

CHANGES IN DESIGN STANDARDS AND REGIONAL CHARACTERISTICS OF
 AVALANCHE SUPPORTING STRUCTURES IN JAPAN

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ABSTRACT: In Japan, avalanche supporting structures are designed based on standards specified in the Swiss Guideline developed in 1961. However, the weather conditions in Japan differ from those in Switzerland. In the 1980s, many snow bridges were damaged by heavy snowfall. Hence, the glide factor was changed to 1.5 times the previous glide factor for Honshu, since the snow there tends to be wet. In contrast, in Hokkaido, the glide factor was set as equal to the Swiss standard. Climate changes in recent years have made wet-snow avalanches more likely to occur even in Hokkaido. In light of this, the design snow pressure for the snow bridges that are currently used in Hokkaido is being reexamined. In the past two years, the snow pressure acting on snow bridges has been measured, as a result of which it was found that the maximum measured values were almost the same as those obtained during the six winters from 1988 to 1993. Also, the measured snow pressure was lower than the current design snow pressure.

KEYWORDS: snow bridge, glide factor, snow pressure

1. INTRODUCTION

This study outlines changes in design guidelines and regional characteristics for avalanche supporting structures in Japan. And we briefly describe the work of the Civil Engineering Research Institute for Cold Region in designing the snow pressure for snow bridges.

First, the winter climate of Japan is outlined. In winter in Japan, seasonal winds carry cold, dry air from eastern Siberia over the Sea of Japan, where it picks up large amounts of moisture. When the air reaches the backbone range of the Japanese archipelago, it rises and cools, and the moisture precipitates as heavy snowfall. When the air reaches the leeward side of the backbone range, it is dry, so areas along the Pacific Ocean see little snowfall (Fig. 1).

Fig. 2 shows the normal values for annual maximum snow depth (JMA, 2003). Areas with annual maximum snow depths exceeding 100 cm tend to be found in Hokkaido and on the western side of the mountain ranges of Japan's main island of Honshu. The values are between 0 and 10 cm on the Pacific Ocean side of Honshu. In addition, snowy regions in Japan stretch a great distance

from north to south. This means that winter temperatures and the physical properties of the snow-pack differ from one region to another.

The design guidelines for avalanche supporting

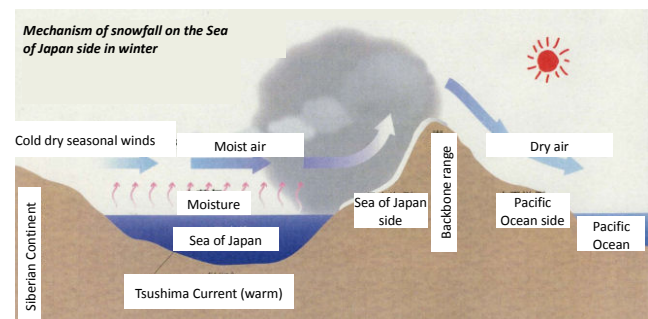
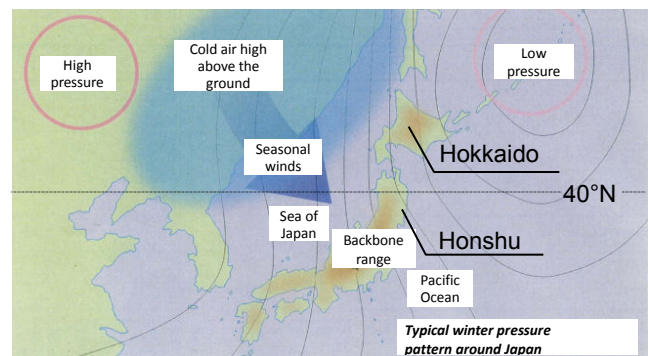


Fig. 1: A pressure pattern typical for winter in Japan (upper). The snowfall mechanism for the Sea of Japan side of Japan (lower). (NNK, 2008)

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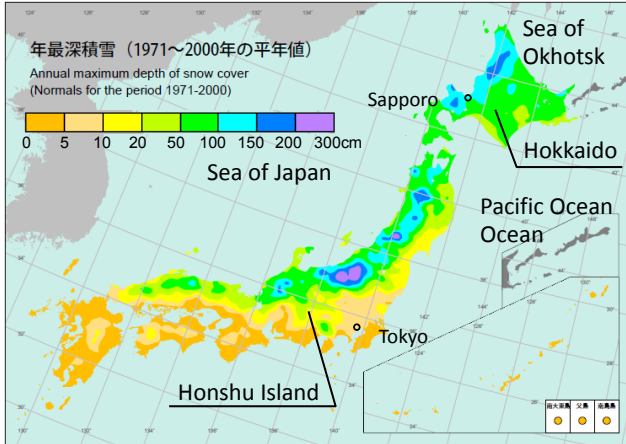


Fig. 2: Normal values for annual maximum snow depth (1971 – 2000). (JMA, 2003)

structures in Japan are based on the *Technical Guideline for Defense Structures in Avalanche Starting Zones* (hereinafter: the *Swiss Guideline*) developed in Switzerland in 1961. In the 1980s, many snow bridges were collapsed by heavy snowfall in snowy areas of Honshu Island. In light of this, an increase in glide factor over the Swiss standard was set for the wet-snow areas of Honshu in the 1990s. The details are discussed in Section 2.

Recently, wet-snow avalanches are increasing in Hokkaido due to climate change. Hokkaido is the northernmost region of Japan and a dry-snow area. Therefore, we conducted snow pressure measurements at two locations in Hokkaido to review the current design snow pressure for snow bridges. The present paper compares the data with those taken about 25 years ago.

2. CHANGES IN DESIGN STANDARDS FOR AVALANCHE SUPPORTING STRUCTURES IN JAPAN

As discussed in Section 1, the design guidelines for avalanche supporting structures in Japan are based on the *Swiss Guideline*. This section discusses the concept of elements associated with design load among the design conditions for Japanese snow bridges, on the basis of technical documents.

2.1 Snow pressure

Snow pressure on a slope is calculated by using Equation (1) and Equation (2) (JCMA and SRC, 2004) (Fig. 3).

$$S_N = \gamma_s \frac{H^2}{2} KN \quad (1)$$

$$S_Q = S_N \frac{a}{\tan \varphi} \quad (2)$$

Here, S_N represents the component of snow pressure in the line of slope per meter run of the supporting surface along the contour line (kN/m), S_Q represents snow pressure component normal to the slope per meter run of the supporting surface along the contour line (kN/m), γ_s represents the unit weight of snowpack (kN/m³), H represents the vertical snow height (m), K represents the creep factor, N represents the glide factor, φ represents the slope gradient, and a represents a coefficient dependent on snow type.

Using the *Swiss Guideline* from the late 1960s, snow bridges mainly have been designed and constructed in avalanche starting zones to address various snow conditions and other weather conditions. In the 1980s, many snow bridges were collapsed by heavy snowfall in snowy areas of Honshu Island. After observations for reexamining the design snow pressure for avalanche supporting structures, the design guidelines in Japan were revised in 1992. The main revisions were to set the glide factor as 1.5 times the Swiss standard for wet-snow areas on Honshu. For Hokkaido, a dry-snow area, the glide factor was set as equal to the Swiss standard (Tbl.1). Also, the idea of snow pressure coefficient was introduced, to account for differences in snow pressure between the fence ends and center. The creep factor (K) is roughly the same as that specified in the *Swiss Guideline*. Tbl.2 outlines the changes in design methods for supporting snow accumulated on a slope in Japan. Fig.4 shows the concept of snow pressure coefficient.

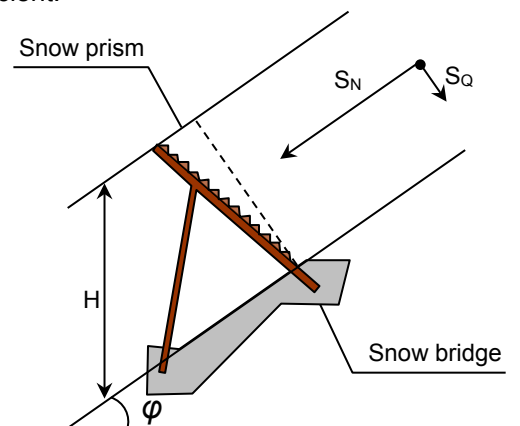


Fig. 3: Relationships of snow pressure S_N and S_Q .

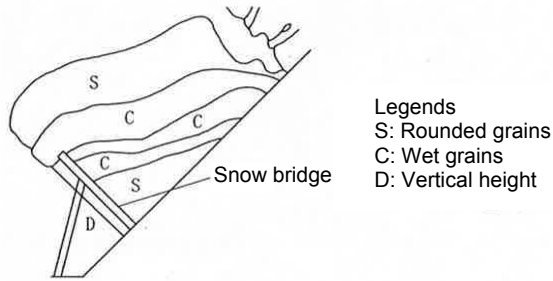
Tbl. 1: Ground classes and glide factors.

Classes	Ground conditions	Glide factor N			
		Swiss Hokkaido		Honshu	
		Exposure		Exposure	
		WNW-N-ENE	ENE-S-WNW	WNW-N-ENE	ENE-S-WNW
Class 1	Coarse scree ($d^* \geq 30$ cm)	1.2	1.3	1.8	2.0
	Terrain heavily populated with smaller and larger boulders				
Class 2	Areas covered with larger alder bushes or dwarf pine at least 1 m in height	1.6	1.8	2.4	2.7
	Prominent mounds covered with grass and low bushes (height of mounds over 50 cm)				
	Prominent cow trails				
	Coarse scree (d^* ca. 10–30 cm)				
Class 3	Short grass interspersed with low bushes (heather, rhododendron, bilberry, alder bushes and dwarf pine below approx. 1 m in height)	2.0	2.4	3.0	3.6
	Fine scree ($d^* \leq 10$ cm) alternating with grass and low bushes				
	Smallish mounds of up to 50 cm in height covered with grass and low bushes, and also those alternating with smooth grass and low bushes				
	Grass with shallow cow trails				
Class 4	Smooth, long-bladed, compact grass cover	2.6	3.2	3.9	4.8
	Smooth outcropping rock plates with stratification planes parallel to the slope				
	Smooth scree mixed with earth				
	Swampy depressions				

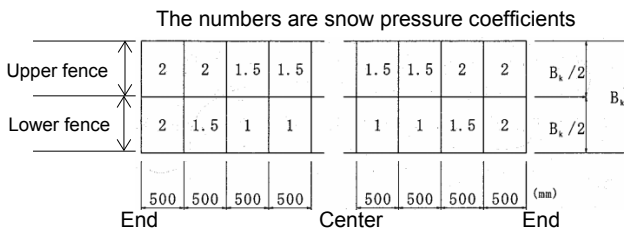
d^* is the boulder diameter characteristic of the roughness of the ground surface.

Tbl. 2: Changes in the design method for supporting snow accumulated on a slope in Japan.

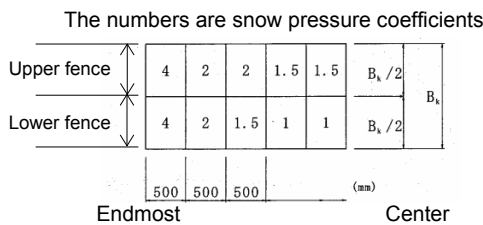
Year	History of Implementations, Revisions and Improvements	Remarks
1963	The <i>Swiss Guideline</i> is translated into Japanese. The Japanese guideline for design and installation is formulated.	
1980s	A number of snow bridges are damaged by heavy snowfall, particularly by the heavy snowfall in 1981.	
1988-1990	The Public Works Research Institute of the Ministry of Construction conducts research on Honshu with a view to reexamining the design snow pressure for avalanche supporting structures.	It is proposed to set the glide factor for Honshu as one and half times that specified in the <i>Swiss Guideline</i> . The concept of snow pressure coefficient is introduced.
	The Civil Engineering Research Institute of Hokkaido Development Bureau performs measurements of snow pressure acting on snow bridges.	The glide factor specified in the <i>Swiss Guideline</i> is found to be appropriate in Hokkaido.
1992	The <i>Guideline for Designing/Installing snow bridges</i> is compiled.	It is proposed to set the glide factor as one and half times that specified in the <i>Swiss Guideline</i> in Honshu. The glide factor value specified in the <i>Swiss Guideline</i> is determined to be used as a glide factor for Hokkaido. Snow pressure coefficients are introduced.
1996	The <i>Technical Guideline for Avalanche Prevention Work for Protecting Communities</i> (draft) is compiled.	This is based on the <i>Guideline for Designing/Installing snow bridges in Japan</i> .
2004	The <i>2005 Handbook for Snow Removal and Snow Hazard Control</i> is compiled and revised.	This is based on the <i>Guideline for Designing/Installing snow bridges in Japan</i> .



Snow cover distribution at the time of snow pressure coefficient examination.



Supporting surface installed at separated structures.



Supporting surface of endmost fences

Fig. 4: Concept of snow pressure coefficients.

2.2 Design snow depths

In Japan, the maximum snow depth in the return period of 30 years is used as the design snow depth for highway snow-control facilities. On the other hand, the greater value between the maximum snow depth in the return period of 50 years and the maximum recorded snow depth is used as the design snow depth for snow-control facilities in communities.

2.3 Unit weight of snowpack

In Japan, 3.5 kN/m^3 is used as the unit weight of snowpack when snow depth is less than 4 m. In the case that the snow depth exceeds 4 m, it is suggested that the value for a unit weight of snowpack should be determined, under the assumption that the value for unit weight of snow-

pack is 4.5 kN/m^3 when the snow depth is 7 m (Fig. 5).

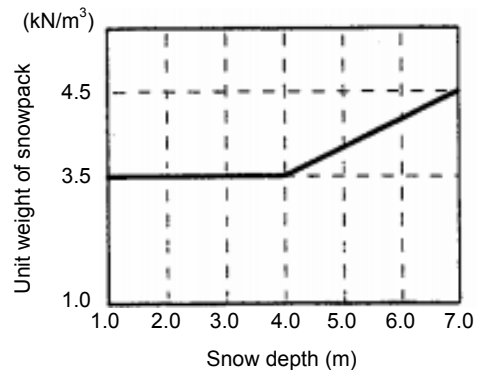


Fig. 5: Unit weight of snowpack.

2.4 Snow prisms

The snow prisms described in the *Swiss Guideline* are employed in Japan without modification. The snow prism load is considered only when the load acting on the snow bridge (fixed type) is calculated. Snow bridges of suspended type are installed perpendicular to the slope; therefore, snow prisms do not apply a load to them (Fig. 7).

2.5 End-effect load

Since fences are installed separated structures, the snow load generated between fences (the "end-effect load") has to be considered. However, if snow pressure coefficients are employed, end-effect load is not considered.

3. MEASUREMENT OF SNOW PRESSURE AT SNOW BRIDGES IN HOKKAIDO

3.1 Background

Abe et al. (1994) measured snow pressure acting on snow bridges installed on cut slopes along highways at the two points shown in Fig. 6 (Point 1: Nakayama Pass; Point 2: Shumarinai) for the six winters from 1988/89 to 1993/94 winter. The maximum total snow load acting on a snow bridge for the six winters was found to be about 80 kN at Nakayama Pass and about 60 kN at Shumarinai. This proved that the glide factor specified in the *Swiss Guideline* is appropriate. The result is reflected in the design of snow bridges in Hokkaido (Tbl. 2).

Due to the impact of climate change in recent years, wet-snow avalanches are no longer isolated to Honshu; they have become more likely to occur

even in Hokkaido. The authors are reexamining the design snow pressure for snow bridges that are used in Hokkaido.

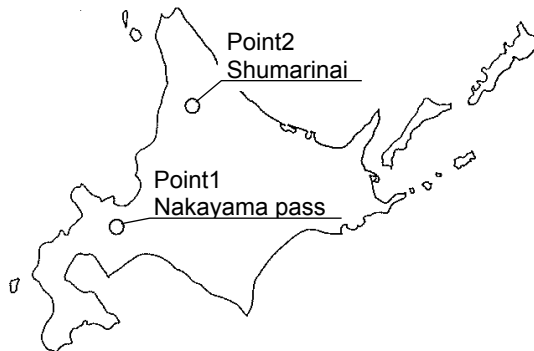


Fig. 6: Measurement points (2 points).

3.2 Measurement locations

The measurements were performed at Point 1 (Nakayama Pass; Fig. 6) from 2012/13 to 2013/14 winter and at Point 2 (Shumarinai; Fig. 6) in the one of 2013/14 winter. Tbl. 3 shows the characteristics of two sites.

Tbl. 3: Characteristics of two sites.

	Point 1 Nakayama Pass	Point 2 Shumarinai
Length of slope	36 m	52 m
Exposure	south	north
Gradient	1:1.1	1:1.2
Ground conditions	grass-covered concrete slope frames (Fig. 7)	grass-covered 1.5m-wide berms
Structures	separated, inter- rupted struc- tures	separated, in- terrupted struc- tures
Distance between structures in the line of slope	13m	12m
Maximum snow depth in the return period of 30 years*	350 cm	260 cm

*Referred to the Highway Snowstorm Countermeasure Manual (CERI, 2011)

3.3 Measurement method

At both locations (Nakayama Pass and Shumarinai), a tension load cell (Fig. 8) was attached to a wire cable supporting an existing snow bridge installed on the slope, and the snow load was recorded in a data logger every hour. Each snow

bridge was supported by three wire cables, to each of which the tension load cell was attached. The snow load measured by three load cells was totaled. The suspended fences installed at Nakayama Pass were 5.5 m wide and 2.0 m high, and those installed at Shumarinai were 5.5 m wide and 2.0 m high.



Fig. 7: Snow bridges installed on a slope along a highway in Nakayama pass.

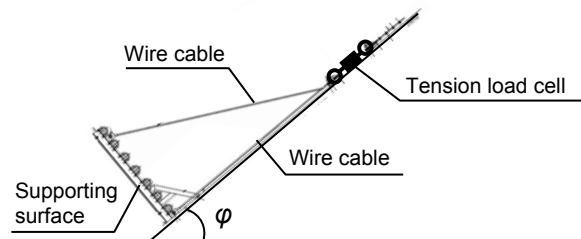


Fig. 8: Tension load cells.

3.4 Results

The changes in snow load and snow depth are shown in Fig. 9 (a) (2012/13 winter) and Fig. 9 (b) (2013/14 winter), and changes in snow pressure

are shown in Fig. 10 (a) (2012/13 winter) and Fig. 10 (b) (2013/14 winter). It should be noted that snow depths obtained at the road telemeter and the AMeDAS (Automated Meteorological Data Acquisition System) stations of the Japan Meteorological Agency in the vicinity of the measurement points were used as measurement points. In addition, the snow pressure (kN/m) in Fig. 10 indicates the snow load per meter width of fence.

The measurements indicate that the maximum snow load is obtained in March and April, when snowmelt begins; this is consistent with the findings of Kurokawa et al. (1992). The maximum snow load measured at Nakayama Pass was 79.4 kN for the 2012/13 winter and 80.5 kN for the 2013/14 winter, and the maximum snow load measured at Shumarinai was 58.5 kN (2013/14 winter). The values were found to be almost the same as those for maximum snow load measured

by Abe et al. (1994) (Nakayama Pass: about 80 kN; Shumarinai: about 60 kN). It should be noted, however, that the maximum snow load obtained by Abe et al. was obtained from measurements performed for six winters. In this measurement, the maximum value for every measurement case was almost the same as that recorded in the past. Additionally, the design snow pressure at the fence installation point calculated by using Equation (3).

$$R = \sqrt{S_N^2 + S_Q^2} \quad (3)$$

Here, R is resultant snow pressure. The results were 40.4 kN/m at Nakayama Pass and 18.6 kN/m at Shumarinai, which were found to be much greater than those obtained in this measurement.

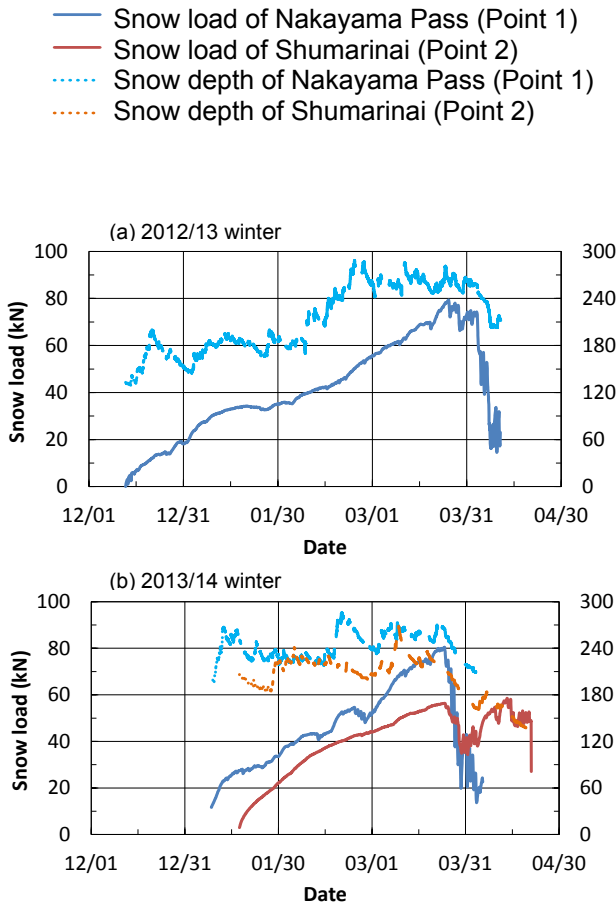


Fig. 9: Changes in snow load and snow depth.

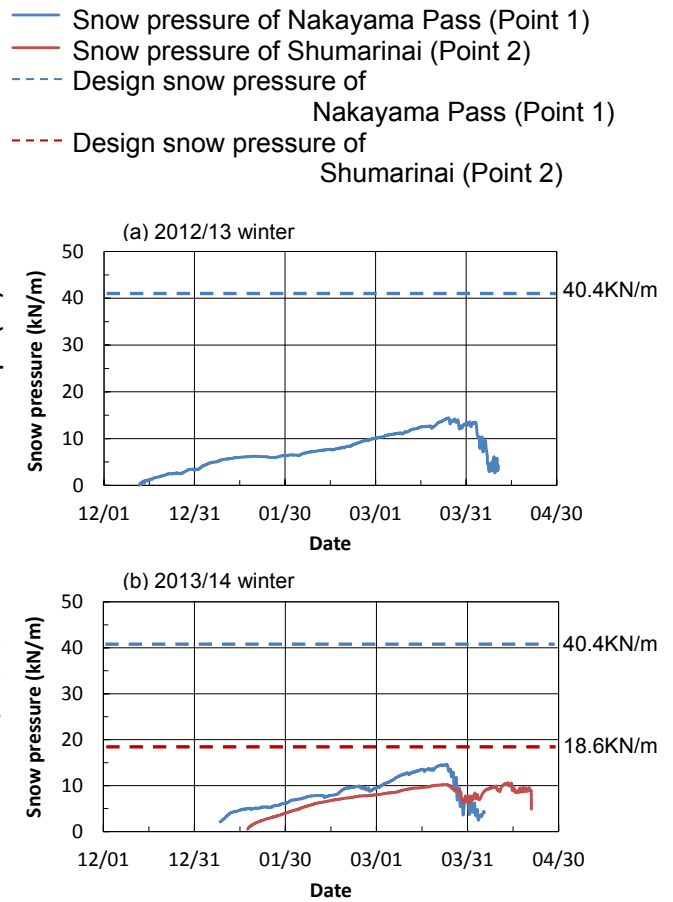


Fig. 10: Changes in snow pressure.

4. CONCLUSION

This paper outlined changes in Japanese design standards for avalanche supporting structures and regional characteristics, and it discussed snow pressure measurements performed in Hokkaido in two winters.

In Japan, avalanche supporting structures are designed based on standards specified in the *Swiss Guideline* developed in 1961. However, the weather conditions in Japan differ from those in Switzerland. This is particularly true for Honshu, where the temperatures are higher, the snow tends to be wet and the snowfall amounts tend to be great. Despite this variation, snow bridges mainly have been designed and constructed in avalanche starting zones. In the 1980s, many snow bridges were damaged by heavy snowfall. Hence, the glide factor was changed to 1.5 times the previous glide factor for Honshu, since the snow there tends to be wet. In contrast, in Hokkaido, the glide factor was set as equal to the Swiss standard.

Climate changes in recent years have made wet-snow avalanches more likely to occur even in Hokkaido, and not just on Honshu. In light of this, the design snow pressure for the snow bridges that are currently used in Hokkaido is being reexamined. In the past two years, the snow pressure acting on snow bridges has been measured, as a result of which it was found that the maximum measured values were almost the same as those obtained during the six winters from 1988 to 1993. Also, the measured snow pressure was lower than the current design snow pressure.

In the future, measurements will be performed on snow pressure acting on the supporting surface of snow bridges as well as on snow load acting on the main cables. In addition, data on creep and glide velocities, snow density and weather conditions must be accumulated. On the basis of the obtained results and data, further examinations will be made toward clarifying whether the snow load has increased in recent years in Hokkaido and determining whether the design standard needs to be reevaluated.

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