Wind tunnel simulations of snow transport on a flat roof during snowfall

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SUMMARY:
Wind tunnel test is an efficient approach to studying snow drifting and predicting drifting snow loads on roofs. This study conducted wind tunnel tests of snow drifting on a flat roof during snowfall. The roof model is designed at a 1:25 geometric scale. The results of snow redistribution and snow transport rate on the roof were analysed in detail, based on which a novel snow transport model was presented. Snow particles are greatly eroded near the windward and leeward roof edges, and the erosion near the windward edge increases with wind velocity, while that near the leeward edge decreases with wind velocity. Snow transport rate increases from the starting point with distance downwind until reaching an equilibrium, which is denoted as the saturated snow transport rate. Snow transport models including the model without snowfall and that during snowfall are presented. In the novel model, the differences between precipitation and deposited snow particles on roofs are considered.

Keywords: flat roof, snow transport, wind tunnel test

1. GENERAL INSTRUCTIONS

In snowy regions, snow load is one of the most important loads for building roofs. It is necessary to determine wind-induced snow loads on roofs in the design of roof structures. There are three ways to study snow drifting on roofs: field measurement, wind tunnel test and numerical simulation. Among them, wind tunnel test can be adopted to study the snow drifting problems systematically due to the controllability in wind speed, wind direction and particle properties. However, whether in the normal wind tunnel or the low-temperature wind tunnel, similarity criteria need to be considered to ensure the accuracy of reduced-scale test (Anno 1984; Kind 1986). In addition, a full process of wind-induced snow deposition on roofs includes snow drifting both during snowfall and after snowfall, while the studies on snow drifting during snowfall are insufficient. Therefore, this study conducts wind tunnel tests of snow drifting on a flat roof during snowfall. The results of snow redistribution and snow transport rate on the roof are analysed in detail, based on which a novel snow transport model is presented.

2. DETAILS OF THE TEST

The tests were conducted in the cryogenic wind tunnel of Shinjo Cryospheric Environment Laboratory of the Snow and Ice Research Center (SIRC), the National Research Institute for Earth Science and Disaster Resilience (NIED) of Japan. The wind tunnel is 1 m in width, 1 m in height and 14 m in length. The artificial snow is made by a snowmaking system in the laboratory. A snow seeder including a vibrator and a sieve is fixed on the ceiling of the wind tunnel, and it can release particles to generate steady and uniform snowfall. A laser displacement sensor (Fig. 1) is used to measure the snow redistribution on roofs.

The roof model (Fig. 1) is designed at a 1:25 geometric scale. The dimension of the roof model is 0.4×0.15×0.1 m, and the corresponding prototype is 10×3.75×2.5 m. A layer of sandpaper is glued on the roof surface to ensure that the particles can be deposited on the roof at the beginning.

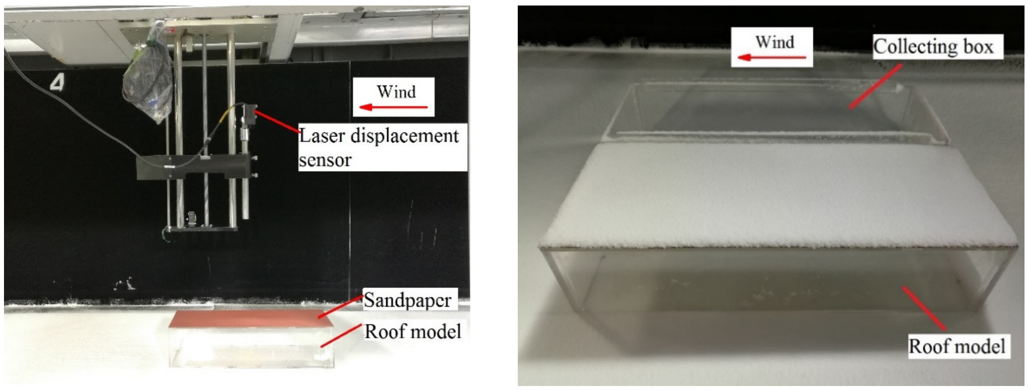

Figure 1. Measuring equipment and roof model.

3. TEST RESULTS

3.1. Snow redistribution

Using the laser displacement sensor, snow redistribution on the roof along the centreline is measured. The shape factor, which is defined by the ratio of remaining snow depth on the roof to snow depth on the ground (Eq. (1)) would be analysed herein.

$$C(x) = \frac{h(x)}{h_g} \quad (1)$$

where $C(x)$ is the shape factor; $h(x)$ is the remaining snow depth on the roof at x position; h_g is ground snow depth.

Fig. 2 shows the shape factors under different wind velocities, in which a value smaller than 1.0 means erosion while that larger than 1.0 indicates deposition. Snow particles are found to be greatly eroded near the windward and leeward edges, and the erosion near the windward edge increases with wind velocity, while that near the leeward edge decreases with wind velocity. In most cases, the erosion starts from the windward edge, then decreases with distance downwind until reaching equilibrium, and finally increases close to the leeward edge. The shape factors are almost 1.0 on a specific region except for the case of $V_H = 2.0\ m/s$, in which large deposition occurs in front of the leeward edge.

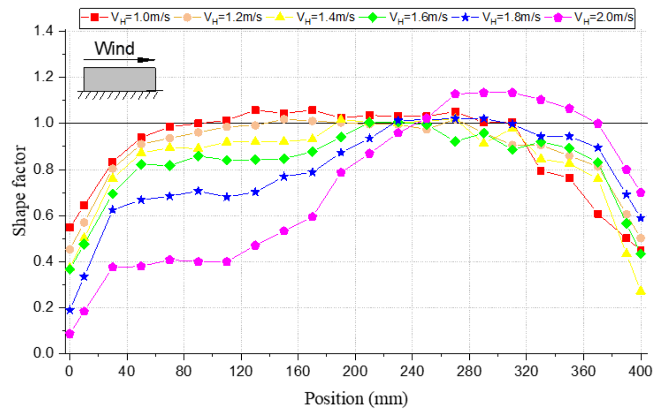

Figure 2. Shape factors induced by drifting during snowfall.

3.2. Snow transport rate

Snow transport rate on the roof is defined by the amount of removed snow per width of the roof per second. During snowfall, the snow transport rate Q(x) can be calculated by

$$Q(x) = I_s \cdot x - I_s \cdot \int_0^x C(x)dx \qquad (2)$$

where I_s is the snowfall intensity.

Fig. 3 shows the distributions of snow transport rate along fetch. The snow transport rate increases from the starting point with distance downwind until reaching an equilibrium, which is denoted as the saturated snow transport rate (marked by the black circle). In addition, in front of the leeward roof edge, the snow transport rate would increase slightly again, which is related to the wind field there.

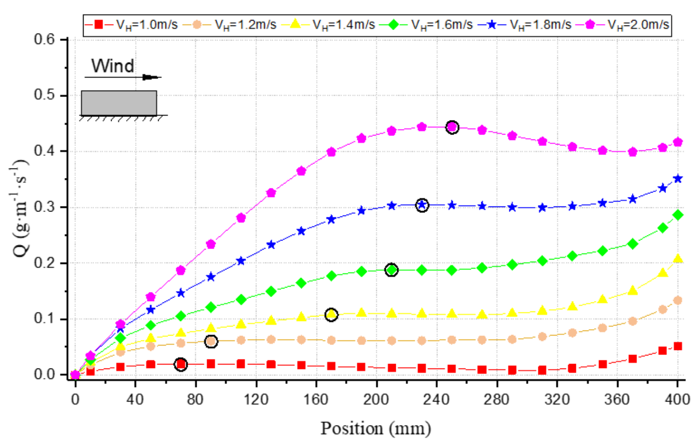

Figure 3. Distributions of snow transport rate under different wind velocities.

4. SNOW TRANSPORT MODEL ON FLAT ROOF

Snow transport models on the flat roof consist of the model without snowfall and that during snowfall.

For snow drifting without snowfall, the snow transport model is

$$Q_r = Q_{sat,d} \sin\left(\frac{\pi}{2}\frac{\min(L, L_{sat,d})}{L_{sat,d}}\right) \tag{3}$$

where $Q_{sat,d}$ is the saturated snow transport rate of deposited snow particles; $L_{sat,d}$ is the corresponding fetch distance; L is the roof length.

Snow drifting during snowfall can be divided into two cases. In the first case, only some of the precipitation snow particles are transported by drifting, and the others accumulate over the old snow. The snow transport model in this case is

$$Q_r = Q_{sat,p} \sin\left(\frac{\pi}{2}\frac{\min(L, L_{sat,p})}{L_{sat,p}}\right) \tag{4}$$

where $Q_{sat,p}$ is the saturated snow transport rate of precipitation snow particles; $L_{sat,p}$ is the corresponding fetch distance.

In the second case, all the precipitation snow particles are transported by drifting, and the deposited particles of old snow are also eroded. The snow transport model is

$$Q_r = I_s L + Q_{sat,d} \sin\left(\frac{\pi}{2}\frac{\min(L, L_{sat,d})}{L_{sat,d}}\right) \tag{5}$$

The first case is likely to happen under relatively weak wind and heavy snowfall, while the second one could occur when the wind is strong and the snowfall is light.

5. CONCLUSIONS

In this study, wind tunnel tests of snow drifting on flat roofs during snowfall were conducted. The results of snow redistribution and snow transport rate on the roof were analysed in detail, based on which a novel snow transport model was presented.

Snow particles are greatly eroded near the windward and leeward roof edges. Snow transport rate increases from the starting point with distance downwind until reaching an equilibrium, which is denoted as the saturated snow transport rate. In front of the leeward roof edge, the snow transport rate would increase slightly again. The snow transport models including the model without snowfall and that during snowfall are presented. In the novel model, the differences between precipitation and deposited snow particles on roofs are considered.

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