Resilient Structures and Sustainable Construction
Edited by Pellicer, E., Adam, J. M., Yepes, V., Singh, A., and Yazdani, S.

ISBN: 978-0-9960437-4-8

MEASUREMENT AND COMPARISON OF SNOW DENSITY ON GROUND AND ROOF

ZHANG QINGWEN, REN ZHICHENG, and WANG SHIYU

Key Lab of Structures Dynamic Behavior and Control, Harbin Institute of Technology, Ministry of Education, Harbin, China
School of Civil Engineering, Harbin Institute of Technology, Harbin, China

With the intensification of global climate changing, the human and economic losses caused by snowstorms becomes higher and higher. Harbin, located in the north of China, has the geographical advantage of heavy snowfall, the density and the distribution of snow on the ground and roof were measured. In the aspect of snow density, the snow density on ground and roofs were measured. The snow is divided into three kinds, and the range of snow density is roughly determined. By comparing the two kinds of measurements on both fields, the effects of location, snow thickness and temperature on snow density are specified. Also, the differences of snow density on both ground and roof, new snow and old snow are got. The results show that the old snow density is greater than the new snow density. The snow density of the roof area is obviously larger than that of the ground area; the ground snow density increases with the accumulation of snowfall.

Keywords: Snowfall accumulation, Snow loads, Snow thickness, Climate, Disaster prevention.

1 INTRODUCTION

Since the world has entered the new century, with the global climate change intensifies, unusual weather phenomenon such as the storm also increasingly frequent. Bad weather led to frequent snow engineering disasters and accidents, resulting in huge property damage and heavy casualties. In 2006, an exhibition hall in Poland was crushed by snow, 65 people were killed and more than 160 people were injured. In 2008 a once-in-a-century snow disaster occurred in the south of China, a direct economic losses of 151.65 billion yuan. Chinese scholars have made an analysis on the cause of the collapse of the house caused by snow in China in recent years, it is generally believed that snow load over structural design and uneven distribution of snow is the main cause of the disaster. Our country "Load Code for the Design of Building Structures" (GB 50009-2012) for the above two problems are considered by the basic snow pressure and the distribution coefficient of roof snow respectively.

Load code for the snow load in our country from every part of the update process are focus on the basic snow pressure, it can be seen that the basic snow pressure in snow load calculation is very important. Snow pressure decided jointly by the snow density and the snow thickness, and the importance of the snow density is self-evident. In this paper, some scholars in our country have carried out a preliminary study. Yang Daqing *et al.* (1992) analyzed the measurement data of eight precipitation periods from 1989 to 1990, and obtained the following important conclusions: When the snow thickness is small, the snow density does not change with the depth;

in time and space, the amplitude of variation of snow depth is larger than that of density. Zhang Zhanliang (2005) studied the method of measuring snow density, and proposed a new measurement method to improve the measurement accuracy. Huang Weijun *et al.* (2007) classified and regression analysis of meteorological data, then they divided the snow density in Xiniang into stable and unstable period. In the stable period, the snow density is a function of time, the maximum average is stable at 191 $kg{\cdot}m^{-3}$. From the basin belt to the mountain zone and then to the altitude of 3800m above the alpine region, the snow density in Xinjiang increased with increasing altitude. Foreign scholars start earlier in the study of snow density, and they have done many studies. Taylor (1980) studied the problem of the value of the roof snow density in Canada. Ellingwood *et al.* (1983) studied the problem of how to convert the snow density of the ground surface to the snow density of the house, Mathias Gergely *et al.* (2010) studied the method of measuring the density of snow with infrared rays, Bormann *et al.* (2013) studied the space-time characteristics of seasonal snow density. By comparing the research status at home and abroad, it can be found that the research on snow load of building roof is carried out more deeply and meticulously. Therefore, we can learn from their research results and methods, then apply it to our country's specific practical situation, to speed up the development in related fields in our country.

In the study of roof snow distribution, the distribution of roof snow is not uniform due to the wind effect, and it is important to clarify the distribution law of roof snow distribution to structural design. Mo Huamei (2011) selected two typical roofs to measure the snow depth. By calculating the snow depth and snow heap length, the results show that when the height difference between high and low roof is not big, the height of snow heap can reach the whole height difference of roof; the length of snow heap is more than 2 times of parapet height. DeGaetano and O'Rourke. (2003) studied the phenomenon of snow drift in roof by using snow transport, physical model of deposition, and combined with historical meteorological data. Sink experiment studies have shown: The snow drift at the roof of the triangle roof did not extend to the eaves, the amount of snow drift was related to the wind speed, the snow on the leeward side was evenly distributed. For the staircase roof, due to the role of snow drift, the accumulation of snow at the corner of the ladder is triangular accumulation state. In addition, O'Rourke *et al.* (1985), O'Rourke and Auren (1997), Hochstenbach *et al.* (2004) and O'Rourke and Kuskowski (2005) also studied snow distribution in roofs with different roof forms.

It is necessary to strengthen the field survey and research analysis of various forms of roofs, in order to grasp the actual distribution of snow roof comprehensively, to promote the research of snow load in building roof.

2 PREPATORY WORK

The snow cover density is closely related to the surrounding environment and meteorological conditions, during the field measurement, according to the provisions to select and measure.

As about selecting the fields of measuring, "Specification for Surface Meteorological Observation" Part 9 "Snow depth and snow pressure observation" stipulate: The fields where snow depth and snow pressure are observed should be "flat, open, with natural underlying surface" characteristics. Considering all these factors, the tennis court, stadium, the roof of the civil engineering college and the roof of the sixth apartment in the second campus of Harbin Institute of Technology were chosen as the fields of measuring (as shown in Figure 1).

The surface of the four fields are good to meet the requirements of the "Specification for Surface Meteorological Observation", and the surfaces of the fields are hard and smooth, the sampling of snow is convenient. In the snowy winter in Harbin, these four fields are in a closed state, the snow is not disturbed by man-made factors.

As about determine the methods of measuring. Snow density and snow distribution are related to meteorological data. So PC-4 automatic weather station is used to record the ambient temperature, ambient humidity, atmospheric pressure, instantaneous wind direction, instantaneous wind speed, 2-minute mean wind speed and 10-minute mean wind speed near the field of measuring. In the course of using, the erection site is selected on the west side of the roof of the Civil Engineering College (as shown in Figure 2).

Figure 1. Location where outdoor measurements were conducted.

Figure 2. PC-4 automatic weather station.

As about measuring the snow density, using a direct weighing method, is to use the balance to weigh the net weight of the snow, then divided by the volume of snow inside the cylinder to obtain snow density.

Before the measurement, first of all, to check whether the instrument work properly; Secondly, clean the measuring instruments. After the measurement should carry out the relevant maintenance work, wipe the straight steel rulers, electronic scales and small shovels, to prevent the instrument rust, so that the next can also be used normally.

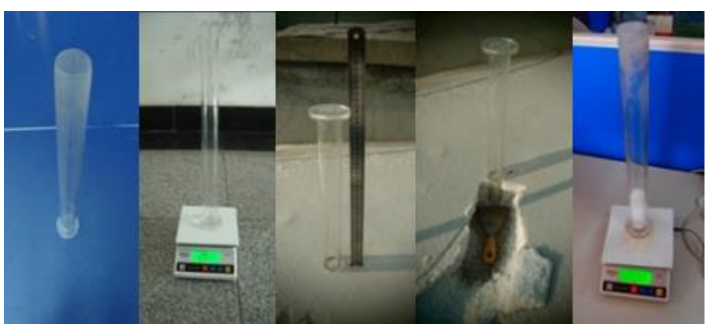

Figure 3. Measurement process of snow density.

In order to reduce the error, some measures were taken in the measurement, such as the steel ruler and the snow gage muse be upright, the end of the measuring cylinder should be polished, the second weighing and increase the measuring points and so on. “Specification for Surface Meteorological Observation” Part 9 “Snow depth and snow pressure observation” stipulate; Select three representative measuring points at each field to measure. In order to improve the accuracy of measurement, this paper adds two measuring points, select five representative measuring points at each field to measure. When measuring the thickness of snow, try to keep the steel ruler parallel to the axis of the snow gage, and all keep vertical, to avoid the measurement results do not match the actual thickness of snow.

3 ANALYZE THE SNOW DENSITY

Using the above methods, the winter snowfall in Harbin from 2012 to 2013 was recorded and statistical analysis. In order to be able to in-depth analysis of the snow density, according to the nature of the snow, the snow measurement results will be divided into three types, namely: new snow, new snow + old snow, new snow + old snow (With the hard shell of the snow surface hardening caused by the wind)

The measurement results new snow are shown in Table 1. There are three reasons for the lack of measurement: snow thickness is less than 5mm, the initial fall of the snow that is melting snow, late snow was sleet. From the data in the table, the new snow density of 103 ~ 135 kg·m^{-3}, with an average of 114.4 kg·m^{-3}.

Table 1. Measured data of fresh snow density/ kg·m^{-3}.

Snowfall date	2012-11-27	2012-12-21	2013-02-28
Tennis court	106.4	—	—
Stadium	103.3	—	—
Civil engineering college	134.8	118.2	109.2

Note: The dash in the table indicates that the measurement was not performed because the measurement conditions did not meet the specifications.

The measurement results of new snow and old snow are shown in Table 2. Its development trend is shown in Figure 4. In the figure, the red and black curves represent the snow cover density of the roof and the ground respectively. Among them, the snow density of the roof is stable with an average of 165 kg·m^{-3}, and the snow density of ground surface is between 125 kg·m^{-3} and 156 kg·m^{-3}, the snow density of ground surface increases with the accumulation of snowfall, and then stabilizes at about 155 kg·m^{-3}. Compared with the snow density of the roof and ground, the snow density of the roof is obviously larger than that of the ground. From the trend of the snow density and snow thickness of ground、roof, these conclusion can be find: The snow thickness has a great influence on snow density, but it has little effect on the snow density. This snow density is significantly larger than the new snow density, indicating that the old snow density is greater than the new snow density.

Table 2. Measured snow density of fresh snow and deposited snow/kg·m^{-3}.

Snowfall date	2012-12-03	2012-12-15	2012-12-21	2012-12-29	2013-01-23	2013-02-28
Tennis court	136.4	150.8	156.4	144.7	154.6	154.6
Stadium	124.5	144.0	154.8	153.2	—	—
Civil engineering college	167.2	163.1	—	163.8	—	—

Note: The dash in the table indicates that the measurement was not performed because the measurement conditions did not meet the specifications.

The surface snow density measurement data were compared and analyzed with temperature, then Table 3 and Figure 5 were obtained. The recording period of temperature is taken from 12:00 the previous day to 12:00 of the day. It can be seen that the relative deviation of the snow density of different points on the ground is less than 10%, which indicates that different points on the ground have little effect on the snow density. In this snowfall time, there is a negative correlation between snow density and temperature, the lower the temperature, the greater the snow density.

The third type of snow is new snow and old snow (with hard shell) (as shown in Table 4). This type of snow is due to the roof wind long time effect on the snow surface caused. The snow density is between 184 kg·m^{-3} and 210 kg·m^{-3} with an average of 198.2 kg·m^{-3}. Due to the wind, the thickness of the roof snow is uneven, but the density of snow with the hard shell layer is not affected by the snow thickness.

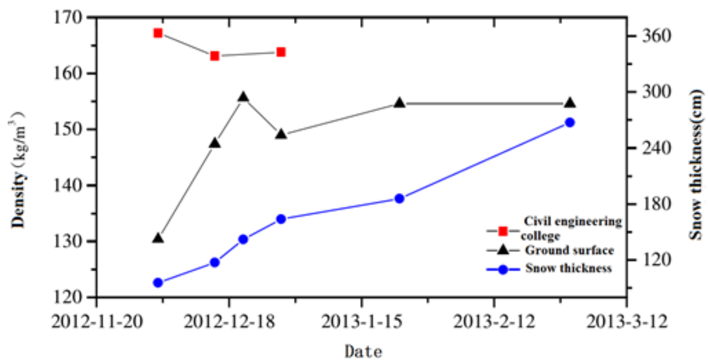

Figure 4. Comparison of snow density on ground and building roofs, and the relationship with snow depth.

Table 3. Comparison of the snow density on different fields and the relationship with the temperature.

Snowfall date	Tennis court/kg·m^{-3}	Stadium /kg·m^{-3}	Relative deviation/%	Average temperature/℃
2012-12-03	136.4	124.5	9.6	-16.4
2012-12-15	150.8	144.0	4.7	-18.1
2012-12-21	156.4	154.8	1.0	-23
2012-12-29	144.7	153.2	5.5	-22.4

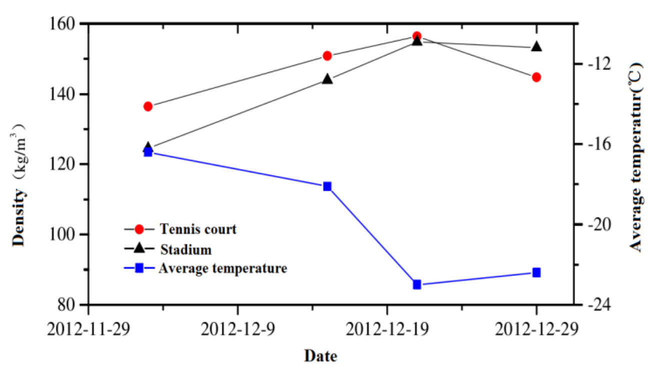

Figure 5. Comparison of snow density on different fields, as well as the relationship with the temperature.

Table 4. Measured snow density of fresh snow and wind covered snow/kg·m^{-3}.

Location of measurement	Date	2012-12-15	2013-01-23
Civil engineering college	Snow density/kg·m^{-3}	210.2	183.9
	Snow thickness/mm	139.6	156.2
The sixth apartment	Snow density/kg·m^{-3}	—	200.4
	Snow thickness/mm	—	186.2

Note: The dash in the table indicates that the measurement was not performed because the measurement conditions did not meet the specifications.

4 CONCLUSION

In this paper, the snow density of roof and ground are measured. The following conclusions can be drawn from the analysis of the measurement results (The snow density of the roof and the ground is measured):

- The old snow density is greater than the new snow density.
- The snow density of the roof area is obviously larger than that of the ground area.
- The ground snow density increases with the accumulation of snowfall, and then stabilizes at about 155 $kg \cdot m^{-3}$.
- The thickness of snow is an important factor in the ground snow density, but it has little effect on the roof snow density.
- There is little difference in snow density at different locations on the ground and on the roof of the same type of building.
- There is a negative correlation between snow density and temperature.

References

Bormann, K. J., Evans, J. P., Westra, S. and McCabe, M. F., Spatial and Temporal Variability in Seasonal Snow Density, *Journal of Hydrology*, 484, pp. 63-73, 2013.

Cai, Y. Y., Enlightenment of the 2007 Snow Disaster in Liaoning Province to the Construction of Light Steel Structure House, *China Construction Metal Structure*, 2007(4), pp. 33-35, 2007.

Chen, S. F., Brief Analysis of the Cause of Damage to Light Weight Steel Structure in Snow Disaster and the Design Proposals, *Zhejiang Construction*, 2010(7), pp. 34-36, 2010.

China Meteorological Administration, *Specification for Surface Meteorological Observation*, China Meteorological Press, Beijing, China, 2007.

DeGaetano, A. T. and O'Rourke, M. J., A Climatological Measure of Extreme Snowdrift Loading on Building Roofs, *Journal of Applied Meteorology*, 43, pp. 134-144, 2003.

Ellingwood, B. and Redfield, R. Ground Snow Loads for Structural Design, *Journal of Structural Engineering*, 109(4), pp. 950-964, 1983.

Gergely, M., Roth, K., and Schneebeli, M., First Experiments to Determine Snow Density from Diffuse near-infrared Transmittance, *Cold Regions Science and Technology*, 64(2), pp. 81-86, 2010.

Hochstenbach, F. M., Irwin, P. A. and Gamble, S. L., *Parametric Studies of Unbalanced Snow Loads on Arched Roofs*, Structures Congress 2004, Tennessee, ASCE, 2004.

Huang, W. J., Huang, Z., Cui, C. X., Feng, Z. M., Li, Q., and Wang, L., Temporal and Spatial Distribution of Xinjiang Snow Density and Its Consequence, *Journal of Glaciology and Geocryology*, 2007(1), pp. 66-72, 2007.

Mo, H. M., *Numerical Simulation and Field Survey of Snow Distribution in Typical Roof*, Harbin Institute of Technology, pp. 23-36, 2012.

O'Rourke, M. and Auren, M., Snow Loads on Gable Roofs, *Journal of Structural Engineering*, 123(12), pp. 1645-1651, 1997.

O'Rourke, M. and Kuskowski, N., Snow Drifts at Roof Steps in Series, *Journal of Structural Engineering*, 131(10), pp. 1637-1640, 2005.

O'Rourke, M. J., Speck, R. S., and Stiefel, U., Drift Snow Loads on Multilevel Roofs, *Journal of Structural Engineering*, 111, pp. 290-306, 1985.

Taylor, D. A., Roof Snow Loads in Canada, *Canadian Journal of Civil Engineering*, 7(1), pp. 1-18, 1980.

Yang, D. Q., Zhang, Z. Z., Kang, E. Q., Zhang, Y. S., Elder, K. and Kattelmann, R., Experimental Study on Comparability of Snowfall Measurement by Precipitation Gage and Snow Survey, *Advances in Water Science*, 3(2), pp. 136-141, 1992.

Zhang, Z. L., How to do Snow Pressure Observation, *Shanxi Meteorological Quarterly*, 2005(1), pp. 39, 2005.