

## CHANGES IN SNOW PRESSURE ON SNOW BRIDGES IN THE HOKKAIDO REGION OF JAPAN

Wataru Takahashi<sup>1\*</sup>, Yusuke Harada<sup>2</sup>, and Masaru Matsuzawa<sup>1</sup>

<sup>1</sup> Civil Engineering Research Institute for Cold Region (CERI), Public Works Research Institute (PWRI), Sapporo, Japan

<sup>2</sup> Snow Avalanche and Landslide Research Center, Public Works Research Institute (PWRI), Myoko, Japan

**ABSTRACT:** The design guidelines for snow bridges of Japan are based on 'Technical Guideline for Defense Structures in Avalanche Starting Zones' developed in Switzerland in 1961. There have been concerns about snow conditions changing as a result of the higher winter temperatures of recent years. Accordingly, snow pressure was premeasured at slopes that were measured in the previous examination about 30 years ago. The results show that the premeasured values of snow pressure do not exceed those of the design snow pressure but exceed the originally measured values. This is thought to be affected by the differences in snow depths and winter temperatures between the years of examinations.

**KEYWORDS:** snow bridges, snow pressure, unit weight of snowpack, snow depth

### 1. INTRODUCTION

In Japan, the design procedures for snow bridges are based on the Switzerland National Construction Specifications (hereafter referred to as the "Switzerland Specifications"), which were formulated in 1961 (Road Engineering & Management Review, 1966). However, the snow quality in Japan is more dense and wet than that in Switzerland, and such snow has damaged many snow bridges in heavy snow years (Public Works Research Institute, Ministry of Construction and Steel Club, 1989). Therefore, the Civil Engineering Research Institute for Cold Region and other organizations measured the snow pressure on snow bridges in many places in Japan. As a result, a glide factor applied for snow bridges in Honshu, Japan, of 1.5 times was obtained (Snow Research Center, 1993). On the other hand, it was confirmed that the value specified in the Switzerland Specifications was satisfactory in Hokkaido, Japan (Abe et al. 1994), and the conventional glide factor is applied in Hokkaido (Snow Research Center, 1993).

There is concern about snow quality change due to recent climate warming in Hokkaido. Therefore, the snow pressure was measured using the same method and the same slope used 30 years ago to evaluate the change in snow pressure and the adequacy of the snow bridges design procedures. This report explains the observed results. Moreover, this report shows the measurement results and discussions following the report by Harada et al. (2014) which describes the design procedure for snow bridges and its evolution in Japan, in addition to the measurement results.

### 2. APPROACH OF THE DESIGN LOAD OF SNOW BRIDGES IN JAPAN

The snow pressure, which acts on snow bridges derived from the Switzerland Specifications, is based on Haefeli's snow pressure theory (Japan Construction Mechanization Association, 1968). Components  $S_N$  parallel to and  $S_Q$  vertical to the slope of theoretical values of the snow pressure.

$$S_N = \gamma_s \frac{H_s^2}{2} K N \quad (1)$$

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

$$a = \frac{1 - 2V_s}{2(1 - V_s)} \quad V_s = 0.04\gamma_s$$

Where,  $H_s$  is the depth of snowfall (m),  $K$  is the creep factor,  $N$  is the glide factor,  $\gamma_s$  is the unit weight of snowpack ( $\text{kN/m}^3$ ),  $\phi$  is the gradient of the slope (degree), and  $a$  is the coefficient of snowfall, obtained from the compression Poissons ratio  $V_s$  and unit weight of snowpack  $\gamma_s$  of the fallen snow using the following equations.

As mentioned before, the glide factor applied in Honshu is 1.5 times the values specified in the Switzerland Specifications, but the factor applied in Hokkaido is the value specified in those specifications. In many cases,  $3.5 \text{ kN/m}^3$  is used for the unit weight of snowpack  $\gamma_s$  in Japan.

Many hanging fences are adopted for snow bridges in Hokkaido. They are supported by anchorages through a wire cable, which is advantageous from the view of design and construction and adopted widely in Hokkaido. The snow prism load is not taken into consideration because the hanging fences are installed vertically to the slope.

---

\* Corresponding author address:

Wataru Takahashi, Civil Engineering Research Institute for Cold Region, Japan 062-8602;  
Tel: +81 11-841-1746; fax; +81 11-841-9747  
Email: takahashi-w22aa@ceri.go.jp

### 3. MEASUREMENT AND COLLECTED DATA

The snow pressure was measured in the winter of 2012-13 to 2014-15 at the cut slope of general national road No. 230 near Nakayama Pass, Sapporo, Hokkaido (N42°52'20", E141°8'27", 760m a.s.l.; Figure 1). The measurement scene was the same slope where Abe et al. (1994) measured the snow pressure in the winters of 1988-89 to 1993-94. The slope of the measurement area and the construction situation of the snow bridges and the design snow depth are shown in Table 1. Measured items were the snow pressure acting on the snow bridges, snow depth, grain shape and size of each layer, and unit weight of snowpack.

Hanging fences are adopted for the snow bridges at the site. Tensile load cells (Type LU-5TE made by Kyowa Electronic Instruments Co., Ltd.) were attached to three wire cables that support the hanging fence, and the tensile load was recorded on the data logger every hour (Figure 1 to 2). The total of the tensile load of each wire cable is the load (kN) that acts on the snow bridges, and the value obtained by dividing the total load by the snow bridges width ( $W=5.5\text{m}$ ) is the snow pressure  $S_N$  (kN/m) of the component parallel to the slope. Measurements of the slope snow depth and unit weight of snowpack were performed between the snow bridges where the snow pressure was measured and the upper snow bridges.

Moreover, the temperature and snow depth were collected with the Higashi Nakayama telemeter, Hokkaido Development Bureau (830m a.s.l.) located 4 km southwest from measurement point.

### 4. MEASUREMENT RESULT

#### 4.1 Seasonal data of the snow pressure acting on the hanging fences

Seasonal data from 2012-13 to 2014-15 winter of the snow pressure obtained by the measurement is shown in Figure 3. The figure shows the design snow pressure (40.8 kN/m), which was obtained from equation (1), substituting the conditions of Table 1. The snow pressure increased immediately after the start of measurement and attained the maximum on March 14 to 25, decreasing thereafter. During the measurement in 2014-15 mechanical trouble occurred, making it difficult to measure the snow pressure just after measuring the maximum snow pressure. The maximum snow pressure in the measurement period was 15.3 kN/m in 2014-15, which did not excess of the design snow pressure.

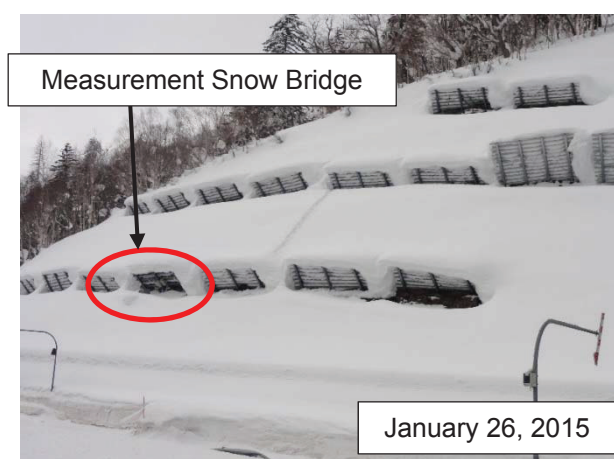
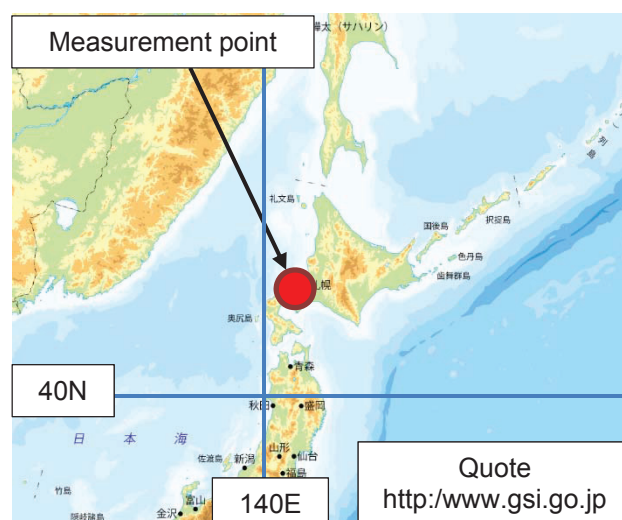


Figure 1: Snow pressure measurement point

Table 1: Characteristics of the measurement point

	Nakayama-Pass
Gradient	42° (1:1.1)
Ground conditions	grass-covered concrete slope fames
Exposure	south
Distance between structures in the line of slope	13m
Width of hanging fence	5.5m
Height of hanging fence	2.0m
Maximum snow depth in the return period of 30 years	3.5m
Creep factor	0.791
Glide factor	2.4
Unit weight of snowpack	3.5kN/m <sup>3</sup>

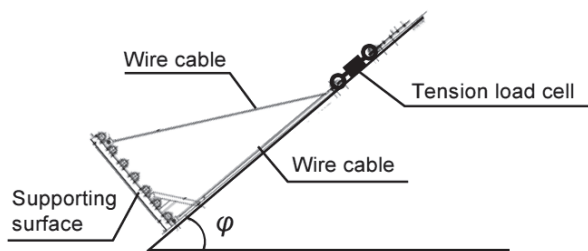


Figure 2: Tension load cells

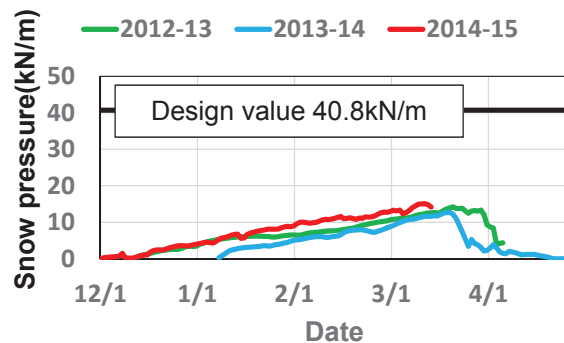


Figure 3: Snow pressure measurements at Nakayama pass (2012-13 to 2014-15)

#### 4.2 Physical properties of the snow on the slope

Figure 4 shows the results of unit weight of snowpack measurement. The unit weight of snowpack between snow bridges was 2.25 - 3.78 (kN/m<sup>3</sup>), which was not greatly excess of the design unit weight of snowpack of 3.5 (kN/m<sup>3</sup>) of Table 1. The difference in the snow unit weight of snowpack between snow bridges was little. On the other hand, the difference between measurement days was observed. The measurement on March 24, during the snowmelt season, was 3.33 (kN/m<sup>3</sup>) on average, about 10% larger than those of other days.

Figure 5 shows the observed snow profile observation performed between fences. On March 23, 2015, the upper layer was Melt Forms, the lower layer was Rounded Grains, and the middle layer was a mixture

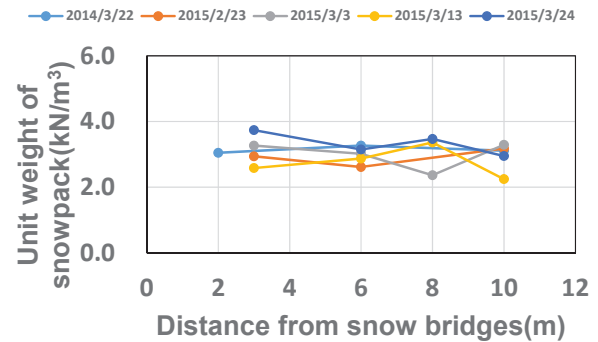


Figure 4: Results of unit weight of snowpack measurements at Nakayama pass

Class	Symbol
Rounded Grains	●
Melt Forms	○

Height(cm)	Thickness(cm)	Class	Diameter(mm)
190-100	90	○	3.0-6.0
100-83	17	○●	2.0-0.5
83-80	3	○	1.0-3.0
80-73	7	●	0.3-0.5
73-69	4	○	1.0-2.0
69-53	16	●	0.3-0.5
53-47	6	○	1.0
47-0	47	●	0.2-0.5

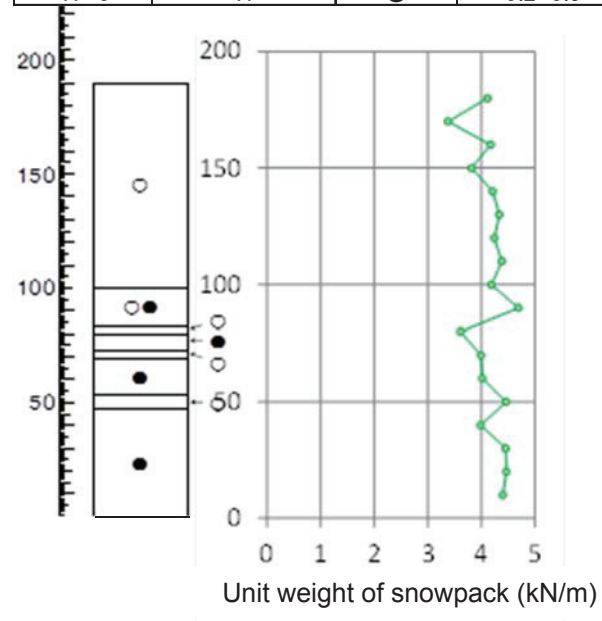


Figure 5: Observed snow profile of Nakayama pass (March 23, 2015)

of those snow types. The site was measured during the snowmelt season, and after the measurement, the snowmelt progressed further.

## 5. DISCUSSIONS

### 5.1 *Comparison with past measurements*

Figure 6 shows the results of snow pressure measurements obtained in the winters of 1988-89 to 1990-91 (Kurokawa et al. 1992). Records of the snow pressure at those times remain (hereafter referred to as the "last time"). Moreover, Table 2 shows the maximum snow pressure and weather data obtained the last time and in the winters of 2012 to 2014 (hereafter referred to as "this time").

The maximum snow pressure measured this time was 15.3 kN/m (2014-15), which was larger than 10.0 kN/m (1990-91) measured last time. Moreover, the maximum snow depth was 269-282 cm this time, which was somewhat deeper than that of 172-240 cm of last time.

The average temperature during the measurement period was  $-4.9$  to  $-7.7^{\circ}\text{C}$  this time and  $-4.9$  to  $-5.2^{\circ}\text{C}$  last time. The average temperature during this winter measurement period was somewhat lower than that last time. Although the snow quality is greatly affected by the temperature, it is not decided only by the temperature. It is not certain how much the temperature affected the snow pressure for the measurement this time.

### 5.2 *Relationship between the snow depth and snow pressure*

Figures 7 and 8 show the relationship between the measured daily average snow pressure and snow depth, which were obtained this both time and last time. Those figures show the snow pressure calculated from equation (1). However, the values of  $\gamma_s$ ,  $K$ , and  $N$  are referred to Table 1. The results show that the measurements of the snow pressure both this time and last time did not exceed the calculate snow pressure. Furthermore, there was no tendency in the change of the relationship between the measured snow pressure and the snow depth.

From the above facts, the difference between the snow pressure this time and last time was considered to be mostly due to the snow depth.

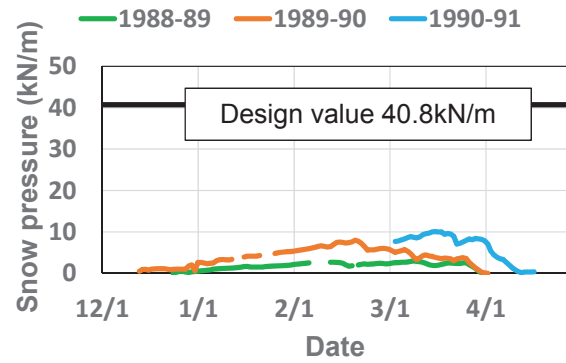


Figure 6: Snow pressure measurements at Nakayama pass (1988-89 to 1990-91)

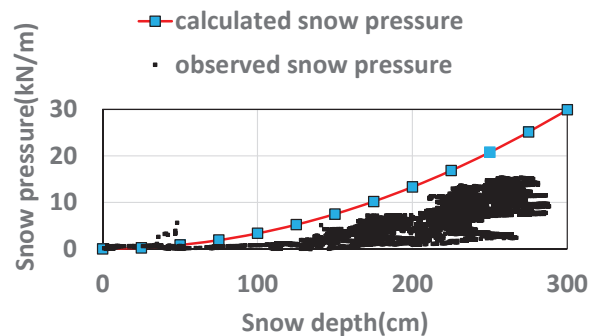


Figure 7: Relationship between the snow pressure and snow depth (Nakayama pass, 2012-13 to 2014-15)

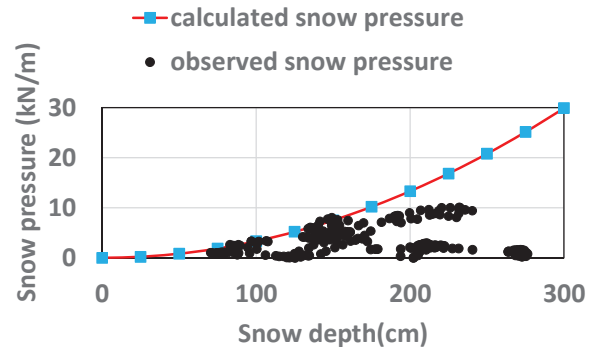


Figure 8: Relationship between the snow pressure and snow depth (Nakayama pass, 1988-89 to 1990-91)

Table 2 Maximum snow pressure, maximum snow depth, and average temperature

Year	This time			Last time		
	2012-13	2013-14	2014-15	1988-89	1989-90	1990-91
Maximum snow pressure(kN/m)	14.4	12.8	15.3	2.9	8.0	10.0
Maximum snow depth(cm)	281	282	269	–	172	240
Average temperature( $^{\circ}\text{C}$ )	$-7.7$	$-6.3$	$-4.9$	$-4.9$	$-5.2$	$-5.0$

- 1) The snow depth at Nakayama pass in 1988 was unknown due to an instrument malfunction.

## 6. CONCLUSIONS

This study aimed to examine the change in snow pressure acting on current snow bridges and to verify the adequacy of the design of the fences in Hokkaido, by measuring the snow pressure acting on the snow bridges at the same site and with the same procedures as those of last time. The results show snow pressure in excess of the design snow pressure. Moreover, the relationship between the snow pressure and the snow depth did not differ from that of last time. The measured snow pressure was less than the design snow pressure.

It is not considered necessary to make any immediate changes to the present design procedures. Because it was confirmed that the measured snow pressure did not exceed the design snow pressure and there is no report of frequent collapses of snow bridges in Hokkaido. Note that the tendency of the snowfall situation differs largely by the year and area, and the results obtained by this study were based on the measurements conducted in three winter seasons at Nakayama pass. However, the need for measuring the snow pressure is considered important as one of the means to verify the design adequacy of snow bridges with due consideration of climate change in winter seasons from now on.

## REFERENCES

- Abe, H., Ishimoto, K. and Kurokawa, K, 1994: Snow Pressure and Load Distribution Acting on the Snow Bridges in Hokkaido, Proceedings of Cold Region Technology Conference, 10, 123-126. (In Japanese)
- Harada, Y., Matsushita, H. and Matsuzawa, M, 2014: Changes in Design Standards and Regional Characteristics of Avalanche Supporting Structures in Japan, ISSW 2014, 1014-1020.
- Japan Construction Mechanization Association: Snow Protection Engineering Handbook, 1968, pp.47-178. (In Japanese)
- Kurokawa, K. and Meike, T, 1992: Measurements of the Snow Pressure Acting on Hanging Fences for Snow Bridges, 35th (FY1991) Hokkaido Development Technical Research Exhibition. (In Japanese)
- Public Works Research Institute, Ministry of Construction and Steel Club, 1989: Joint Research Report on the Design and Establishment of Avalanche Prevention Facilities (No. 1), 73. (In Japanese)
- Road Engineering & Management Review, 1966: Design Manual of Avalanche Defense Structures (No. 1) - Avalanche Control in the Birthplace - (Translation and Commentary of the Switzerland National Construction Specifications), 301, 63-73. (In Japanese)
- Snow Research Center, 1993: Design and Establishment Guidelines of Snow Bridges and Hanging Fences, PP.28. (In Japanese)