurred on the fluorine-coated steel pipe dummy lighthouse. On the other hand, development of heavy icing on the membrane was rare, although the distortion effect of the membrane was not observed once icing had developed on it.

Further investigation of the icing and deicing processes is necessary for the practical use of the membrane structure in small lighthouses.

V. Acknowledgment

We are grateful to Ship and Ocean Foundation for supporting the research. We express our gratitude to N. Yamamoto and K. Ishizuka of the 1st Regional Coast Guard Headquarters, Japan Coast Guard for their support in the sample preparation. We also thank Dr. H. Aburakawa and T. Yoshikawa of Hokkaido University of Education, Iwamizawa campus, and S. Mochizuki and T. Takeda of National Research Institute for Earth Science and Disaster Prevention, for their support of the laboratory experiment and data analysis.

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