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by D.A. Taylor

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SNOW ON SLOPING ROOFS

D. A. Taylor*

ABSTRACT

Snow loads have been measured on 11 sloping asphalt-shingled, steel and glass roofs over the last 3 to 12 years. The results indicate that snow loads and densities are lower on steeper slopes with the greatest reductions on slippery roofs. This is caused primarily by frequent sliding of the snow. Sliding snow can be dangerous. Measures to prevent sliding and the formation of icicles are discussed. Examples of problems in practice are also given.

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SOMMAIRE

On a mesuré, au cours des 3 à 12 dernières années, les charges de neige sur 11 toits inclinés en bardeaux d'asphalte, en métal et en verre. Les résultats révèlent que les charges et densités de neige sont moins grandes sur les pentes prononcées, en particulier si la couverture est glissante. Ce fait s'explique principalement par les fréquents glissements de neige. La neige tombant des toits peut être dangereuse. L'auteur examine les mesures qui peuvent être employées pour empêcher les glissements et la formation de glaçons. Il donne aussi des exemples de problèmes pratiques.

INTRODUCTION

Inclined glass and metal roofs have recently become popular on major buildings. The designer will as a matter of course allow for the snow load which accumulates on them but may not always recognize that this snow may suddenly slide off endangering people and property below. This paper discusses the results of an investigation into loads on rough and smooth sloping roofs. This is followed by a discussion of snow fences, and some examples of problems in practice.

SNOW LOADS ON SLOPING ROOFS

The National Building Code of Canada

Design snow loads on roofs in Canada are obtained as the product of a number of factors which account for slope, shape of building, and exposure to wind, etc. As early as 1941 the first National Building Code of Canada (NBC 1941) reduced the design snow loads on steeper roofs. This reduction in load evolved over the years as more measurements of loads became available, to the one used now (NBC 1985).

$$
\begin{array}{ll}
C_s = 1.0 & 0° \le \alpha \le 30° \\
C_s = 1.0 - (\alpha - 30°)/40° & 30° \le \alpha \le 70° \\
C_s = 0.0 & 70° \le \alpha \le 90°
\end{array}
$$

where C_s is the slope-reduction factor and α is the slope. Due to the lack of measurements nationwide, the NBC still does not distinguish between rough and smooth surfaces or warm and cold roofs. The appendix to the 1985 NBC does, however, allow the designer to use smaller values for slippery roofs of slope ≥15°, where snow can slide completely off the roof. However it gives no guidance on what these values should be.

Codes in Other Countries

Slope-reduction curves in use in some European countries and in the USSR though similar to Canada's, generally permit no reduction for slopes up to 20° to 30° and then define a linear reduction to zero at 60° to 75° (Ghiocel and Lungu 1975, ISO 1981). In the United States the ANSI model standard A58.1-1982 permits a special reduction for warm slippery roofs from $C_s = 1.0$ at 15° to zero at 70°; further research has been conducted (Sack and Pinkard 1986) which may lead to more reductions in future editions.

Mechanics of Sliding

Gravity encourages the mass of snow, A , on the gable roof in Fig. 1 to slide down the slope α, while the forces F, C and T restrain

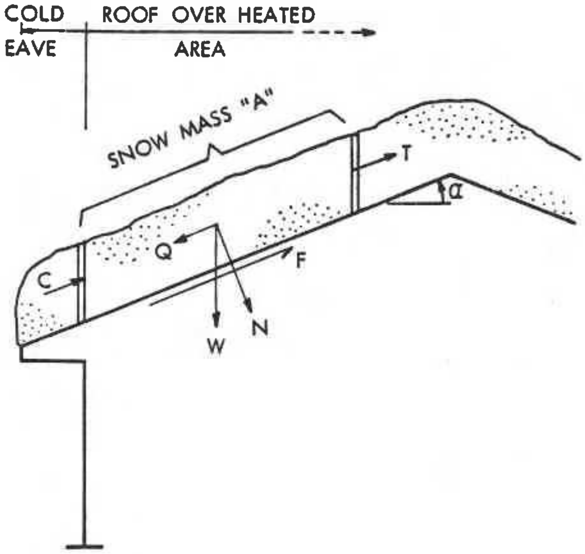

Fig. 1. Forces on the snow mass "A" on a sloping roof (C - compression force; T - tension force; W - weight; N - normal force; Q - sliding force = W sinα; F - friction force).

it. The driving force is the component Q of its own weight, W, resolved parallel to the slope (Q = W sinα). T is the tensile force due to the snow above frozen to the roof or anchored over the ridge, while C, a compressive resisting force, is due to snow and ice frozen to the cold eave below A. The resisting force F under A varies widely depending on the climate, weather, heat loss, and roughness of the roof surface. Heat loss from the building, for example, causes the 0° isotherm to move up into the insulating snow layer resulting in melting at the roof surface, and reduce the resisting force F. Then if T is reduced by a crack which penetrates the snow cover above, the compressive resistance at the eave may be overwhelmed by the unrestrained snow mass pushing from above, and sliding occurs.

NRC Experimental Study 1974-1986

In the autumn of 1974 six inclined metal and asphalt-shingled roofs were built in a sheltered wood lot at the National Research Council (NRC) Ottawa to study the influence of slope and surface roughness on the snow loads. The roofs were 2.4 x 2.4 m, north facing, sheltered from the wind, and had slopes from 0° to 60°. Three were prepainted steel and three asphalt-shingled. Over the years, as shown in Table 1 other roofs were added, including two glass roofs, each with two horizontal bevelled frames 10 mm high. The undersides of all the roofs were covered by white-painted plywood and vented to avoid heating from sunlight reflected off the snow.

Table 1. Experimental roofs at sloping roof site

Year of Installation	Green Pre-Painted Steel	Green Asphalt Shingles	Glass	Years of Record
1974	20° 35° 50°	35° 50° 60°	-	12
1977	0°	-	-	9
1979	10°	20°	-	7
1983	-	-	20° 35°	3

Snow depths were measured weekly at nine points on each roof and averaged. Density samples were taken, but not on each roof weekly, because the roofs are small and sampling disturbed the snow. The results (Fig. 2) indicate that the densities tend to decrease on steeper

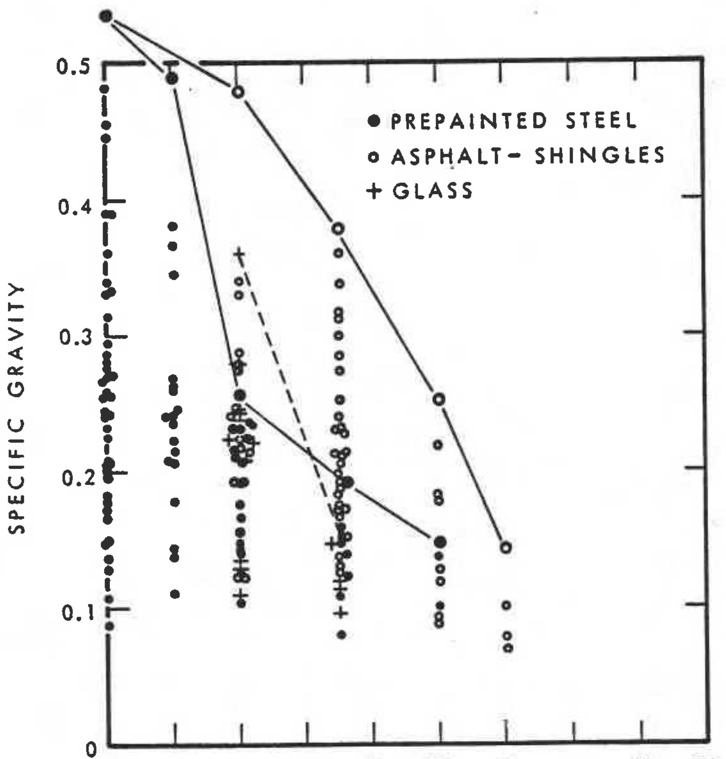

Fig. 2. Specific gravity versus slope measured on experimental roofs at National Research Council Canada over 12 winters, 1974-1986.

slopes (Taylor 1985). Why? Because snow on steeper roofs slides more often, the snow on the roof when measurements are taken is usually newer and therefore less dense. Furthermore, steeper slopes drain off rain and meltwater more readily. There is, as well, another fundamental reason. With time the snow on flat surfaces settles and increases in density. On sloping roofs, the component of deformation parallel to the slope becomes shearing or creep deformation, and the component perpendicular to the slope contributes to increased density. Hence the steeper the slope, the less the perpendicular component, and the less the increase in density or specific gravity due to settlement.

The general decline in specific gravity with slope is shown in another way in Fig. 3. These values were obtained by selecting the specific gravities corresponding to the maximum loads on the slopes. Higher specific gravities were recorded but they occurred late in the season when the loads had decreased markedly. Using only eight years of data, to 1982, Taylor (1985) reported that the decline for asphalt-shingled and steel roofs was almost linear. Now with more density data, collected over the last four years, there is more scatter. Nevertheless the trend towards lower density with increasing slope is clear.

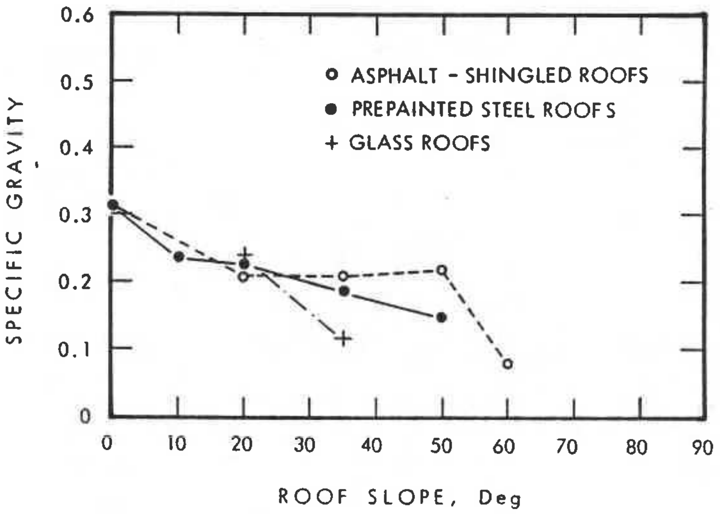

Fig. 3. Specific gravity corresponding to the maximum roof load versus slope over 12 years at National Research Council Canada, Ottawa.

When the loads computed from measured depths and densities are plotted as in Fig. 4, it is clear that they drop as slopes increase, and

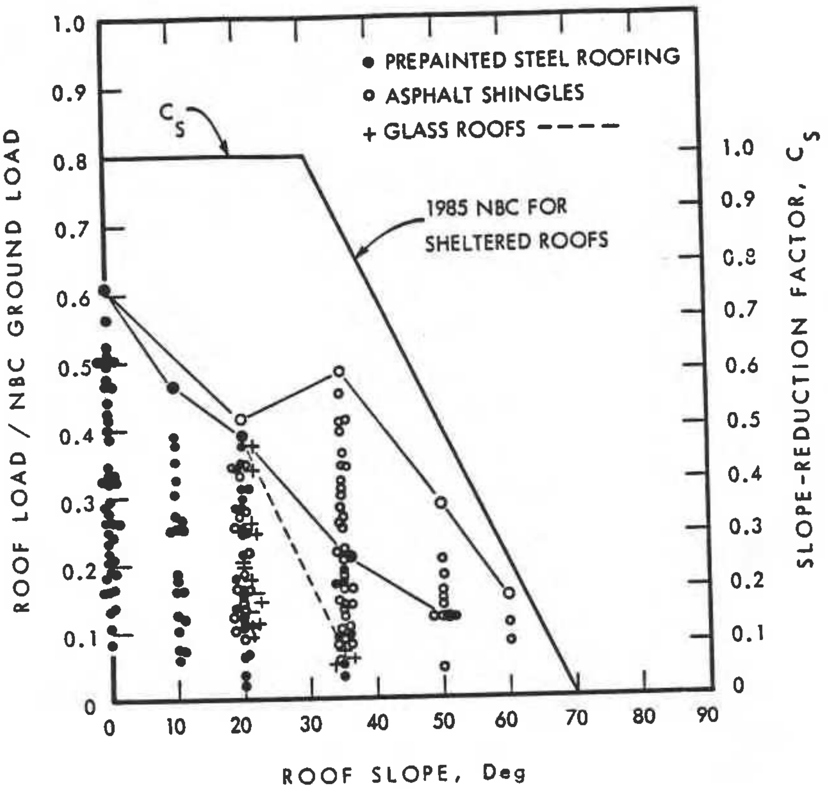

Fig. 4. Data from 1974-1986 plotted versus ratio of roof load to National Building Code ground loads. Axis on right is the slope reduction factor C_s. At 50° there were many measurements of zero snow on the steel roofs.

that loads on metal roofs decrease more rapidly than those on shingled surfaces. Preliminary indications are that snow on glass slides off earlier than on metal roofs even though the snow has to slide over two 10 mm high horizontal framing members on the glass.

What is the explanation? As the roof load, W, increases, so does the tendency to creep and slide. Sliding or shearing resistance at the roof surface (F in Fig. 1) is composed of adhesion/cohesion and friction. Though the friction component, which is a function of the angle of internal friction of the snow, may increase with increasing load, the adhesive/cohesive resistance does not. The overall shear resistance will therefore increase less rapidly than the driving force $Q = W \sin\alpha$. The result is that the ratio of roof to ground load tends to decrease as the snow continues to accumulate (Fig. 5). In other words, the more snow there is, the more likely it will slide off.

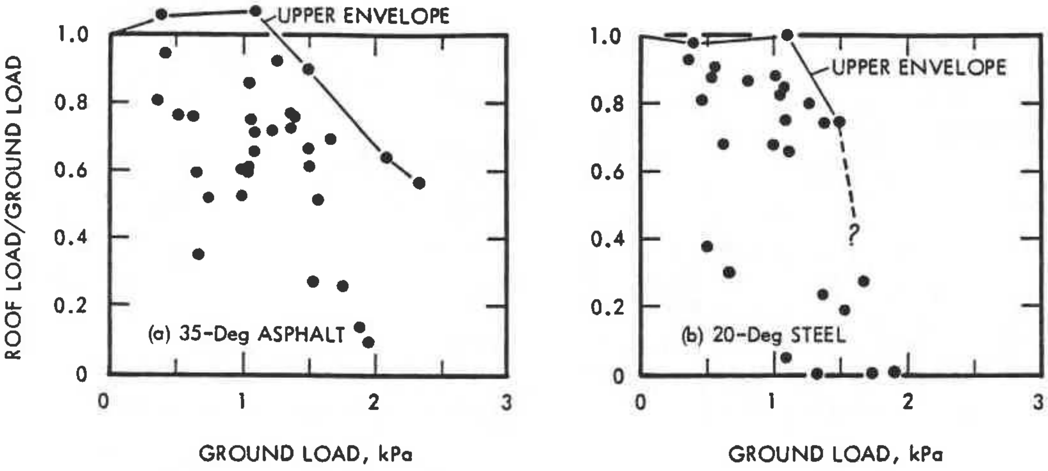

Fig. 5. Reduction ratio of roof to ground load as ground load increases.

Summary

The experimental work at the NRC test site in Ottawa indicates that snow densities and snow loads on sloping roofs decrease as slopes become steeper -- more so on slippery roofs of metal and glass than on rough ones. The slope-reduction factor C_s in the National Building Code, as it applies to Ottawa, seems to be conservative for all surfaces but particularly so for slippery ones.

PUBLIC SAFETY FROM FALLING SNOW

Falling Snow Trajectories

The danger due to snow and ice falling from a roof must be considered. Under sloping roofs, especially slippery sloping roofs, is a hazard zone which should be fenced in to avoid pedestrian access during the winter. This zone will extend from under the eave to the point of impact below of snow sliding down the roof surface under zero friction (Taylor 1983). If the assumption of zero friction is too conservative, account can be taken of the decrease in acceleration of sliding snow due to friction at the roof-snow interface. The decrease is from $g \sin\alpha$ to $g(\sin\alpha - \mu\cos\alpha)$, where g is the acceleration due to gravity and μ, the coefficient of sliding friction (Taylor 1983). Generally, however, the coefficient of friction is quite low on smooth surfaces (Langham 1981).

Snow Fences/Barriers

As there is no space for a fenced off area around many buildings, snow fences or barriers of some kind are often considered to prevent the snow from falling. The author has observed multiple rows of fences across a steeply sloping roof at Whistler, B.C. but normally a single fence near the eaves suffices. The failure of a snow fence may result in danger below; it may also damage the loadbearing structure of the roof and rip the roof cladding. For this reason snow fences must be designed to avoid buckling, overstressing and undue deformation under vertical and lateral loads. This includes careful consideration of how the forces on them are to be carried into the structural members supporting the roof and ultimately to the ground. The horizontal members of a snowfence should have enough clearance under them to allow for drainage without the ready passage of snow and ice (2 to 3 cm). Because the snow will fail at the roof/snow interface on most moderate inclines (<25°) (Schaerer 1981), a low fence, 15 to 30 cm high, will probably suffice. On steeper roofs there is a possibility that the snow could fail in shear, at the top of the fence, for example. Then the snow above the fence could slide off. In any case, the designer should check that a snow fence/barrier will not cause more snow to accumulate than the roof can safely support.

The forces imposed on obstructions by snow trying to slide can be large. For example the force on a snowfence at the eave of a 6 metre long 4 in 12 roof covered uniformly with 60 cm of snow, of density 2.4 kN/m^3, could be as high as 2.7 kN/m (185 lb/ft).

Icicles and Ice

The use of a snowfence may only exchange one problem for another. If snow is retained on a slope, it will eventually melt, or at least melting will occur at the roof/snow interface of a heated building, without a well ventilated attic, because of the insulating value of the snow. Although a well insulated roof will accumulate snow without melting, eventually the insulating value of the snow, as it piles up, will shift the 0°C temperature line up to the roof surface. The resulting meltwater will run down the roof, to form an ice dam if the eave is cold (Baker 1967), and icicles, which are a hazard! They may be avoided by using a snowfence and a heat-traced gutter to carry away the meltwater. On the other hand, if the drip at the eave is heated, icicles will not form on it and use of a gutter is avoided.

Sloping glass roofs over marginally heated or sunlit spaces may pose particular problems because of the rate of heat loss through them. When a snow fence is used, the snow retained on the slope may melt during the day and convert to ice at night. During the day this ice will extrude under the bars and around the posts of the fence and pose a danger below. A heated gutter at the eave or a canopy below may be the only feasible protection.

CASE HISTORIES

1. The first is from a roof in western Canada where the membrane on the flat roof was damaged and the parapet destroyed (Fig. 6). The sloping portion of the roof was of metal at 45°; it ended at a flat section covered with a membrane which was underlain by insulation and a metal deck. Heat loss from the building caused the breakdown of resisting forces on the sloping section, leading to the heavy vertical and horizontal forces shown at the bottom of the slope. The vertical forces damaged the underlying structural metal decking and the horizontal forces caused the parapet to fail. Then the icy underside of the snow, moving slowly down the slope, gouged the membrane as it traversed the flat portion of the roof.

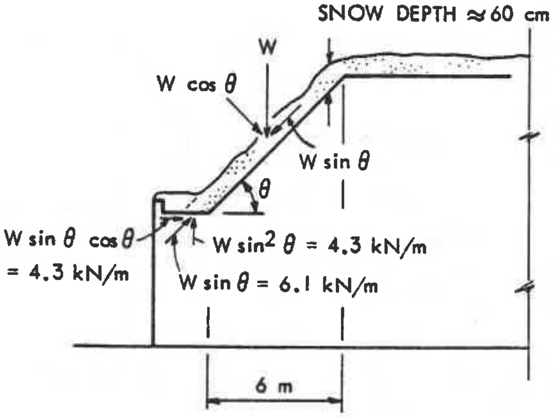

Fig. 6. Forces applied to a flat roof and parapet by snow on a 45° metal roof (snow density = 2.4 kN/m^3).

2. In another case the designer of a multistorey office tower realized, as the structure was being built, that the bevelled roof/wall intersection around an equipment room (Fig. 7) might cause problems.

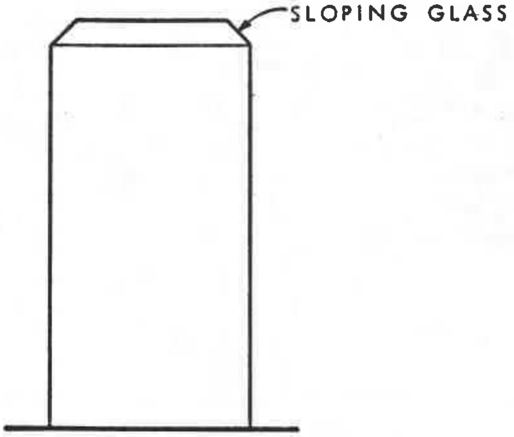

Fig. 7. High-rise building showing 45° sloping glass around top of building.

Where would falling snow or ice land after dropping many stories? How could sliding be avoided? There were sidewalks around three sides of the building. One possibility was the use of a heated gutter with a high outer lip strong enough to prevent the snow from sliding, while another was to remove the insulation behind the sloping glass and direct excess building heat to the area to prevent accumulation of snow. Other less palatable solutions, at that stage, were to redesign the roof using a setback and strong parapet at the bottom of the slope, or to get rid of the sloping portion entirely. It is not known what the designer decided to do.

3. Modern convention centres occasionally have sloping glass or metal roofs over plazas, parking lots or even lower (glass) roofs. Some of these have proven to be a problem as the danger due to sliding snow was not recognized until the structures were nearly finished. Retrofitting architecturally acceptable snow fences to these very large buildings was an enormously challenging and expensive task. One centre required more than one kilometre of fence.

4. Some high glass-covered atria on shopping centres and tall mixed-use buildings in North America have had such problems with sliding snow that the mullions were heat-traced and the glass kept warm to prevent the accumulation of any significant amount of snow and ice on them.

5. In an unusual case in 1986 snow slid down a 30 metre long roof of about 10° slope that was covered with a new smooth plastic membrane. The low parapet at the end of the slope was damaged as the snow mounted it and fell to the ground.

6. In a final case that can be discussed in some detail, a large burnhall at the new National Research Council Fire Research Station not far from Ottawa, had some serious trouble due to sliding snow in 1983. The building is an unheated gable roofed building, 60 metres wide, with a steel roof of 4 in 12 slope. In December 1983 a 20 cm fall of heavy snow occurred without wind, followed by two days of temperatures above freezing. During the night the burglar alarm brought police to the building to observe snow sliding slowly out over the eaves, breaking off, and falling 12 metres to the ground. The snow was landing in a long triangular pile below the eaves, and as new chunks fell some hit the pile and deflected towards the building. The steel siding along both sides of this large building was dented.

Summary

Designers should recognize and avoid situations where sliding snow or ice will compromise public safety. If snow fences are required to keep snow and ice on a roof, they must be designed to transmit the substantial forces involved into the building structure. Heated gutters (or drips) may also be required to prevent the growth of icicles. Other solutions include heating the sloping surface by dumping excess heat from the building under the surface or by using heating cables.

CONCLUSIONS

1. Measurements made on 11 sloping roofs in a sheltered experimental site in Ottawa show that snow densities on inclined roofs decrease as slopes increase and that loads decrease as slopes increase or as roughness decreases.
2. Slope-reduction equations in Codes should account for surface roughness.
3. Designers should be vigilant and avoid situations where snow or ice sliding off a roof would be dangerous to people and property below. Fenced off `hazard zones', snow fences/barriers at the eaves, heated gutters, and heated roofs are some of the approaches which may provide the required safety.
4. Snow fences/barriers are part of the building structure and should be designed as such.

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REFERENCES

ANSI. 1982. Minimum design loads for buildings and other structures. ANSI A58.1-1982. American National Standards Institute, Inc., 1430 Broadway, New York, NY, 10018, 100 p.

BAKER, M.C. 1967. Ice on roofs. Canadian Building Digest 89, Division of Building Research, National Research Council of Canada, Ottawa, 4 p.

GHIOCEL, D., and LUNGU, D. 1975. Wind, snow and temperature effects on structures based on probability. ABACUS Press, Tunbridge Wells, Kent, England, 411 p.

ISO. 1981. Bases for design of structures--determination of snow loads on roofs. ISO 4355-1981(E). International Organization for Standardization, Standards Council of Canada, 18 p.

LANGHAM, E.J. 1981. Physics and properties of snowcover. In Handbook of Snow - Principles, Processes, Management and Use, Gray, D.M. and Male, D.H., eds., Pergamon Press Canada Ltd., Willowdale, Ontario, pp. 275-337.

NATIONAL BUILDING CODE 1941. National Research Council of Canada, Ottawa, Ontario, NRC 1068, p. 162.

NATIONAL BUILDING CODE 1985. National Research Council of Canada, Ottawa, Ontario, NRCC 23174, p. 162.

SACK, R.L. and PINKARD, J.J. 1986. Probabilistic prediction of snow loads on sloped roofs. Proceedings of 54th Annual Meeting of the Western Snow Conference, Phoenix, Arizona, April 15-17, pp. 41-50.

SCHAERER, P.A. 1981. Avalanches. In Handbook of Snow - Principles, Processes, Management and Use, Gray, D.M. and Male, D.H., eds., Pergamon Press Canada Ltd., Willowdale, Ontario, pp 475-518.

TAYLOR, D.A. 1983. Sliding snow on sloping roofs. Canadian Building Digest 228, Division of Building Research, National Research Council of Canada, Ottawa, Ontario, 4 p.

TAYLOR, D.A. 1985. Snow loads on sloping roofs: two pilot studies in the Ottawa area. Canadian Journal of Civil Engineering, 12(2), pp. 334-343.