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DESIGN FOR SNOW LOADING OF ROOFS

New Findings From the Finite Area Element Method

by Scott Gamble, Principal

Even in regions of moderate to low annual snow fall, snow loading can be the governing factor in the design of entire building structural systems. Recently, research funded by the National Research Council of Canada, was carried out by RWDI. This snow loading research, combined with experiences on actual case studies of roof failures for the private sector, has indicated that previous generations of building codes and standards may not adequately address several issues.

A drift that formed in the step of a large roof.

RWDI has developed a method of accurately simulating the complexities of the snow accumulation, drifting, and melting processes on building roofs called the Finite Area Element (FAE) technique. The technique is a hybrid of model testing and computer simulation that allows fine tuning of shape (i.e., flat, sloped, gabled, vaulted, etc.) factors specifically for the geometry of the roof being designed. These shape factors are used to account for the localized accumulation of fallen and drifted snow on roofs and are generally applied to the ground snow load for the building's geographic location. This approach is particularly applicable to roofs of unusual geometry, buildings in complex wind flow situations, or other situations where the generalized building code guidelines are felt to be inappropriate due to over-conservatism or non-conservatism.

One such case is that of very large buildings. Typically, building codes apply a reduction factor to the ground snow load in calculating the loading of the roof. This accounts for the wind's tendency to remove snow from the roof by drifting while snow is generally not able to drift up onto the building from the ground. This is true of typical smaller roofs, but as the roof's plan dimensions become large, the roof increasingly emulates the ground. Therefore, logically, the reduction factor should approach 1.0. Most building codes were based on field measurements. Since the collection of this data is time consuming and expensive, sufficient information on the snow loads on very large roofs is not available. Also, these field measurements cannot be easily translated into design loads since the representative probability of occurrence of each case is difficult to assess.

RWDI's research used the FAE tool to carry out parametric studies on a range of roof sizes, plan length to width aspect ratios, and climatic conditions to obtain an improved treatment of basic roof loads and peak loading of roof steps. A revised formula for the peak loading in roof steps has been produced by RWDI and accepted for the 1995 version of the National Building Code of Canada (NBCC). The following compares the 1990 and 1995 treatment of loads accumulated in the step formed by adjacent flat roofs with differing elevations.

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1990 NBCC Peak Step Load

$$S_{peak} = 3S_s + S_r$$

where

S_s is the basic ground snow load for the geographic location

S_r is the rain-on-snow load

1995 NBCC Peak Step Load

$$S_{peak} = S_s \times \left[\; 0.35\sqrt{\frac{\gamma l^*}{S_s} - 6\left(\frac{\gamma h_p}{S_s}\right)^2} + 0.8 \;\right] + S_r$$

where

γ is the assumed typical density of the snow pack

h_p is the height of a parapet surrounding the upper roof which has the effect of retaining some snow on the upper level

$l^* = 2w - \frac{w^2}{l}$ is the calculated "characteristic length" of the upper level roof which provides the source of snow available to drift into the step region

w is the shortest plan dimension of the rectangular roof

l is the longest plan dimension of the rectangular roof

Some comparisons with the 1990 NBCC and the ASCE 7-95 standard and some of the important implications of the use of the 1995 NBCC expression follow.

Higher Loads in Steps in Geographic Regions of Low Ground Snow – The basic ground snow is now a major part of the 1995 NBCC calculation in the form of the non-dimensional roof length ($\gamma l^*/S_s$). Therefore, peak step loads are now predicted to be greater than previously calculated in regions of low ground snow load, as illustrated in the following table.

Peak Load in Simple Step[1] for 30 x 30 m (100 x 100 ft) Roof

Ground Snow Load	*RWDI / NBCC 1995*	*NBCC 1990*	*ASCE 7-95*
S_s= 1 kPa (20 psf)	3.9 kPa (80 psf)	3 kPa (60 psf)	3.3 kPa (67 psf)
S_s= 2.5 kPa (50 psf)	7.5 kPa (152 psf)	7.5 kPa (150 psf)	5.8 kPa (118 psf)

[1]Rain-on-snow allowance (S_r) not included.

Higher Loads in Steps on Very Large Roofs – The characteristic roof length (l*) is the edge dimension of a square (in plan) roof which exhibits similar snow loads to the rectangular roof being considered. As this length increases (larger roofs) the snow loads in roof steps increase due to the larger source of snow available to drift into the step. This effect has been incompletely accounted for or not accounted for at all in many codes and standards. Several examples are presented in the following table.

Peak Load in Simple Step[1] for Geographic Location with S_s= 2.5 kPa (50 psf)

Roof Dimensions	*RWDI / NBCC 1995*	*NBCC 1990*	*ASCE 7-95*
90 x 90 m (300 x 300 ft)	11.5 kPa (235 psf)	7.5 kPa (150 psf)	8.3 kPa (170 psf)
180 x 180 m (600 x 600 ft)	15.4 kPa (315 psf)	7.5 kPa (150 psf)	10.3 kPa (210 psf)
60 x 180 m (200 x 600 ft)	12.0 kPa (245 psf)	7.5 kPa (150 psf)	7.2 kPa (145 psf)[2] 10.3 kPa(210 psf)[3]

[1] Rain-on-snow surcharge (S_r) not included. [2] Assuming shortest dimension upwind.
[3] Assuming longest dimension upwind.

Longer Drifts – Many codes indicate that the sloped upper surface of the drift would have a 3:1 or 4:1 length to height ratio. Experience with ground level drifting patterns indicates that with a very large source of snow, drift ratios could reach 6:1 or 7:1. An example of a long drift which formed in a step on a very large roof (250m, 800ft) is shown in the photograph on page 1. In most situations, varying wind directions would tend to scour back the "toe" of the drift. To allow for this, we recommend that the drift load be considered to taper from the peak value to the uniform roof load on a 5:1 slope.

Parapets on Upper Roof May be Used to Reduce Step Loads – The effect of a parapet on the upper roof is to provide a location for trapping some of the drifting snow on the upper roof. This drift reducing effect on the lower step is included in the 1995 NBCC calculation by the $-6(\gamma h_p/S_s)^2$ term. The following table provides an example of the potential magnitude of this reduction and that reasonable parapet heights become less effective as the roof size increases.

Peak Load in Simple Step[1] for Geographic Location with S_s = 2.5 kPa (50 psf)

Roof Dimensions	*hp=0.3 m (1 ft)*	*hp=0.75 m (3 ft)*	*hp=1.5 m (6 ft)*
30 x 30 m (100 x 100 ft)	7.4 kPa (150 psf)	7.1 kPa (145 psf)	5.5 kPa (85 psf)
90 x 90 m (300 x 300 ft)	11.4 kPa (240 psf)	11.3 kPa (235 psf)	10.5 kPa (210 psf)

[1]Rain-on-snow allowance (S_r) not included.

Other research into step accumulations and experience with case studies for private clients carried out by RWDI have indicated these other important considerations.

Reduced Loads in Steps of Large Elevation Change or Unusual Aerodynamics – Snow loading provisions of codes and standards generally imply that a typical triangular drift surcharge can be expected on any lower roof that is adjacent to a higher roof. In the case of a small roof that is at a much lower elevation than the upper level, a large percentage of snow particles that drift from the upper level can be expected to be carried further away from the step. Therefore, it may be overly conservative to apply a full peak step load to this situation. This is typical of a canopy roof near the base of a multistorey building. Typical reduction factors determined by RWDI, through complex particle motion calculations, for this situation are shown in the following table.

Reduction Factor for Drift Component of Load on Base Level Canopy 6 m (20 ft) Wide Varying Step Heights (h_{step})

h_{step}=3 m (10 ft)	h_{step}=10 m (30 ft)	h_{step}=20 m (60 ft)	h_{step}=40 m (120 ft)	h_{step}=80 m (240 ft)
1.0 (1.0)	0.90 (0.90)	0.70 (0.75)	0.35 (0.40)	0.00 (0.00)

Similarly, where the wind flows over the lower level roof are likely to be highly three-dimensional (i.e. not simple flow over the upper roof onto a lower flat roof) the code provisions are also not applicable. In some of these cases special studies of the drift patterns are warranted.

Increased Loads due to Limited Roof Drainage in Areas of High Rain-on-Snow Conditions – Low-slope roofs designed with only perimeter drainage can experience snow loads that exceed the loads indicated in building codes by significant margins in areas where repeated snow/rain/melting cycles are experienced. In average conditions these roofs will allow drainage of melt and rain water in the thaw periods between snow storms, but in the extreme cases (50 year return) ice and snow damming will inhibit or eliminate runoff. In this case, virtually all precipitation that falls on the roof can remain and accumulate to high load levels. Cases have been documented and re-created, using the FAE technique, where general loading of flat roofs has almost doubled the basic 50 year ground snow load due to ineffective drainage. Internal, recessed, heated drains are highly recommended to minimize the potential for structural failure. The following compares code provisions versus field measurements for one case.

Comparison of Code Provisions Including Rain-on-Snow with Field Measurement for Geographic Location with S_s=1.1 kPa (23 psf)

Measured Value	*NBCC 1990*	*ASCE 7-95*
2.0 kPa (42 psf)	1.4 kPa (29 psf)[1]	1.2 kPa (24 psf)[2]

[1] 0.5 kPa S_r added. [2] 5 psf rain-on-snow allowance added

Note: A paper describing RWDI's research work in snow loading was written by the author of this article, Peter A. Irwin of RWDI, and D. A. Taylor of the National Research Council of Canada and published in the Canadian Journal of Civil Engineering. This paper has been awarded the Gzowski Medal for 1995 by the Canadian Society for Civil Engineering.

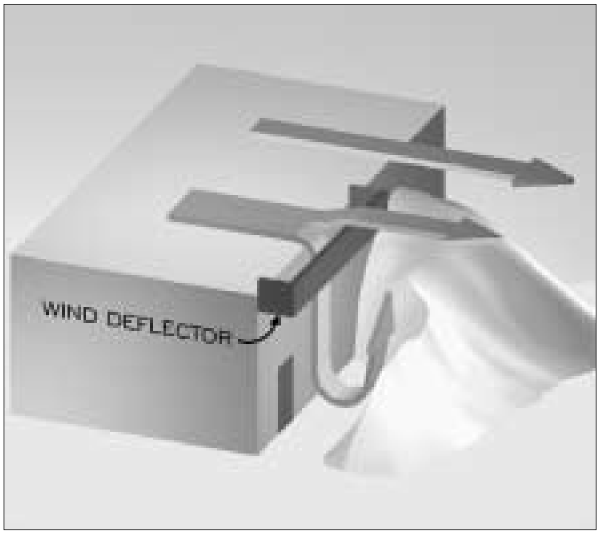

FIGURE 1: Deflected wind scours the snow clear of the door.

WORKING WITH NATURE

Wind Deflection Fins in Action

by Bill Waechter, Project Director

A building's design can be at odds with nature. Roof steps, clerestory windows, and the buildings themselves inevitably create areas of localized shelter from the wind. Nature has a way of finding wind sheltered regions and filling them with snow. Excessive snow may block ventilation louvres, windows, or doors, and increase snow loads and structural steel costs.

Roof steps and loading docks are two familiar examples of these sheltered areas. In many Arctic regions, such as those I have visited in Alaska and the Northwest Territories, main entrances and emergency exits are often in wind sheltered and drift prone areas. The end result is a door that is frequently barricaded with snow.

A wind deflection fin (deflector) is one tool that we use to assist designers to work with nature to reduce such deposition problems. Figure 1 shows snow deposition with and without a wind deflector. The wind deflector directs the approaching wind downward, increasing the local wind speed and turbulence below, which in turn causes snow to be deposited away from the door.

The wind deflector applied to the school shown in the photograph on page 4 was developed nearly two decades ago through snow simulation testing of a scale model. More recently, wind deflectors have also been developed through a review of drawings, meteorological data, and consultation with project architects.

Wind can be redirected to move more than snow. For example, a wind deflector was installed at an outdoor gun range located at the Ontario Provincial Police College in Alymer, Ontario. In this case, the concern was the outdoor range's ability to naturally ventilate the firing area of lead laden smoke from discharged firearms. Wind speeds along the firing line were measured for the most dominant wind directions by testing a scale model of the gun range in RWDI's wind tunnel.

Tests indicated that an observation building, located close to the firing line, created a wind sheltered region for several of the nearby shooting positions. To expedite solutions that were compatible with the function and aesthetics of the development, the architect participated in the wind tunnel tests. Various solution concepts were examined, including landscaping, solid walls, etc.; however, a wind deflector installed on the observation building produced the best results by creating needed wind flow through a calm area containing smoke.

Snow drifts form on either side of the entrance because of the wind deflector over the doors.

Care must be taken when using wind deflector fins. For instance, snow that is scoured from a roof step could be deposited in an area that has not been designed for higher snow loads. Taller wind deflectors generally are needed on buildings with sloped roofs as the roof peak will reduce the amount of wind approaching the deflector. In more exposed and windy sites, such as Arctic applications, too large a wind deflector can create blustery winds in front of a door. Perhaps this is a small price to pay, considering the alternative is not being able to open the door at all because of a snow drift!

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Rowan Williams Davies & Irwin Inc.
(519) 823-1311 www.rwdi.com

RWDI Anemos Ltd.
01582 470250 www.rwdi-anemos.com

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