STUDY ON THE PREVENTION OF SNOW AND ICE ACCRETION ON ROAD STRUCTURES

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1. Aims of the Study

Road structures include those parts that span the entire road width or cover traffic lanes, such as upper chord members of arch/truss bridges, and entrances of snow sheds and tunnels. In cold and snowy Hokkaido, snow and ice can accrete to these parts and, due to traffic vibration and/or a rise in temperature, may subsequently fall, potentially causing accidents and injuries. In recent years, various measures have been incorporated into the design of road structures to help prevent such accidents and injuries from occurring. Although snow removal operations are undertaken, snow that has accreted to the higher parts of bridges, for example, is extremely difficult to remove.

In this paper, the findings of our observation of snow and ice accretion on bridges will be described, and cases of measures to prevent snow and ice accretion on bridges attempted in the past and the results will be discussed. Additionally, based on the results of our outdoor experiments on snow accretion/falling using bridge members, important points for the prevention of snow and ice accretion will be proposed.

2. Typical Snow and Ice Accretion on Bridges in Hokkaido

Previous survey data indicate that in Hokkaido, snow accretes and persists on such bridge structural members as arch ribs, struts, upper lateral braces, and roofs. In some cases, freezing may occur at the interface of snow and the member.

3. Anti-accretion Design and Measures

Anti-accretion design and measures should focus on minimizing factors contributing to accretion. This may be achieved by adopting appropriate designs and structures (both shape and material) and also by utilizing heat.

(1) Appropriate design and structure

There is no design or structure that can prevent snow and ice accretion in every type of winter weather. Thus, design and structural measures should aim at reducing snow and ice accretion.

● It is possible to reduce the amount of snow accretion by using appropriately shaped structures. Wind, as a key contributing factor to snow accretion, should also be taken into consideration when designing the shapes of structures.

● Snow and ice accretion can be reduced by coating members with highly water-repellent paint and using members of appropriate materials. However, it is uncertain how long these measures would remain effective.

(2) Utilization of heat

This method uses infrared lamps, surface heaters, and heating wire to heat the surface of members and thereby melt snow that has landed on them. Such a heating system would require relatively high initial and running costs. It will also be necessary to ensure that the switching on and off of devices is timed appropriately.

4. Observation of Snow and Ice Accretion and the Findings

Observation was carried out of snow and ice accretion on road bridges.

(1) Observation of snow and ice accretion on road bridges

Observation was carried out at the four bridges shown in Figure 1. Observation consisted of the recording of weather data, filming, and the observation of snow accretion. Following are the findings that were made. Snow and ice were seen to remain for an extended period on the Shikotsu and Fukusui bridges, while snow accretion and ablation were repeated on the Ryumon Bridge. As Figure 2 indicates, the thicker the member, the deeper the snow accretion tended to become. (The snow accretion depth in Figure 2 is the maximum depth observed.) A total of seven cases of snow falling were observed. In five of the seven cases, the temperature of the bridge at the time the snow fell was 0°C or over, having been heated by sunshine. Based on this, a bridge temperature of 0°C may be regarded as a threshold factor for snow falling. Figure 3 indicates that the bridge maintained a temperature ranging between -3 and +5°C relative to the air temperature. This may be considered to be the cause of the freezing, thawing, and subsequent falling of accreted snow. Figure 4 shows the relationship between the average wind velocity during the observation period and that at the time the snow fell from the member. It appears that no definite relationship can be deduced from the figure. One typical phenomenon observed was that snow accreted on arches would start creeping while simultaneously cracking laterally shortly before falling (ref. Photograph 1).

Based on the above findings, factors contributing to snow accretion and falling are summarized in Table 1. As more conditions are met for snow accretion, freezing of the accreted snow, and the falling of the accreted snow and ice, a greater potential for pedestrians and vehicles to be struck by the falling snow and ice arises. While we have no control over the weather, the design of future bridges should take into account how to avoid snow accretion and, should snow accrete, how to remove it in a timely manner. Similar considerations should also be given to bridges already in use.

5. Cases of Past Attempts to Prevent Snow and Ice Accretion on Bridges and the Associated Results

Anti-accretion attempts on national highway bridges

(1) Toyokoro Ohashi Bridge (a Nielsen-Lohse bridge) on Route 38, Toyokoro (ref. Photograph 2)
Length of bridge: 140 m (Arch section)
Height of members from the road surface: 22.5 m
Anti-accretion method: Painting (top surfaces of arches and struts were coated with highly water-repellent fluororesin paint.)
Coating performed in 1999.
Observation of subsequent anti-accretion performance was carried out from January 2000 to March 2001.

Observation was carried out in the first and second winters after coating to monitor the persistency of the coating's water-repellent effect. Moreover, snow accretion rates (area of accreted snow divided by total top surface area of arches and struts) were compared between the two winters as shown in Table 3. For each winter, the observation was carried out on six days, each of which was the day following a snowfall.

Table 2 shows the weather conditions at the time of observation. Table 3 shows a low average snow accretion rate (snow-repelling effect present) six hours after the start of a light snow in the first winter, whereas the table suggests no apparent snow-repelling effect, irrespective of snow accumulation, in the second winter. Table 4 clearly shows the soiling and degradation of the coating film after 12 months, which could explain the increase in snow accretion rates (in the second winter).

(2) Katsurazawa Ohashi Bridge (Lohse bridge) on Route 452, Mikasa (ref. Photograph 3)
Length of bridge: 111.5 m (Arch section)
Height of members from the road surface: 18 m
Anti-accretion method: Covering method (portal bracings, gussets for upper lateral braces, and crossing points of upper lateral braces and arches were shielded with aluminum covers and highly water-repellent fluororesin-coated steel covers at an inclination angle of 60°)
Painting (Top surfaces of the RH side arches were coated with highly water-repellent fluororesin paint.)
Covering and coating performed in 1999 and 2000.
Observation of subsequent anti-accretion performance was carried out from January 2000 to March 2001.

Observation was carried out on ten days, each of which was the day following a snowfall, for the purpose of determining differences in anti-accretion performance between the aluminum and steel covers as well as between the fluororesin and standard paints. Table 5 shows the average snow accretion rates (area of accreted snow divided by area of covering) during the first six hours and after six hours. While the initial anti-accretion performances of the aluminum and steel covers were almost equal, beyond six hours the aluminum covers turned out to be slightly better than the steel covers. This may be due to the fact that the aluminum covers could be heated easily by sunshine (ref. Figure 5: hourly change in member surface temperature). There was little difference in snow accretion rates between the top surfaces of arches coated with standard paint and those coated with highly water-repellent fluororesin paint (ref. Figure 6). This result may be influenced by there having been 60 snow days during the course of the winter (ref. Table 6).

(3) Other anti-accretion attempts

● Lattice fences have proved to be effective in preventing cornices from forming on the roof of a snow shed (ref. Photograph 4).

● Covering reduces snow and ice accretion on member joints, whose uneven surfaces easily invite accretion. However, in this case the covering also formed bleeding channels, with the result that water froze into ice columns (ref. Photograph 5).

● Heating panels installed on the lateral braces of an arch bridge, a high priority area for anti-accretion measures, are known to be effective in preventing snow and ice accretion there. Care should be taken that meltwater will not freeze into ice columns (ref. Photograph 6).

6. Outdoor Experiments on Snow Accretion

The shape and surface treatment of a member are regarded as key contributing factors to snow and ice accretion on road structures. In line with this assumption, outdoor experiments of snow accretion were carried out using members with various shapes and surface treatments to compile data for the purpose of developing anti-accretion shapes and member materials.

(1) Experiments on shapes

Steel bridge members of H, round, and diamond shapes were set up outdoors. For comparison purposes, the top-front faces of all of these members had the same projected area (400 cm^2). By filming the snow accretion and measuring the wind velocity, attempts were made to find relationships between the members and factors. Snow accretion was expressed in snow accretion area rate (projected area of snow-accreted member divided by projected area of member) and snow accretion volume rate (volume of snow accretion divided by projected area of member). Wind velocity was divided into three classes; light breeze (0 - 0.5 m/sec.), breeze (0.5 - 4.0 m/sec.), and strong wind (over 4.0 m/sec.). Figure 7 shows that in strong wind the H-shaped members had the highest volume and area rates, that in a breeze the diamond-shaped members had the highest rates, and that in light breeze members in all of the shapes had almost equally high rates.

(2) Experiments on surface treatments

Five sets of two steel bridge members each, with all members measuring 20 cm x 20 cm and each set having different surface treatments (physical properties) from the others, were set up outdoors. All of the members had been coated with alkyd resin, the paint commonly used on steel bridges. On the alkyd resin coating, the following treatments were made: Set A members were coated with a water-repellent agent; Set B members were coated with liquid wax; Set C members received no treatment; Set D members were roughened by unidirectional sandpapering; and Set E members were roughened by sandpapering in random directions. The outdoor experiments included filming of the members and measurements of wind velocity. Indoor measurements were also carried out of such surface properties as contact angle, surface roughness, coefficient of dynamic friction, and gloss. The indoor and outdoor data were then compared in order to find any relationship between the falling off of snow and surface properties. For each of the members, the average interval between snow fallings was obtained by averaging the time elapsed from the 1st falling to the 2nd falling and for the subsequent five intervals. Figure 8 shows the snow falling interval for each of the members. The "original" members had been in use for 12 months before the experiments, while the "washed" members had been washed with water prior to the experiments. The "washed" members tended to have shorter snow falling intervals than the "original" members. Figures 9 to 12 show the relationships between the various surface properties and the average snow falling intervals. The smaller the surface roughness (Rz) and coefficient of dynamic friction, the shorter the snow falling interval. Also, the greater the gloss, the shorter the snow falling interval. There was little, if any, correlation between the contact angle and the snow falling interval. The "original" versus "washed" comparison revealed that washing helped recover the various surface properties, which indicates that cleaner and less degraded members may exhibit shorter snow falling intervals.

7. Conclusion

The following design characteristics and maintenance actions have been found effective in preventing snow and ice accretion and thus should be taken into account in future preventive considerations.

Design:

● Snow accretion in strong wind can be minimized by reducing vertical member surface size as much as possible. Likewise, snow accretion in light breeze can be minimized by reducing horizontal member surface size as much as possible. Overall, round members are the least susceptible to snow accretion.

● Smaller-sized members are likely to sustain less snow accretion.

● It appears that members with smoother surfaces, smaller coefficients of dynamic friction, and greater gloss tend to have shorter snow falling intervals.

Maintenance:

● Treated surfaces should be kept clean by washing or other methods to help maintain the anti-accretion properties, which degrade continuously.

● Accreted snow requires removal, and expeditiously if sunshine is intense, as ice columns begin to form, or accreted snow beginns to creep.

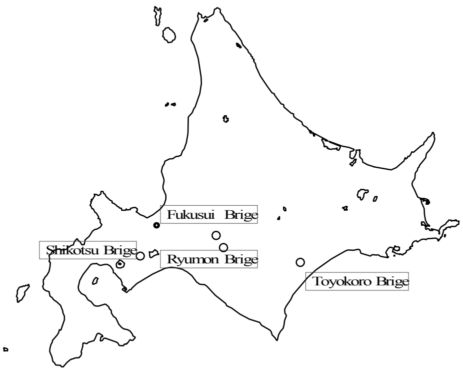

Figure 1 Observation Points

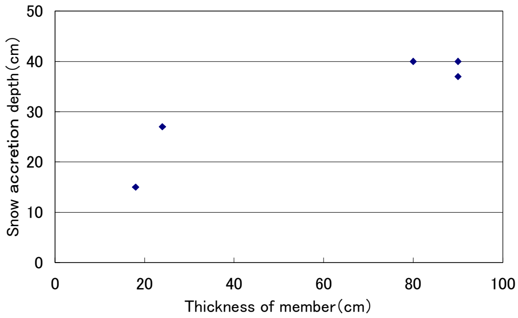

Figure 2 Relationship between Thickness of Members and Snow Accretion Depths

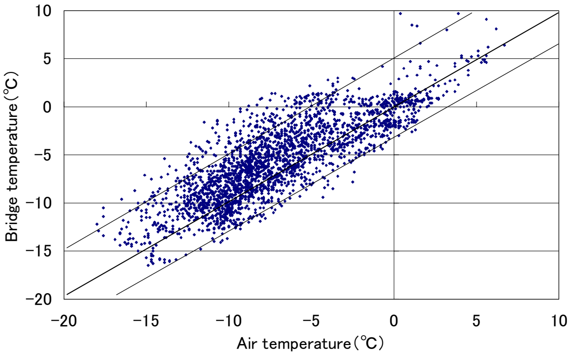

Figure 3 Relationship between Air and Bridge Temperatures

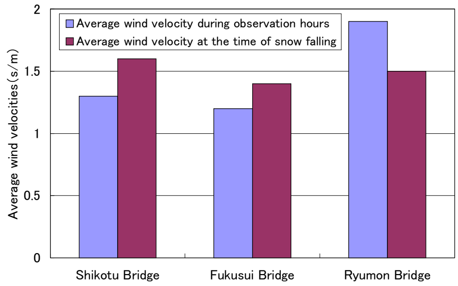

Figure 4 Average Wind Welocities

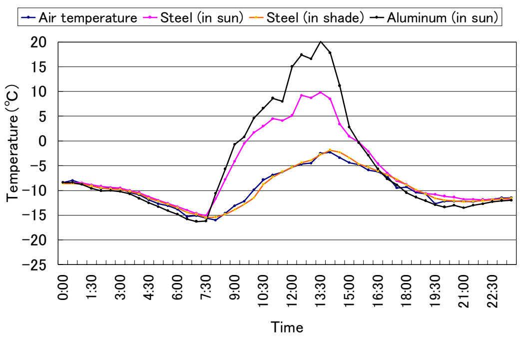

Figure 5 Hourly Change in Member Surface Temperature

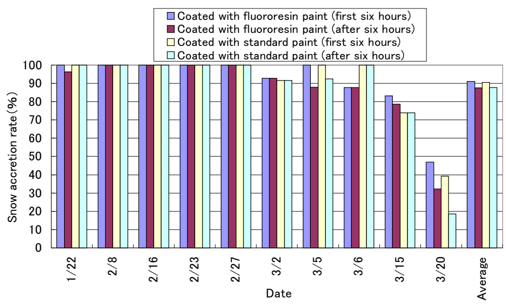

Figure 6 Snow Accretion Rates on Arch Top Surfaces

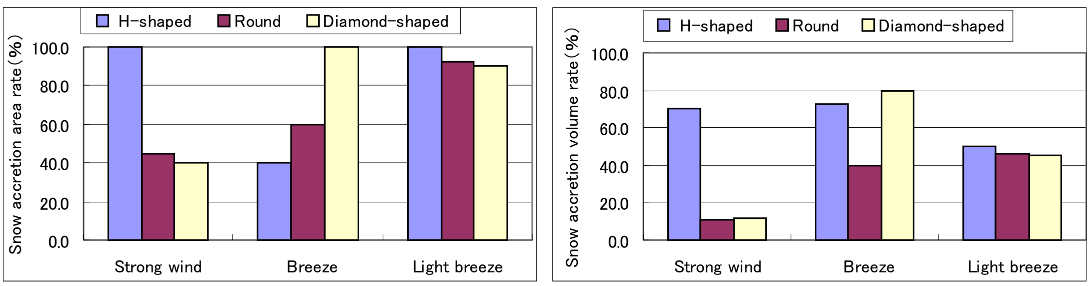

Figure 7 Relationship between Wind Velocities and Snow Accretion Area/volume Rates

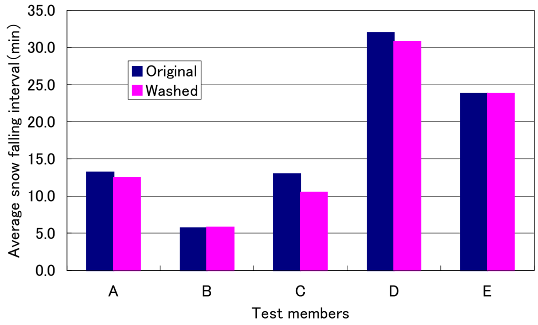

Figure 8 Test Members and their Average Snow Falling Intervals

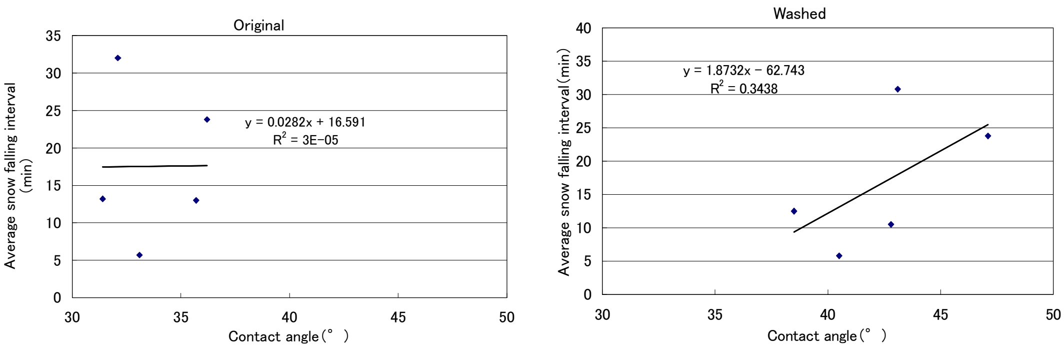

Figure 9 Relationship between Contact Angles and Average Snow Falling Intervals

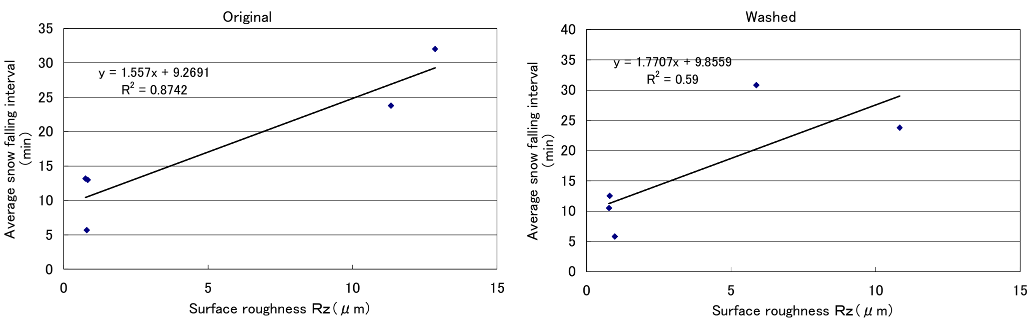

Figure 10 Relationship between Surface Roughness (Rz) and Average Snow Falling Intervals

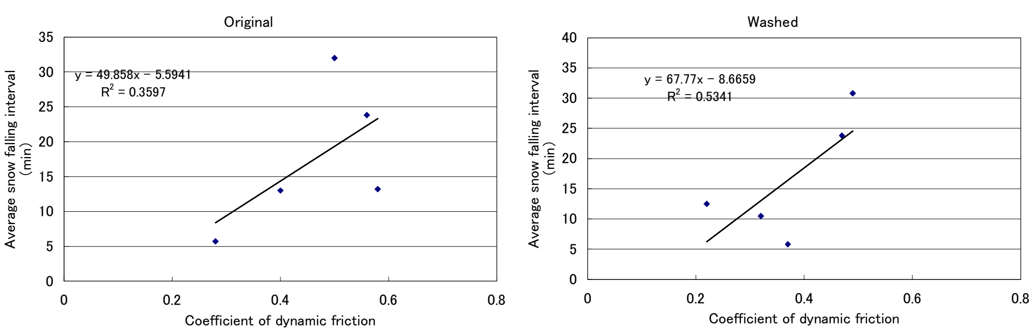

Figure 11 Relationship between Coefficients of Dynamic Friction and Average Snow Falling Intervals

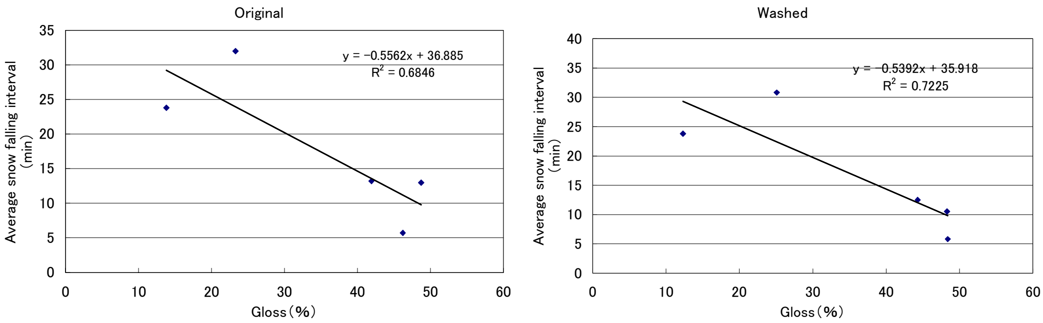

Figure 12　Relationship between Gloss and Average Snow Falling Intervals

Table 1　Factors Contributing to Snow and Ice Accretion

Item	Factor	Contributing to snow accretion	Contributing to snow falling
Weather	Air temperature	△	○
	Wind direction	○	×
	Wind velocity	○	△
	Snowfall	○	△
	Sunshine	×	○
Structure	Thickness of members	○	△
	Inclination of member	○	○
	Joint	○	○
	Temperature of member	△	○

○ : Great impact　△ : Small impact　× : No impact

Table 2　Weather Conditions in Toyokoro

Item	1999	2000
Precipitation ㎜	15	19
Maximum wind velocity s/m	0.5	6.8
Duration of sunshine h	0	2.8

※Figures are the daily means

Table 3　Average Snow Accretion Rates on Top Surfaces of Members

		Snow accretion rate (%)	
		1999	2000
Light snow	First six hours	46	27
	After six hours	2	16
Heavy snow	First six hours	12	82
	After six hours	12	82

※Light snow resulted in a snow accumulation of less than 5cm. Heavy snow resulted in a snow accumulation of 5cm or more

Table 4　Soiling and Degradation of Coating Film

Test item	First	After 7 months	After 12 months	After wiping with dry cloth
Color difference (△E)	―	2.05	2.85	1.14
		Worsened	Worsened	Recovered slightly
Water repellency Contact angle (°)	97	75.8	53.9	95.4
		Worsened	Worsened	Recovered
Gloss	54.4	59.8	47	64.2
		Same	Worsened	Recovered

Table 5　Average Snow Accretion Rates on Covers

	Snow accretion rate on (%)		
	First six hours	After six hours	Difference
Aluminum covers	57	39	18
Steel covers	58	43	15

Table 6　Weather Conditions during the Observation Period

Item	2000
Cumulative snowfall m	15
No. of snowy days day	60
Average air temperature ℃	3.2

※Data collected during the period Dec. 2000 – March 2001

Photograph 1 Snow Accretion

Photograph 2 Toyokoro Bridge

Photograph 3 Katurazawa Bridge

Photograph 4 Other Anti - accretion Methods: Case 1

Photograph 5 Other Anti - accretion Methods: Case 2

Photograph 6 Other Anti - accretion Methods: Case 3