Possibility of damage caused by impact and scattering of falling snow on road information signs

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***Abstract*—To clarify the damage falling snow could cause to passing vehicles, and accidents due to impaired visibility, an experiment was conducted regarding the impact and scattering conditions of falling snow. The results of this experiment and those of previous studies revealed that the possibility of damage is thought to increase if the density of snow becomes 600 kg/m^3 or more due to thawing and freezing of snow. Additionally, accidents caused by impaired visibility due to the scattering of snow are more likely in the case of dry snow with density of 200 kg/m^3 or less.**

Keywords; snow falling; impact load; scattering; possibility of damage; road

I. Introduction

Snow accumulation and accretion falling from structures above roads may cause damage to passing vehicles and people, or accidents due to impaired visibility (Fig. 1). Currently, in Hokkaido, Japan, snow accumulated on structures is mainly removed manually to reduce such risk [1]. However, the workers who remove snow that has accumulated on the structures also face other risks, such as being hit by passing vehicles, and efficient working practices are required. If the snow accumulation conditions deemed acceptable so as not to cause damage are clarified, such work to remove snow from structures can be carried out efficiently. Attention was focused on the impact loads and scattering conditions as indices to assess the risks due to falling snow.

Figure 1. Example of snow accumulation on road information sign.

There have been a number of cases in which impact loads of compacted high-density snow were measured [2] [3], but not low-density or wet snow. Neither have there been any studies on the reduction of visibility due to the scattering of snow. Accordingly, this experiment was conducted to clarify the impact loads and scattering conditions of falling snow, including low-density and wet snow.

II. Method

A. Outline of experiment

Experiments were performed on March 2 and 20, 2009 at the Civil Engineering Research Institute for Cold Region in Sapporo, Japan. The experiments used natural snow cut or packed into solid rectangles with sides measuring 10 to 30 cm. The density of these snow blocks was measured, and snow grain type, including dry or wet conditions, was observed before falling.

B. Measurement of the impact loads of falling snow

The impacts applied by the snow blocks falling from a height of 5 m onto a wooden pressure-receiving plate placed horizontally on the ground were measured as the impact forces of falling snow (Fig. 2). The pressure-receiving device for measuring the impact force consisted of two 9mm-thick wooden plates and four load cells (LC1205-K100) installed between the two plates. The impact force F (N) of falling snow was determined as the sum of the forces measured by each of the four load cells. Fig. 3 shows an example of the wave (N/10^{-3} s) measured as the impact force F. The value of the maximum impact force was divided by

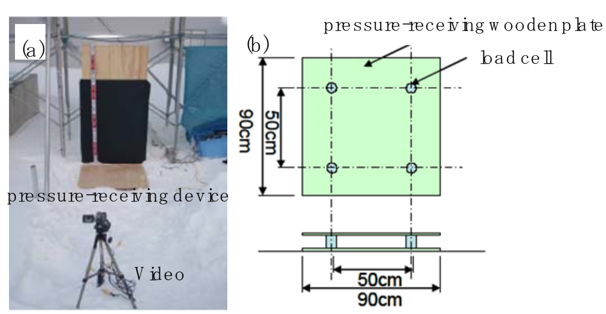

Figure 2. Devices for measuring the impact of falling snow. (a) Situation of experiment, (b) pressure-receiving plates and load cells.

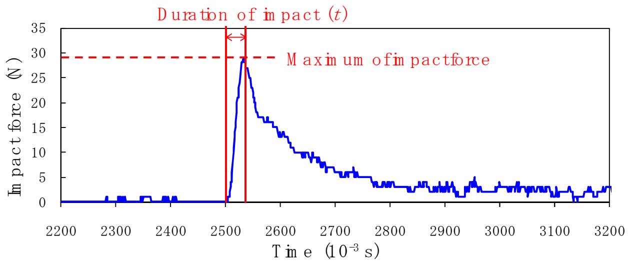

Figure 3. Example of the wave measured as the impact force and the duration of impact.

the area of the snow block after contact, to determine the value of the impact load P (N/m^2). The time from the moment of snow contact to the maximum impact force shown in Fig. 3 was assumed to be the duration of the impact t (s).

C. *Measurement of the scattering of snow caused by impact*

The scattering of snow caused by impact from the fall was observed by taking photographs as shown in Fig. 4. The maximum diameter of each snow block after impact was determined from the photographs, and was divided by the length of the longest side of the block before falling, to find the scattering rate.

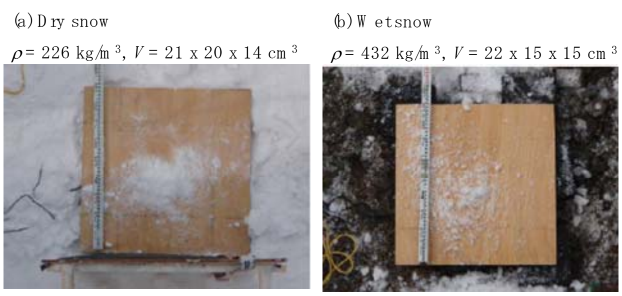

Figure 4. Example of scattering of falling snow in cases of (a) dry snow and (b) wet snow. ρ means density and V is volume of snow block before impact.

D. *Measurement of the velocity of falling snow*

The conditions of snow during falling were recorded on video (1/30 s), and the velocity of the snow on impact was estimated from the video images (Fig. 5). The images were also used for confirming whether the snow block landed on a face or an edge. Only cases in which the faces of the snow blocks hit the pressure-receiving plate were utilized in the following analysis.

Figure 5. Example of video image on impact of falling snow.

III. Results

A. *Impact loads of falling snow*

Fig. 6 shows the relationship between the impact load of falling snow and the density of the snow. It was found that the impact load was greater when the density of the snow block was higher. In the case of dry snow, there is a linear correlation between the impact load and density. In the case of wet snow, however, the relationship is not so clear, and the coefficient of correlation is lower than that in the case of dry snow. In particular, the impact load of wet snow is slightly greater than that of dry snow of the same density, within a range of 400 to 500 kg/m^3. However, regression analysis revealed that the relationship between the impact load and density was irrespective of the type of snow, suggesting that this could be expressed by one equation without distinguishing between dry or wet snow.

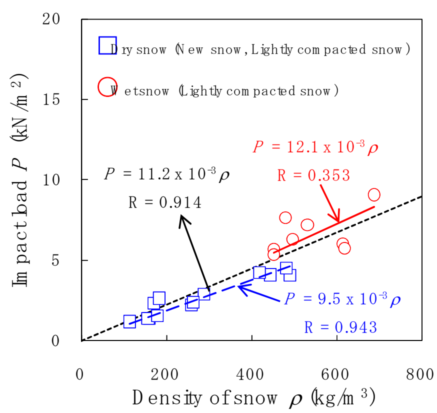

Figure 6. Relationship between the impact load of falling snow and the density of the snow. The regression lines for dry snow (blue broken line), wet snow (red solid line) and both of snow (black dotted line) are also shown in figure. R means the correlation coefficient.

B. *The scattering caused by impact*

Fig. 7 indicates the length of the longest side of a snow block before falling, and the maximum diameter of the scattered snow block after impact. As shown in this figure,

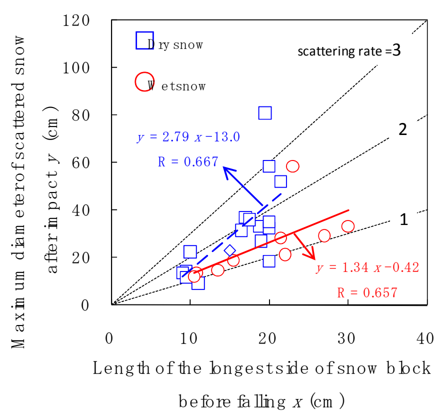

Figure 7. Comparison of sizes of snow blocks before and after impact. The regression lines for dry snow (blue broken line), wet snow (red solid line) are also shown. R means the correlation coefficient. Black dotted line means the rate of scattering.

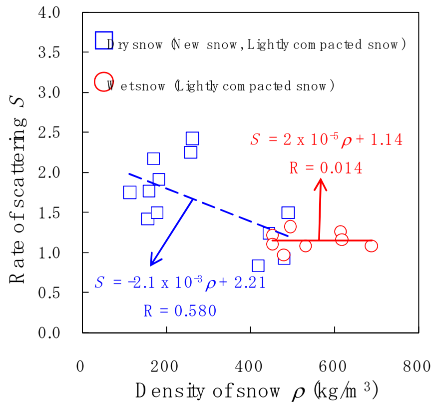

Figure 8. Relationship between the rate of scattering and the density of snow. The regression lines for dry snow (blue broken line), wet snow (red solid line) are also shown. *R* means the correlation coefficient.

while the size of the snow block did not change so much after impact in the case of wet snow, the snow block scattered to 2 or 3 times its size after impact in the case of dry snow. The rate of scattering is the greatest in the case of dry snow, with sizes of 15 cm or more.

The relationship between the rate of scattering and the density of snow is shown in Fig. 8. In the case of dry snow, while the rate was also around 1 when the density was 400 kg/m^3 or more, it increased to between 2 and 3 when the density was as low as 100 to 200 kg/m^3. In the case of wet snow blocks, the rate of scattering caused by the impact was around 1, regardless of density.

C. *The duration of impact of snow*

Fig. 9 shows the relationship between the duration of impact and the density of snow. The duration of impact of snow became relatively longer in the case of dry snow with density of no more than 100 kg/m^3. The time tends to decrease with an increase in the density of snow, and approaches 0.02 s. In the case of wet snow, the duration of impact is more or less constant at 0.02 s, regardless of density.

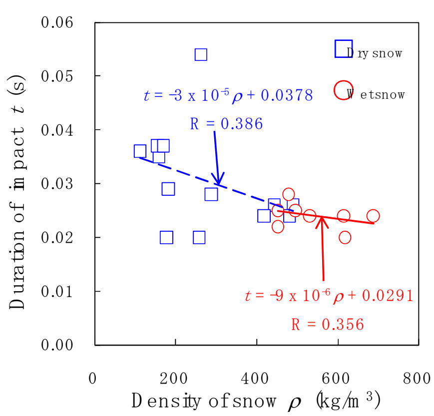

Figure 9. Relationship between the duration of impact and the density of snow. The regression lines for dry snow (blue broken line), wet snow (red solid line) are also shown. *R* means the correlation coefficient.

IV. Discussion

A. *The impact of falling snow*

The impact loads measured in this experiment will be discussed with the measurements obtained by Kotake et al. (2001) [2], which used snow blocks with sides measuring 30 cm, and measured the impact forces of free fall snow from a height of 5 m, the same as in our experiment. However, the snow blocks in that experiment were made by artificially compacting natural snow or by freezing snow, which increases the water content and therefore increases the density and hardness. The duration of impact in the case of the hard snow block is shorter than that of the natural snow that contains no ice, as used in our experiment. Therefore, the duration of impact estimated from the wave of the impact force shown by Kotake et al. (2001) [2] is approximately 0.005 s, and is one quarter of the impact time shown in Fig. 9.

When a non-compressible body moving at a velocity *v* (m/s) is stopped by a collision and its velocity becomes 0, the impact force *F* (N) can be expressed simply as

$$F\,t = M\,v \qquad (1)$$

When the rebounding of the body is neglected, *M* is the mass of snow (kg), and *t* is the duration of impact (s). The velocity *v* in our experiment corresponds to the velocity of falling snow, and is approximately equivalent to the free fall velocity of 9.9 m/s from a height of 5 m. Therefore, the velocity in the Kotake et al. (2001) [2] experiment is assumed to be the same as that in ours. In Fig. 10, the product of the impact force multiplied by the duration of impact *Ft* [i. e., the left side of equation (1)] is compared with the mass of snow *M*. The measurements investigated by Kotake et al. (2001) [2] are also shown in this figure. As seen in Fig. 10, there is a linear correlation between the product of the impact force multiplied by the impact time *Ft*, and the mass of snow *M* regardless of snow density or hardness.

Equation (1) can be rewritten in the form of the impact

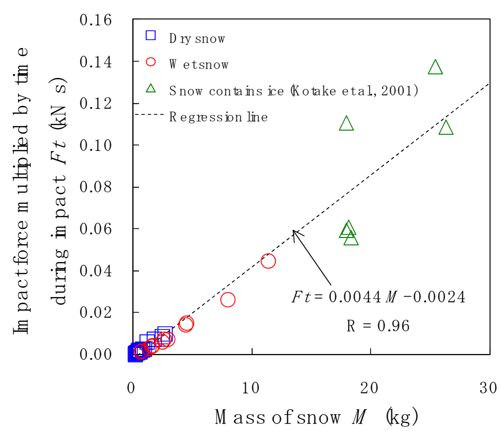

Figure 10. Relationship between the product of the impact force multiplied by the duration of impact and the mass of snow. The duration of impact in Kotake et al. (2001) [2] is estimated 0.005 s. The line shown in the figure means the regression line, and *R* is the correlation coefficient.

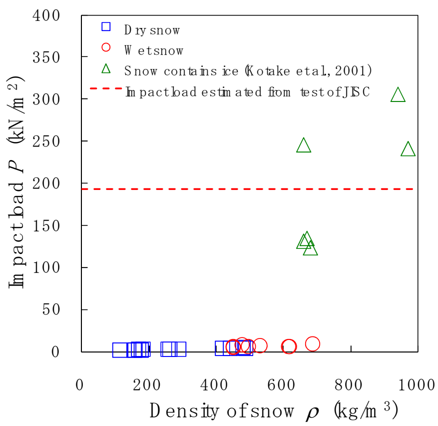

Figure 11. Comparison of the impact load with the snow density. The dotted line means the lowest impact load estimated from the impact resistance test for automobile windshields of the JISC (1998) [4].

load P (N/m^2) as follows.

$$P\,t = \rho\,v\,h \tag{2}$$

Where ρ is the density of snow (kg/m^3), and h is the height of snow perpendicular to the receiving plate. Fig. 11 shows a comparison of the impact load P with the snow density ρ. The impact loads measured in our experiment were extremely low compared with the values measured by Kotake et al. (2001) [2]. As mentioned above, the duration of impact t in the Kotake et al. (2001) experiment [2] was shorter than that in our experiment. Fig. 11 and equation (2) suggest that the impact load P becomes higher due to the short impact time t, if the snow density is high; while the impact load P becomes lower due to the longer impact time t, if the snow density is low. The former corresponds to the Kotake et al. (2001) experiment using hard artificial snow [2], while the latter corresponds to our experiment using softer natural snow without ice. Therefore, in the case of softer snow, part of the impact force causes interior destruction in the snow's structure, and the impact load depends on the hardness of the snow.

B. Potential damage caused by falling snow

One of the risks induced by falling snow is damage to automobile windshields due to impact. According to impact resistance tests for automobile windshields, described in the Japanese Industrial Standards Committee (1998) [4], in which a 38 mm-diameter steel sphere with a mass of 227 g was allowed to freefall from height of at least 8.5 m, the impact load estimated from equation (2) was 193 kN/m^2, where rebounding of the steel sphere was neglected. The duration of impact t is assumed to be 0.02 s; ρ = 7874 kg/m^3; v = 12.9 m/s and h = 0.038 m. However, this estimation is the lowest value because the impact loads become greater if the duration of impact is shorter than that assumed above. In Fig. 11, a comparison of the measured impact loads and impact loads estimated from impact resistance tests on automobile windshields suggests that the possibility of damage is thought to increase if the density of snow becomes 600 kg/m^3 or more due to thawing and freezing of snow. In the case of the snow used in our experiment, the possibility of damage to windshields was considered to be low when snow that did not contain ice fell from a height of 5 m. However, there are cases in which more than 50 cm of snow accumulates on road information signs during heavy snowfall in cold regions [5]. In future, we hope to examine the impact caused by amounts of snow larger than those used in this experiment.

Another risk associated with falling snow is accidents caused by impaired visibility due to the scattering of such snow. The results of this experiment, shown in Fig. 8, reveal that the rate of scattering increased to between 2 and 3 when the density was as low as 100 to 200 kg/m^3 in the case of dry snow. The area of scattered snow after impact is between 60 and 90 cm if the maximum size of the block of snow is 30 cm. This is enough to cover the windshield of an automobile, and accidents could be caused by the driver's impaired visibility. To avoid the risks caused by falling snow, it is necessary to make sure the amount that falls is within the amount deemed permissible in consideration of the scattering rate in relation to the size of windshields. However, because of the different conditions involved, the problem of snow falling and scattering on moving vehicles still remains.

V. Concluding Remarks

To clarify the possibility of falling snow causing damage to passing vehicles, and accidents due to impaired visibility, an experiment was conducted concerning the impact and scattering conditions of falling snow. The results of this experiment those of previous experiments by Kotake et al. (2001) [2] revealed that the possibility of damage is thought to increase if the density of snow becomes 600 kg/m^3 or more due to thawing and freezing of snow. Additionally, accidents due to impaired visibility could be caused by dry snow with density of 200 kg/m^3 or less.

Experiments will be continued to determine more detailed characteristics of impact and scattering according to various snow conditions. In particular, larger amounts of snow falling on moving vehicles need to be examined.

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