Predicting snow falling from cables of a cable-stayed bridge

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1. Introduction

This study introduces the development of a system to predict when snow is likely to fall from suspension bridge cables, toward enhancing road safety and scheduling bridge snow removal. The Tokachi-Ohashi Bridge, a cable-stayed bridge on National Route 241 between Obihiro City and Otofuke Town in Hokkaido (Figure (1)), was selected for monitoring to collect data for system development. The traffic volume on this arterial road at the Tokachi Ohashi Bridge is about 46,000 vehicles per day. During the morning and evening traffic peaks, the volume averages 3,700 vehicles per hour. The bridge has a three-span continuous prestressed concrete cable-stayed structure (Figure 2). It is 501.0 m long and 32.8 m wide. The superstructure stretches over the Tokachi River, a first-class river, between two 68.0-m-high main towers.

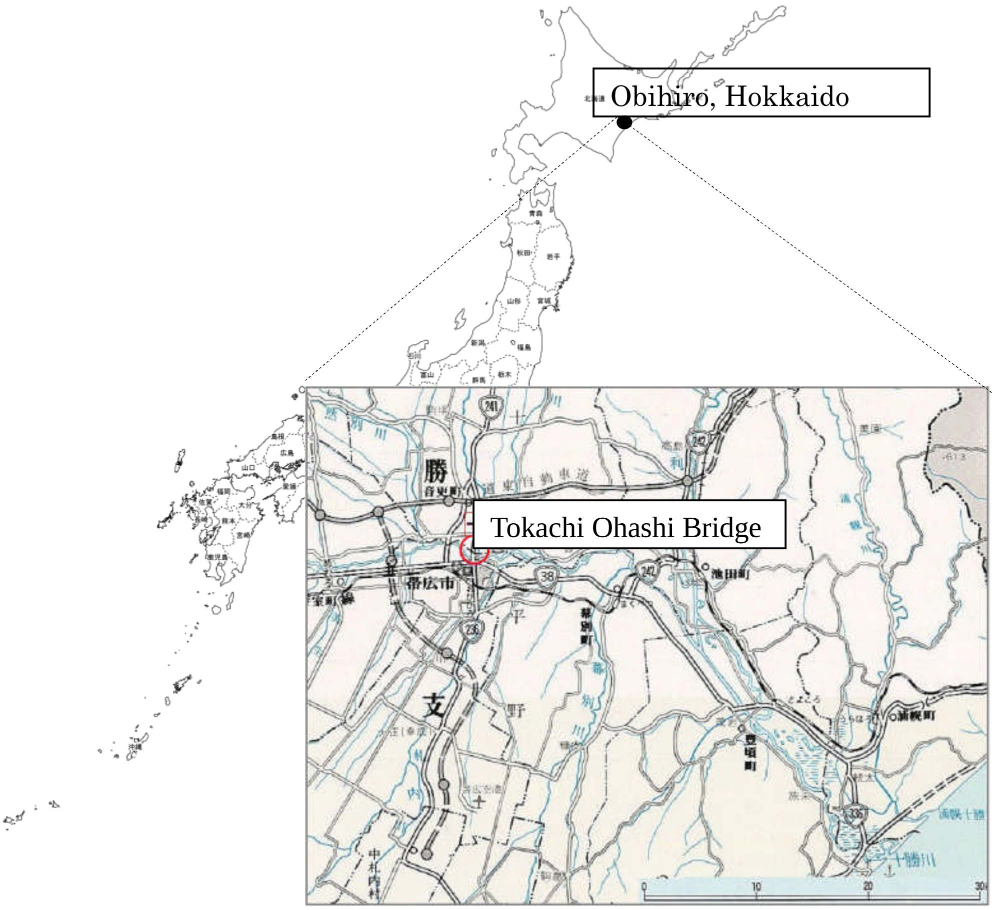

Figure 1. Location of the Tokachi Ohashi Bridge

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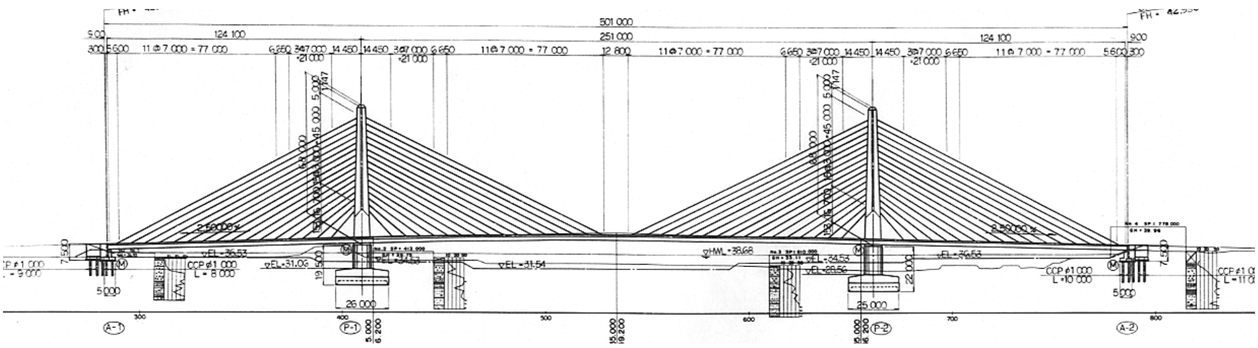

Figure 2. Side view of the bridge

2. Snowfall in the survey area

To investigate snowfall in the area including the bridge, snowfall events of 10 cm or more for the 15 years from 1992 were extracted from meteorological records recorded at the nearby Obihiro Weather Observation Station of the Japan Meteorological Agency.

A measure to snow on Toyokoro bridge was tested near the survey area using the lattice fence[1].

2.1 Pressure systems under which snowfall tended to occur

Each snowfall event resulted from a low-pressure system that was intense enough to bring about heavy snowfall in eastern Hokkaido as it passed east of Hokkaido or off of the eastern coast of northern Tohoku. Figure 3 indicates typical air pressure patterns under which heavy snowfall was likely to occur. The left meteorological chart shows a low-pressure system that approached Hokkaido from the Sea of Japan, where there was a cold air mass that resulted from the precedent wintry pressure pattern. During periods of such snowfall, the temperature tends to be low. During snowfall that occurred at the times of the left-hand pressure pattern in Figure 3, the temperature ranged between −7 and −5°C. The right-hand pressure pattern in Figure 3 is a low-pressure system that approached Hokkaido along the northeast coast of Honshu, intensifying as it moved up through multiple high-pressure systems oriented south to north. During snowfall that occurred under such pressure pattern, the temperature tends to be higher than in the former case.

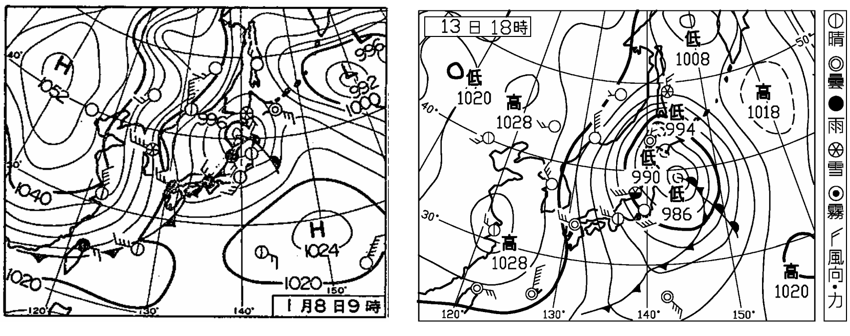

Figure 3. Pressure patterns under which snowfall tends to occur

(left: Jan.8, 1996; right: Jan. 13, 2004)

2.2 Annual number of heavy snowfall events

Table 1 breaks down the number of heavy snowfall events (10 cm or more) by 10-cm depth intervals for each of the 15 winters (Nov. to Mar.) from 1992-1993 to 2006-2007. The average is about seven heavy snowfall events. Extraordinarily heavy snowfall events (30 cm or more) were recorded about twice per winter after 1999.

snow / year	10-19cm	20-29cm	30-39cm	40-49cm	50-59cm	60-69cm	10cm-	30cm-
1992-93	7		1				8	1
1993-94	6	1		1		1	8	1
1994-95	4			1		1	6	2
1995-96	3	3			1		7	1
1996-97	2	2	1				5	1
1997-98	3					1	4	1
1998-99	4	3					7	0
1999-00	6	1	1	1			9	2
2000-01	2	3	1	1			7	2
2001-02	5	2	1				8	1
2002-03	3			1	1		5	2
2003-04	3	2		3			8	3
2004-05	3	3		1		1	8	2
2005-06	3	1	2				6	2
2006-07	4	1					5	0

Table 1. Heavy snowfall events (10 cm or more) recorded at the Obihiro MetrologicaStation (1992 to 2006)

2.3 Temperature fluctuation during snowfall

Figure 4 shows typical temperature fluctuations on a snowy day. When snow started falling, the temperature was low, about −12◦C, and the longer the snow fell, the more the temperature rose, finally exceeding 0˚C. The relationship between the temperature and solar radiation from the unobstructed sky in Figure 7 indicates that snow cover on the main cable of the bridge starts becoming unstable from thawing as the temperature rises to about −1˚C. Unusually intense solar radiation may accelerate snow thawing.

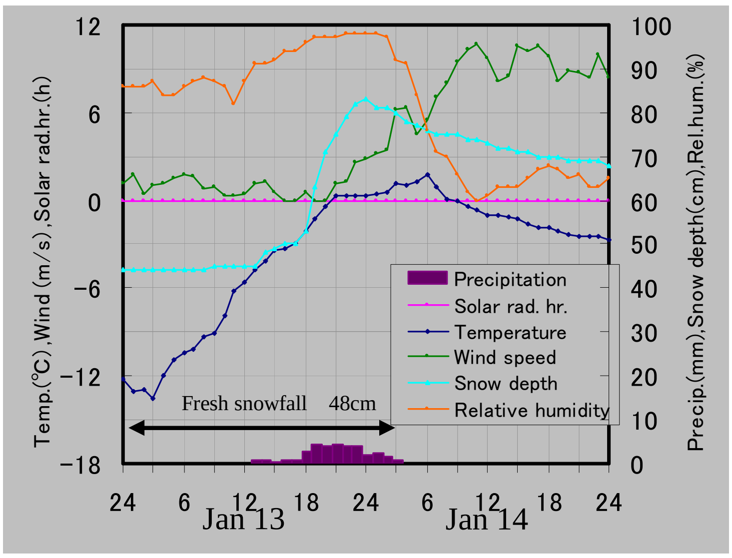

Figure 4. Weather conditions during snowfall by Obihiro Met. Station, January 13-14, 2004)

3. Survey on snow cover on the main cables

Snow cover on the main cables of the bridge was monitored by onsite video camera.

3.1 Snow cover on the main cables

(1) Fresh snowfall and snow cover on the main cables

Table 2 shows the number of times when snow cover was observed on the main cables of the bridge after each snowfall event for the winters of 2001-2002 through 2005-2006. Occurrences of snow coverage on the bridge's main cables are classified by the depth of fresh snowfall on the ground by less than 1 cm, and by 1-cm intervals from 1 cm to 5 cm or more. In most cases of 1 cm or more snowfall, snow cover was observed on the main cables (Photo 1); however, snow accretion on the cables, which is caused by strong winds, was rarely observed.

Photo 1. Main cables covered with snow (Jan.8, 2004)

Table 2. Number of times snow cover was observed on the main cables after each snowfall during the winters from 2001-2002 to 2005-2006.

Fresh snowfall (cm)	Number of times snow cover was observed on the cables	Number of times snow accretion was observed on the cables	Number of times neither snow cover nor snow accretion was observed
Less than 1	8		68
1	12		2
2	12	1	
3	7		
4	3		
5 or more	61		

(2) Relationship between air temperature and wind speed when snow was observed on the cable

Figure 5 shows the daily minimum temperatures and minimum wind speeds for the cases when snow was observed on the main cables for the three winters from 2000-2001 to 2002-2003. In Figure 5, the daily minimum temperatures vary widely from 0˚C to lower temperatures, and most of the minimum wind speeds are between 0 m/s and 1 m/s.

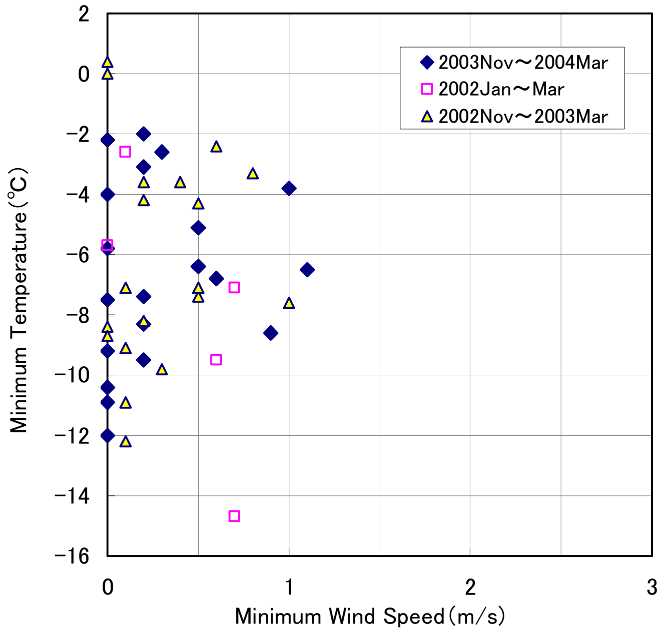

Fig. 5 Minimum temperature and wind speed when snow was observed on the cable

(3) Relationship between the depth of snow cover on the main cable and amount of snowfall on the ground

A survey to identify the relationship between the depth of snow cover on the main cables and the amount of snowfall on the ground was conducted in the 2003-2004 winter. The depth of snow on the main cables tended to increase in depth in proportion to increases in the amount of the snowfall on the ground. However, in some cases, continuous falling of a great deal of humid snow compacted the snow cover on the main cables such that the depth of snow cover there was significantly lower than the amount of snowfall on the ground.

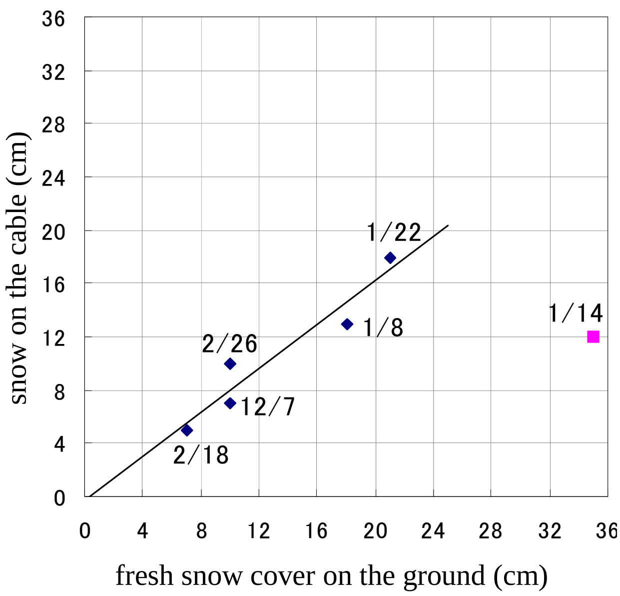

Figure 6. The amount of snowfall on the ground and the depth of snow cover on the main cables of the bridge(The purple square indicates data from when the snow on the main cable was compacted because of the snow's high humidity.)

4. Survey of snow falling from the main cables

The weather conditions under which snow tended to fall from the main cables of the bridge were analyzed by using the results of a bridge monitoring survey conducted in the 2003-2004 winter.

(1) How snow falls from the main cables

In cases in which thawing caused snow to fall from the cable, one side of the snow on the cables started thawing first, followed by thawing at the bottom center of the snow cover, which spread all over the bottom. Snow tended to fall from the west side of the cables, although some fell from the east side. The process of snow falling from the main cables is proposed here.

a) Solar radiation causes snow on the eastward side of the main cables to thaw. Snow on the westward side of the main cables becomes heavier than that on the eastward side, and the snow tilts westward and falls.
b) Strong winds from the west hinder snow deposition on the westward side of the main cables. The decrease of snow on the westward side makes the east side heavier than the west side, so that when the bottom snow thaws, the snow falls from the east side.

(2) Weather conditions at the time snow fell from the main cables

The temperatures and clear-sky solar radiation at times when snow fell from the main cables as a result of thawing are indicated in Figure 7. The cases of snow falling from the main cables include those that caused damage to passing vehicles. Figure 7 shows that when the air temperature is between −1°C and 0°C, snow falls even if the solar radiation is weak, and that when the solar radiation is intense, snow falls even at the temperatures lower than those under weak solar radiation. The dots in Figure 7 plot temperatures and solar radiation hours under which snow fell from the cable. The temperatures and solar radiation hours for the dots above the solid line are likely to result in accidents of damage to vehicles.

The dashed circles show cases of falling snow that did not result in damage to vehicles at times of 2~3 cm snowfall.

Those risky conditions are expressed as 2T+S>1, where

T is air temperature (°C) and S is clear-sky solar radiation (MJ/m^2)

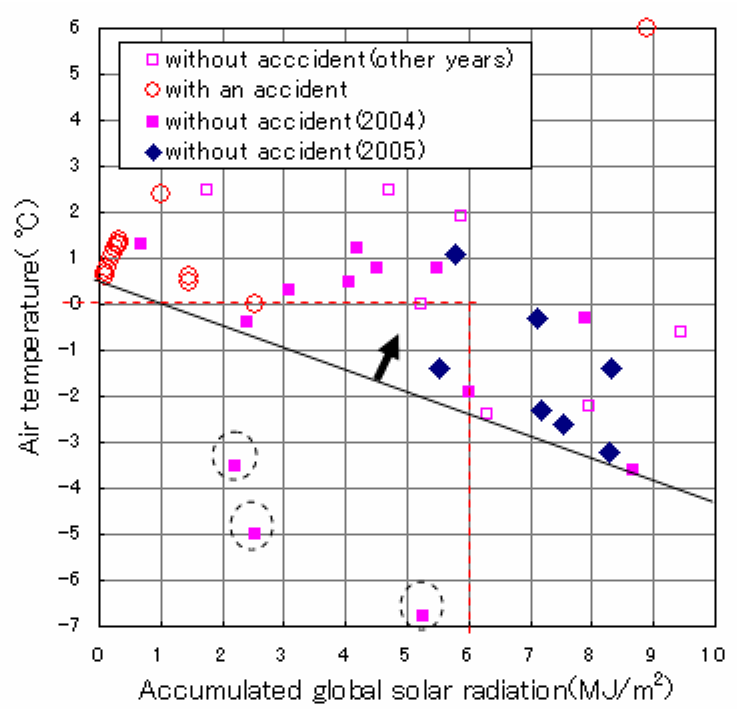

Figure 7. Temperature and clear-sky solar radiation at times when snow fell from the main

Snow falls from the cables without accident (2005)

5. Development of a falling-snow prediction system

A falling-snow prediction system is proposed by using the results of the survey on weather conditions associated with snow falling from the main cable. The falling-snow prediction information provided by the system could be used for scheduling main cable snow removal.

(1) Development of a flow chart for likelihood of snow falling from bridge cables

Figure 8 is a flowchart for judging whether the weather conditions and the state of snow cover on the main cable are likely to produce falling snow resulting in damage to vehicles on the bridge. The flowchart is based on the following assumptions:

- Snow of 2 cm or less on the cable of has completely thawed, or snow cover at times of 3-cm snowfall has fallen or completely thawed.
- As a result of analyses of the conditions under which falling snow results in damage to vehicles, such snow falling from the cables occurs when the wind speed is 2 m/s or greater and snowfall is 5 cm or more.

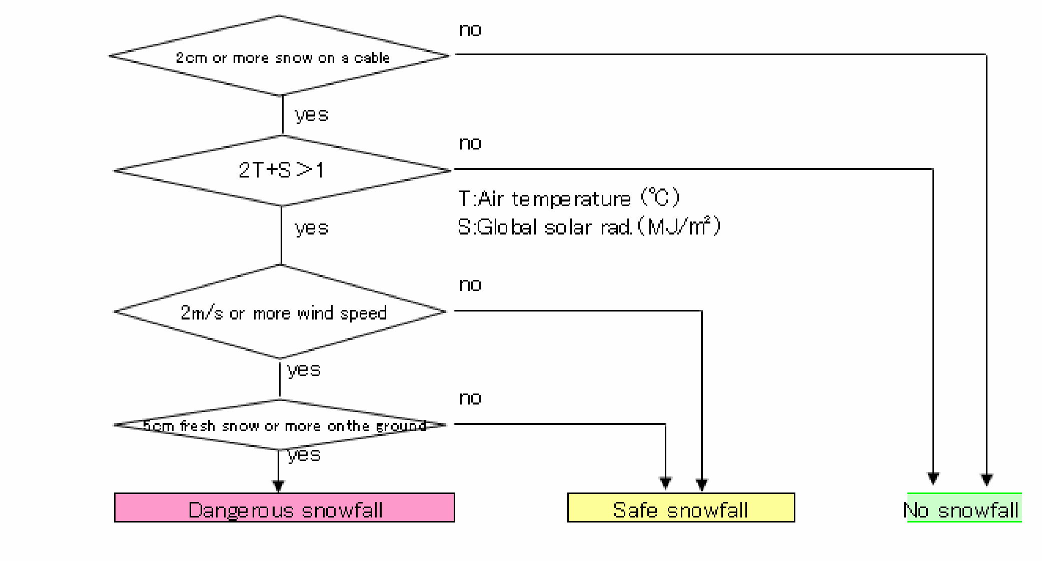

Figure 8. Flow chart for judging the likelihood of snow falling from the main cables

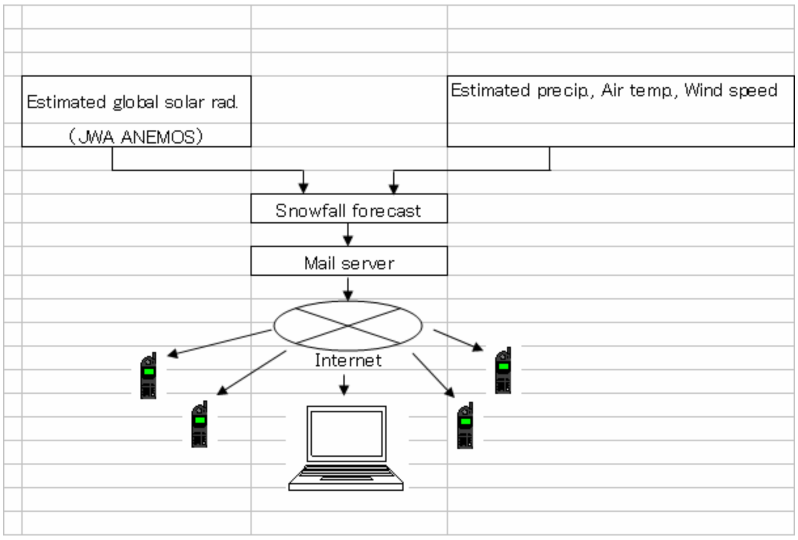

Figure 9. Internet provision of prediction information on snow falling from a bridge cable

(2) Figure 9 shows a system for e-mail notification of weather-based predictions of accidents from snow falling from the cables. Examples of predictions of snow falling from the main cables of the bridge are presented in Figure 10.

Application of the weather forecast data to a formula that suggests the weather conditions which tend to result in falling snow that damages to vehicles

6. Concluding remarks

Snow precipitation, wind speed, air temperature and global solar radiation are factors to predict falling snow from a cable of a cable-stayed bridge. The prediction model supports to make the work plan to remove snow on the cable.

The model of snow falling prediction can be improved after the operational use in Tokachi Ohashi Bridge. The contribution of each factors mentioned above generally depends on the bridge design and the local weather condition.

7. References

1: H. Takemoto, H. Ueno, M. Takeuchi and T. Chiba, Evaluation of various measures against snow and ice accretion on Bridge Members, and the development of an Anti-Accretion Lattice fence, The proceedings of XII International winter road congress (2006).