

# SNOW LOADS FOR THE DESIGN OF ROOFS IN CANADA

By

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Structural engineers are well aware of the dangers created by heavy snow loads on roofs and need not be reminded that these loads must be recognized in design. It is difficult, however, for the engineer or code writer to strike a balance between safety and economy. In most areas of Canada the magnitude of the design snow load governs the structural design of the roof and therefore has considerable influence on the cost of construction. Thus it is that design snow loads play an important role among the design loads specified in any Canadian building code such as the National Building Code of Canada (1,2). Stated in general terms, the object is to select a design load that is high enough to reduce the probability of failure to an acceptable level but not so high that unnecessary and unreasonable costs result.

The amount and distribution of the snow load that accumulates on roofs depends on many factors: geographical location (climate), wind exposure (or shelter) of the roof, and shape and type of roof. It is the purpose of this paper to describe how these factors affect snow loads and how they were taken into account in the development of design snow loads for the National Building Code of Canada.

The wide variations of climate in Canada produce wide variations in snow load conditions across the country. Coastal regions (both Atlantic and Pacific), because of frequent thaws during the winter, are characterized by snow loads of short duration, often caused by a single storm. The mountainous regions of British Columbia and Alberta experience the heaviest snow loads in the country, lasting the entire winter and varying considerably with elevation. Prairie and northern regions have very cold winters, with small annual snowfalls; but owing to frequent strong winds there is considerable drifting of snow on both roofs and the ground. Finally, the central region, including Ontario and Quebec, is marked by varying winds and snowfalls and sufficiently low temperatures to allow snow accumulation all winter.

In perfectly calm weather falling snow will cover roofs and ground with a uniform blanket of snow. Truly uniform loading conditions, however, are rare and have been observed only in certain mountain valleys and areas where roofs are well sheltered. In contrast, snowfalls in most regions are accompanied or followed by winds, resulting in removal of snow from some areas and accumulation in others. Many roofs are so exposed that little snow stays on them; other roofs or parts of roofs over which wind speed is slowed down sufficiently by vertical projections or elevation changes to let the snow "drop out," allow snow to accumulate in drifts as it would behind snow fences.

Two examples will illustrate the severity of the drift loads that may occur: (1) In 1962, a snow drift 14 ft deep with a maximum load of 260 psf caused the collapse of a low flat roof adjacent to a large higher roof near Montreal, P.Q. The ratio of the maximum drift load to ground load was 6:1. (2) In 1969 maximum loads of 238 and 221 psf were measured on one-storey lean-to roofs east and west of a large high roof of a hanger in Quebec, P.Q. (Figure 1). The ground snow load was approximately 54 psf, and the upper roof was virtually clear of snow. This example illustrates clearly the need in Canada to consider all wind directions.

Various factors other than wind may modify or redistribute snow loads on roofs. Solar radiation and heat loss through roofs are effective under certain conditions. In very cold weather solar radiation has little effect in reducing loads, but heat loss through the roof can cause melting, depending on the thermal design of the roof and the depth of snow. During thaws and toward the end of the winter, when the air temperature rises nearer to the freezing point, both solar radiation and heat loss contribute to melting. This may reduce the load considerably if good drainage for the melt water is provided.

Redistribution of snow load can occur on sloped roofs from melting and subsequent refreezing near the eaves and on overhangs, or from drainage of melt water onto a lower roof where it refreezes or is retained in the snow. On flat roofs melt water tends to flow

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into the lower areas in the centre of bays where the snow has produced maximum deflection in the roof member, particularly when the drains are located near columns,



Figure 1. Example of a deep drift (max load = 238 psf) on a flat one-storey roof west of a large flat roof in Quebec City. A similar roof east of the building also carried a deep drift (max load = 221 psf). (Photo courtesy of M. Drouin.)

Even more serious than the problem of melt water on sloped and adjacent lower roofs is the condition of snow sliding from a high roof onto a lower one. A very high additional load is produced on the lower roof, while a reduction of load on the upper roof occurs.

#### Survey of Snow Loads on Roofs

In the 1953 NBC<sup>(1)</sup> design roof loads were considered to be equal to the ground snow loads, with a reduction allowed only for sloped roofs. Superficial observations, however, indicated that snow depths on roofs were appreciably different from those on the ground and it became apparent that ground snow depths were not directly applicable to the determination of roof snow loads. It was also realized that this simple approach resulted in over-design of some roof areas (with accompanying unnecessary costs) and under-design of others (leading to undue risk of failure).

Recognizing these criticisms and appreciating the influence of snow loads on the cost of construction, the Division of Building Research of the National Research Council in 1956 inaugurated a countrywide survey of snow loads on roofs in order to provide the information on which to base a more rational design snow load. The Division established more than 50 observation stations across Canada where snow depth and density measurements were taken once a week and immediately following major snowfalls on the ground and for a variety of roofs and exposures. The roofs were both flat and sloped and varied in size from those of single-family dwellings to those of aircraft hangars over 120,000 sq ft in area. Snow depths on the roofs were usually measured by means of mounted gauge sticks (Figure 2) and on the ground with a yard stick. Density was determined by taking samples of a known volume of snow (Figure 3) and weighing the melt water.

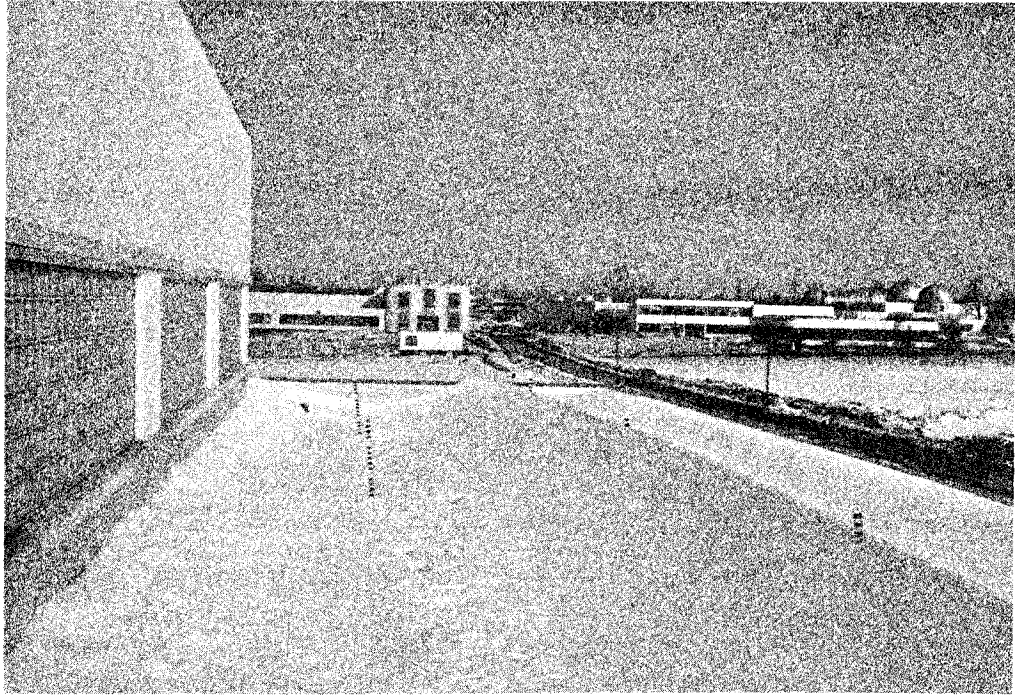


Figure 2. 3-ft gauges installed on flat roof for snow depth observations. Unusual accumulation away from wall resulted from wake produced by lower roof (wind blowing from the right).



Figure 3. Observer taking snow density samples on a roof for DBR snow load survey.

Additional observations were made on roofs other than those under regular observation in order to gather information on unusual snow load accumulations. Roof failures due to snow loads were also studied when possible. Although the number of failures was considerable, what was really surprising was how many structurally inadequate roofs survived year after year. The survey provided evidence that many roofs are seldom subjected to their full design load because of the beneficial effects of wind, heat loss, solar radiation, and even shoveling.

### Results of Survey

The survey confirmed the early indication that average snow loads on the majority of roofs are considerably lower than the true ground load; and that the ratios of roof load to ground load depend primarily on the degree to which a roof is sheltered from wind. The effects of shelter, are, however, difficult to predict exactly. Well sheltered roofs had ratios up to approximately 0.9, whereas nearly all unobstructed roofs had ratios of less than 0.6. Well exposed, unobstructed roofs in generally open areas had ratios of less than 0.3.

Heavy drift loads, on the other hand, were found in roof areas having localized shelter. The peak load in the drifts exceeded the ground load at the time by factors of up to 12. The magnitude of the drift load depended on, among other things, the shape of the building, snowfall, size of the "tributary roof area" (i.e. area of roof contributing the snow for the drift process) and the height of the localized shelter.

The general survey, having provided a basis for the revisions of the snow load requirements in the NBC, was discontinued in 1967 in favour of two more specialized studies concentrating on the problems of snow loads on large flat roofs and snow loads in mountains.

### Present Requirements for Snow Loads on Roofs in Canada.

In the 1970 edition of National Building Code of Canada<sup>(2)</sup> the minimum design snow load on a roof is obtained by multiplying the ground snow load for the municipality or area considered by the snow load coefficient (shape factor) applicable to the particular roof area considered.

### Ground Snow Loads

Observations of snow on the ground were used as an indicator of precipitation in the form of snow to provide the basis for roof loads. Records of annual maximum depths of snow on the ground were available from over 200 stations of the Meteorological Branch of the Department of Transport for periods ranging from 12 to 20 years. These recorded depths were assembled and analysed by an extreme value method developed by Gumbel to determine the ground snow loads for all of Canada<sup>(3)</sup>. At each station the snow depth that will probably be equalled or exceeded, on the average, once in 30 years was obtained. Maximum snow loads nearly always occur immediately after an unusually heavy snowfall, when a large proportion of the snow has a low density. (Freshly fallen snow has a specific gravity of about 0.05 to 0.1, compared with that of old snow which has a specific gravity of 0.2 to 0.4). A relatively low value of 0.2 for specific gravity was therefore used to calculate ground snow loads.

Because the heaviest snow loads often occur when an early spring rain falls into and is retained by snow cover, the ground snow loads were increased by the maximum 24-hour rainfall for the period of the year when snow depths are greatest. Ground snow loads calculated in this way are shown on a map (Figure 4) in Supplement No. 1 to the National Building Code of Canada, "Climatic Information for Building Design in Canada"<sup>(4)</sup> and in a table giving specific values for cities and larger towns. The map applies mainly to permanently populated areas because most of the weather observations used in preparing the map were taken in inhabited locations. This is particularly significant in mountain areas where the lines of the map apply only to populated valleys and not to the mountain slopes where, in some cases, much greater snow depths are known to accumulate and must be taken into account in the design of roofs.

### Snow Load Coefficients

Based on the results of the survey of roof loads, the basic snow load coefficient

(i.e. for flat roofs in sheltered locations) was set at 0.8 by the committee responsible for the revision of Section 4.1 of the NBC "Loads and Structural Procedures." This basic snow load coefficient must be modified (increased or decreased) by the designer to account for the following influences:

- (a) decrease of snow loads because of the effect of slope for roof slopes exceeding 30 deg;
- (b) accumulation of non-uniform snow loads on gable and hip roofs;
- (c) accumulation of non-uniform snow loads on arched and curved roofs;
- (d) accumulation of increased snow loads in valleys of butterfly and multispan curved or sloped roofs;
- (e) accumulation of increased non-uniform snow loads due to drifting snow on the lower of two-level or multi-level roofs such as canopy, marquee or porch roofs, provided the upper roof is part of the same building or of an adjacent building not more than 15 ft away;
- (f) the accumulation of increased non-uniform snow loads on areas adjacent to roof projections such as penthouses, large chimneys, ventilating equipment;
- (g) the accumulation of increased snow or ice loads from snow sliding or melt water draining onto these areas from adjacent roofs sloping towards them.

#### Reduction of Snow Load for Exposed Roofs

The survey showed that in most areas of Canada, where a roof or part of a roof is fully exposed to wind, part of the snow is blown off under most conditions. Snow load coefficients may therefore be reduced by 25 per cent for such exposed roofs. This reduction should be used only if:

- (a) the roof is not shielded from the wind on any side and there is no likelihood that it will become shielded by obstructions higher than the roof for a distance of  $10h$  from the building (where  $h$  is the height of the obstruction above the roof level); and
- (b) the roof does not have any projections such as parapet walls that prevent snow from being blown off.

#### Alternating Strip Loading

A roof and its structural members subject to snow accumulations must be designed for full load distributed over the entire area or full load distributed on any portion of the area and zero load on the remainder of the area, whichever produces the greatest effect on the members concerned. Even on areas not subject to drift accumulations snow very seldom accumulates perfectly evenly. Consequently, because certain structural members (such as certain diagonals of trusses) are subject to stress reversals or are otherwise sensitive to changes in load distribution, non-uniform loading must always be considered by the designer in addition to uniform loading.

#### Guidance for the Designer

Snow load distributions and coefficients,  $C_s$ , for various common roof shapes are given in Figure 5 as extracted from Supplement No. 4, to the 1970 edition of the National Building Code of Canada "Canadian Manual for Structural Design"<sup>(5)</sup>. It should be noted that the provisions of the Supplement are not mandatory but merely recommended information providing guidance for the designer who is responsible for making the best possible estimate of the probable snow load.

As many unusual types of roofs and conditions must be considered, it may be necessary for the designer to resort to special information such as wind tunnel experiments or other model tests, special theoretical studies, and local experience to provide adequate design values. A collection of case histories of interesting snow loads has been published by DBR/NRC<sup>(6)</sup> to provide further guidance.

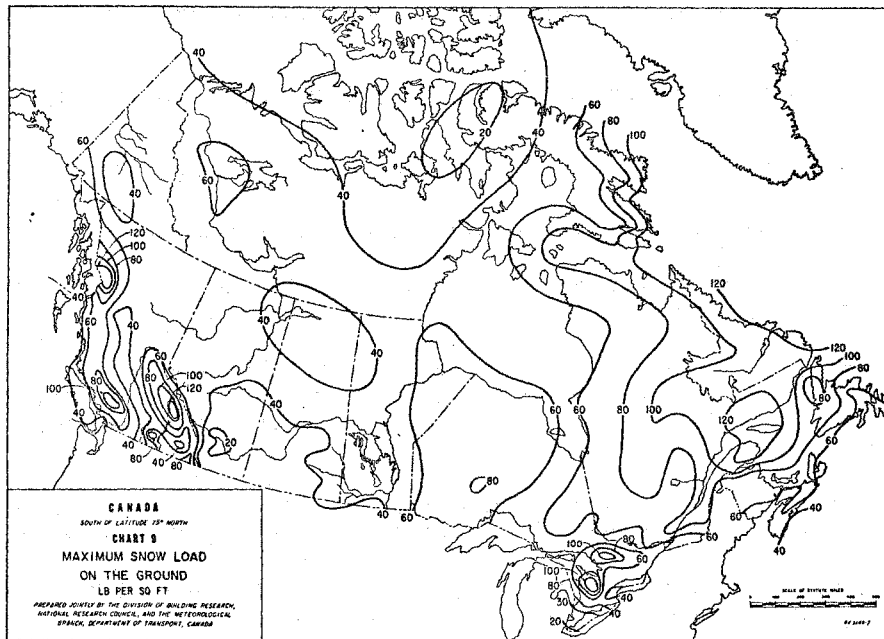


Figure 4

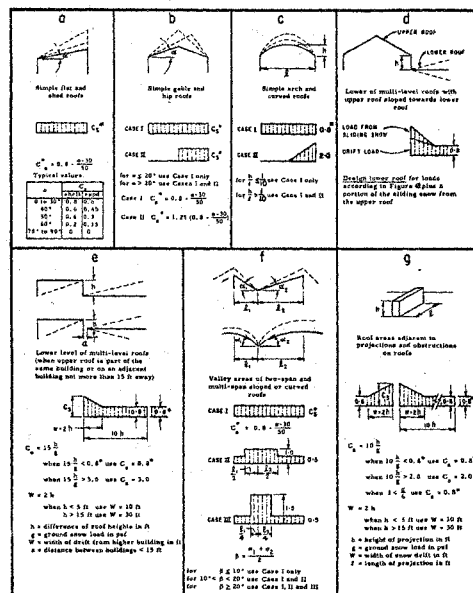


FIGURE 5 - SNOW LOAD DISTRIBUTIONS AND COEFFICIENTS FOR SNOW LOADS ON SOME COMMON ROOF SHAPES.

NOTE: For exposed roofs all values of  $C_s$  marked with an asterisk (\*) may be reduced 25 per cent.  
All load distributions shown in these figures are to be applied as strip loading (full and zero load).

The term  $\frac{\alpha - 30}{50}$  is valid only for  $\alpha$  greater than 30 deg

NR 3782

## Conclusions

In Canada snow loads are the most important loads with regard to the safety and economy of roof structures. Determination of proper design snow loads in accordance with the National Building Code of Canada may be broken down into two parts:

- (a) selection of a suitable snow load on the ground (including a certain amount of rain load) on the basis of statistical evaluation of meteorological data; and
- (b) modification of the load by means of snow load coefficients to represent the actual conditions of snow accumulation on roofs of simple and complex shapes.

This more rational approach to snow loads for the design of roofs has been made possible by the 10-year countrywide survey of actual snow loads on roofs completed in 1967. Recognizing the need for still further research on snow loads, DBR/NRC is now carrying out two more specialized studies on the problems of snow loads on large flat roofs and snow loads in mountains.

This paper is a contribution from the Division of Building Research, National Research Council of Canada, and is published with the approval of the Director of the Division.

## References

- (1) National Building Code of Canada, Section 4.1 "General Requirements," Associate Committee on the National Building Code, National Research Council, Ottawa, 1953.
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