Consolidation, Melting and Refreezing Process of Snow on Roads by Vehicles

T. Kobayashi[1], T. Sato[2], K. Kosugi[2], S. Mochizuki[2] and A. Sato[1]

[1] Nagaoka Institute of Snow and Ice Studies, NIED,
Suyoshi, Nagaoka, Niigata, 9400821, Japan.
Email: tk@bosai.go.jp
[2] Shinjo Branch, Nagaoka Instiute of Snow and Ice Studies, NIED,
Tokamachi, Shinjo, Yamagata, 9960091, Japan.
Email: tsato@bosai.go.jp

ABSTRACT

In order to investigate the relation between the mechanical properties of snow/ice on roads and the traffic volume, some experiments were performed in the Cryospheric Environment Simulator (CES). In these experiments, the artificial new snow made by a snowfall machine was deposited almost levelly on the floor of the cold room. After that, the snow was compacted by the shuttle action of a vehicle, meanwhile, the density and the hardness of snow and the skid resistance number (BPN) of the snow surface were measured, under several snow temperatures of 0, -3, -5, -10 and -15°C. At every snow temperatures, the skid resistance number decreased with the traffic volume. The skid resistance numbers were more than 45 at the snow temperatures of -5, -10 and -15°C even on the maximum traffic volume in this experiment of 486. On the other hand, the skid resistance numbers at the snow temperatures of 0°C and -3°C were less than 45. In particular, in the case of the snow temperature of 0°C, very slippery snow surface was formed when the traffic volume exceeded 200. When the snow surface was melted by the solar radiation and the free water content of snow changed from 0% to 10% and 15%, the snow hardness decreased suddenly and the skid resistance number increased suddenly conversely.

Keywords: snow/ice on roads, skid resistance number, traffic volume, snow hardness.

1. INTRODUCTION

In snowy areas in Japan, many traffic accidents occurred in winter and many people were killed in their accidents. To prevent the traffic accidents caused by slipping vehicles on slippery roads in winter, winter road maintenances like snow removal and ice control are performed. But it is important not only performing road maintenances but also informing drivers and the people live in the areas about forecasting weather and road conditions such as "dry", "wet", "ice", "snow"and "slush"to reduce the number of their traffic accidents. In addition, it is also important to predict the skid resistance between the tire and the slippery road surface. Then to investigate the relation between the skid resistance and the traffic volume, temperature, compacted snow conditions, some experiments were performed in a cold room using the artificial snow.

2. METHOD

2.1 Consolidation process

The experiments were carried out using a real vehicle in a cold room. In these experiments, the artificial new snow made by a snowfall machine (Higashiura *et al.,* 1997) was deposited levelly on the track of the cold room floor, 7.5m long, 2.3m wide. The snow depth on the track was about 30~40cm and the density of the snow was about 100~150kg/m^3. Then preliminary consolidation was made by two person's weight through a plate onto the snow surface. As a result, the snow depth on the track was 13~21cm and the snow density on it was 120~213kg/m^3 after preliminary consolidation. After that, the snow was compacted by the shuttle action of a vehicle (displacement:1,590cc) with 4 studless tires, meanwhile, the density and the hardness of snow using a portable load gauge called "push gauge"and the skid resistance number (BPN) of the snow surface using a portable skid resistance tester were measured, under several snow temperatures of 0, -3, -5, -10 and -15°C at the traffic volume of 2, 6, 18, 54, 162 and 486 (see Fig. 1). In addition, when the condition of the snow surface changed obviously, snow samples were picked and the microphotographs of them were taken.

Fig. 1. Measurement of the properties of snow.

2.2 Melting process

The experiments were carried out using a real vehicle (displacement:1,760cc) with 4 studless tires in a cold room. The experimental method was almost the same as the previous experiment about the consolidation process. But the temperature condition was only -3^{o}C. After the snow on the track was compacted by the shuttle action of a vehicle for 486 times, the temperature of the cold room was increased from -3^{o}C to 0^{o}C. After that, the solar radiation produced by the use of the solar simulator, and the snow surface was melted. The density and the hardness of snow and the skid resistance number were measured, and snow samples were picked and the microphotographs of them were taken.

2.3 Refreezing process

The room temperature was decreased from 0^{o}C to -3^{o}C by the solar simulator stopped and the freezer operated. As a result, the snow surface was refreezed again. The density and the hardness of snow and the skid resistance number were measured, and snow samples were picked and the microphotographs of them were taken.

3. RESULTS

3.1 Consolidation process

3.1.1 Snow density and traffic volume

Fig. 2 shows the relation between the snow density and the traffic volume. The snow density increased with the traffic volume rapidly until the traffic volume of 54. The snow density at the traffic volume of 2 was 2~3.6 times as large as that of 0. However, the range of a change in snow density was small between the traffic volume of 54 and 486 (Kobayashi *et al.,* 2004).

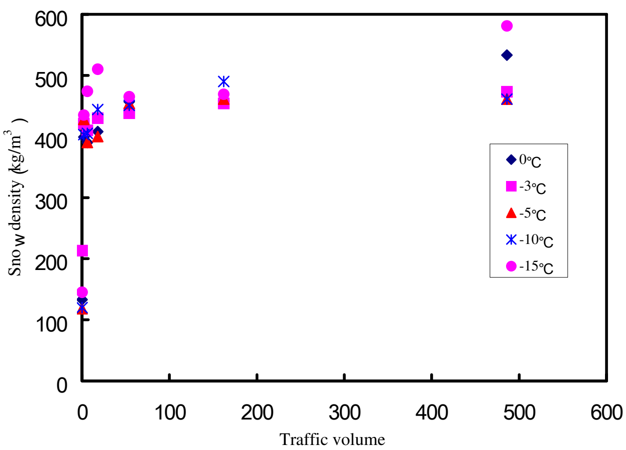

Fig. 2. Relation between the snow density and the traffic volume.

3.1.2 Traffic volume and skid resistance number (BPN)

The skid resistance number was measured using the portable skid resistance tester. Fig. 3 shows the relation between the traffic volume and the skid resistance number (BPN). BPN decreased with increasing the ttraffic volume under the five temperature conditions. The skid resistance numbers at the temperatures of 0°C and -3°C were below 45. According to the standard of the portable skid resistance tester (Ichihara and Onoda, 1997), it is possible to slip on roads. In addition, very slippery snow surface appeared when the traffic volume exceeded 200, and BPN under the traffic volume of 486 was 24. On the other hand, the skid resistance numbers at the temperatures of -5, -10 and -15°C were over 45. Then it is concluded that it is relatively safe at their temperatures.

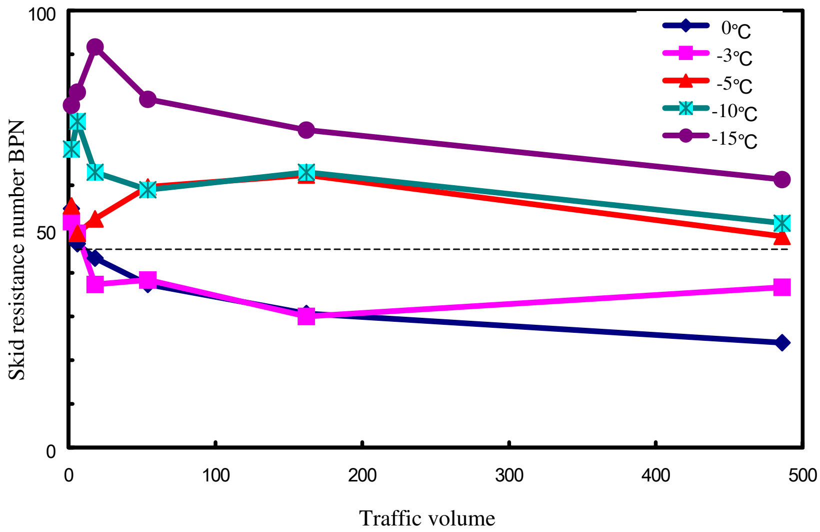

Fig. 3. Relation between the traffic volume and the skid resistance number.

3.1.3 Snow hardness and skid resistance number (BPN)

Fig. 4 shows the relation between the snow hardness and the skid resistance number. The skid resistance numbers decreased with increasing the snow hardness as a whole. The relation between the skid resistance number BPN and the snow hardness *PR* (kPa) is represented by

$$\mathrm{BPN} = \mathrm{a}PR^{\mathrm{b}} \tag{1}$$

Where a and b are coefficients.

Table 1 shows the equations obtained by a least squares method.

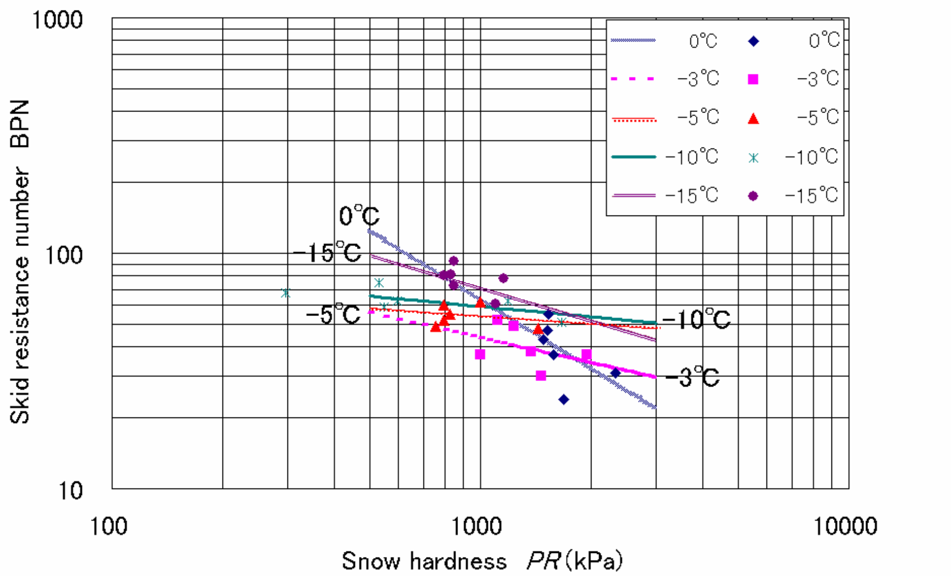

Fig. 4. Relation between the snow hardness and the skid resistance number.

Temperature(℃)	Equation
0	$\mathrm{BPN} = 51582 PR^{-0.969}$
-3	$\mathrm{BPN} = 521 PR^{-0.357}$
-5	$\mathrm{BPN} = 119 PR^{-0.114}$
-10	$\mathrm{BPN} = 163 PR^{-0.146}$
-15	$\mathrm{BPN} = 1743 PR^{-0.462}$

Table 1. Equations about BPN and the snow hardness.

3.2 Melting process

Fig. 5 shows the relation between the snow hardness, the skid resistance number and the traffic volume when the snow on the track was compacted by the shuttle action of a vehicle for 486 times. The snow hardness increased suddenly until the traffic volume of 54, but that increased gradually under the traffic volume of 54 to 486. On the other hand, the skid resistance number decreased suddenly until the traffic volume of 54, but that decreased gradually under the traffic volume of 54 to 486 conversely. Fig. 6 shows the relation between the snow hardness, the skid resistance number and the snow temperature under the melting and refreezing process. At that time, the vehicle did not pass on the snow, then the traffic volume was 0. The snow hardness decreased and the skid resistance number also decreased from 40 to 29 under the snow temperature from -3°C to 0°C. After that, the snow surface was melted by the solar radiation and the free water content of snow (θ) changed from 0% to 10% and 15%. As a result, the snow hardness decreased suddenly and the skid resistance number increased suddenly conversely. The surface condition of the snow under the free water content of 10% and 15% was very rough as if it was the condition after the antifreezing agent was spread on the snow surface. Then the snow surface became slipless. After that, the rough layer with the thickness of about 5mm was removed from the surface.

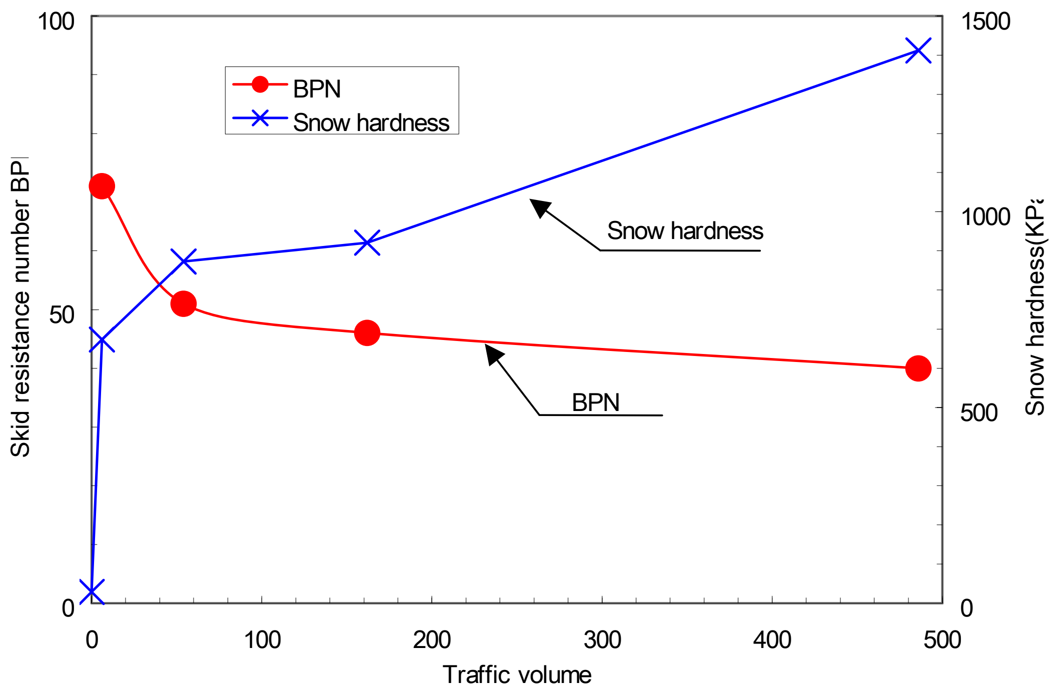

Fig. 5. Variation of the properties of snow in consolidation process.

3.3 Refreezing process

When the snow temperature increased from 0°C to -3°C step by step after the melting process, a reversible change between the snow hardness and the skid resistance number occurred from the free water content of snow (θ) of 15% to 0%. But the correlation between the snow hardness and the skid resistance number from 0°C (free water content of snow of 0%) to -3°C did not become evident. It was considered that the small roughness of the snow surface affected the result (see Fig. 6).

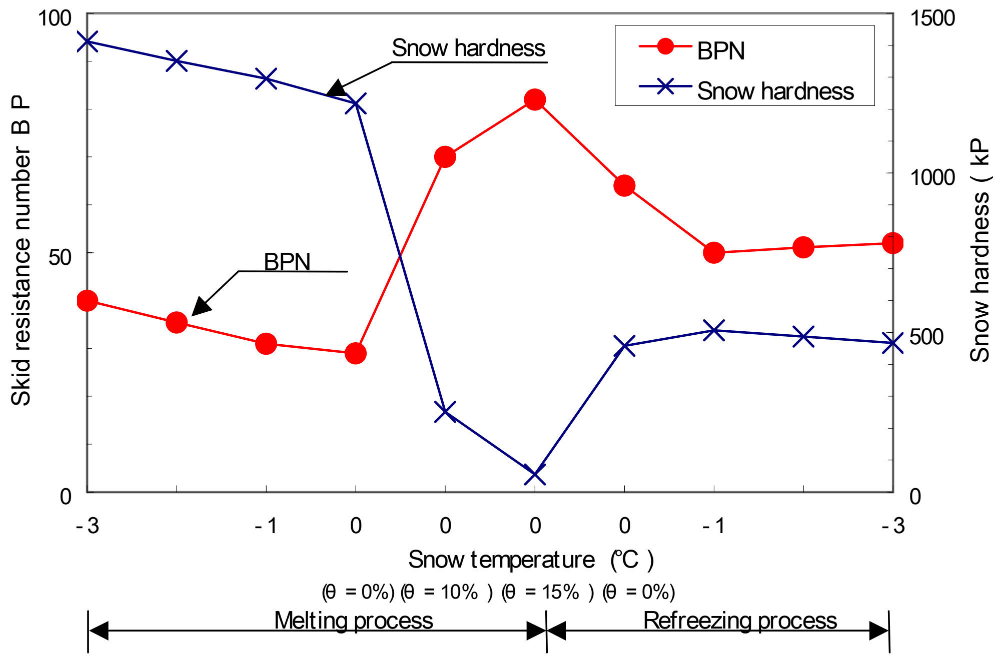

Fig. 6. Variation of the properties of snow in melting and refreezing process.

4. CONCLUSIONS

To investigate the relation between the mechanical properties of snow on roads and the traffic volume, some experiments were performed. The results of them are as follows:

(1) The snow density increased with the traffic volume rapidly until the traffic volume of 54. The snow density at the traffic volume of 2 was 2~3.6 times as large as that of 0. However, the range of a change in snow density was small between the traffic volume of 54 and 486.

(2) The skid resistance numbers at the temperatures of 0°C and -3°C were below 45, it was possible to slip on roads. In addition, very slippery snow surface appeared when the traffic volume exceeded 200, and BPN under the traffic volume of 486 was 24 at 0°C. On the other hand, the skid resistance numbers at the temperatures of -5, -10 and -15°C were over 45, it was relatively safe.

(3) The skid resistance numbers decreased with increasing the snow hardness as a whole. The relation between the skid resistance number BPN and the snow hardness *PR* (kPa) is represented by
$\mathrm{BPN} = a PR^{b}$
Where a and b are coefficients.

(4) The snow hardness decreased and the skid resistance number also decreased from 40 to 29 under the snow temperature from -3°C to 0°C.

(5) When the snow surface was melted by the solar radiation and the free water content of snow changed from 0% to 10% and 15%, the snow hardness decreased suddenly and the skid resistance number increased suddenly conversely.

5. REFERENCES

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