PANEL DISCUSSION ON SNOW LOADS

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INTRODUCTION

by N. Isyumov

Two papers dealing with roof snow loads and their predictions were presented at the 33rd Eastern Snow Conference at Glens Falls, New York. These papers stimulated interest and discussion both during and after the formal conference program. An informal meeting took place outside the conference program to discuss full scale roof snow load measurements planned at that time by the U.S. Army Cold Regions Research and Engineering Laboratory and to exchange information. This interest by members of the Eastern Snow Conference and the current activities in the area of snow load evaluation and specification in the U.S.A. and Canada have prompted the organization of this panel discussion. The specific objectives of the panel are as follows:

i) to review current approaches to the establishment of suitable snow loads with emphasis on U.S. and Canadian practice;

ii) to outline current problem areas and those associated with future codification; and

iii) to identify areas for future research.

We are fortunate to have assembled a panel whose members are active in this area and whose interests and expertise include research, engineering practice and codification. In reviewing current practice and outlining problem areas and future research needs, the panel hopes to generate interest among members of this conference and to stimulate research efforts which may contribute towards furthering our understanding of this field. It is furthermore felt that the Eastern Snow Conference can provide the proper forum for future exchanges of ideas and information and thus encourage U.S. – Canadian joint efforts towards improving snow load specifications.

The program for the panel discussion comprises prepared presentations by members of the panel, in the sequence summarized below, and followed by an open discussion. Contributions by the individual panel members and written contributions from the floor as well as the responses from the panel, are presented below.

SEQUENCE OF PANEL DISCUSSION

	Subject	Panel Member	Affiliation
1.	Historical Development of Ground Snow Loads in Canada	D. W. Boyd (meteorologist)	Canadian Atmospheric Environment Service National Research Council
2.	Snow Loads on Building Structures – Comparison of Selected U.S. Standards, Model Codes and U.S. Federal Standards	R. Crist (civil engineer, standards)	National Bureau of Standards
3.	Relationship Between Roof and Ground Snow Loads – New NBC Specifications – Problem Areas	W. R. Schriever (civil engineer, standards)	National Research Council of Canada
4.	Update on Snow Load Research at CRREL	W. Tobiasson and R. Redfield (civil engineer and mathematician)	U.S. Army CRREL
5.	Statistical Techniques for Predicting Extreme Ground Snow Loads; Advantages of Lieblein Extreme Value Distribution	D. Dunlop (meteorologist)	Rutgers University
6.	Alternative Method for Predicting Roof Snow Loads and their Variability	N. Isyumov (civil engineer, research)	Boundary Layer Wind Tunnel Laboratory University of Western Ontario
7.	Open Discussion		

HISTORICAL DEVELOPMENT OF GROUND SNOW LOADS IN CANADA

by Donald W. Boyd

Design snow loads have undergone several changes in the last 35 years and to put our discussion in perspective it might be a good idea to review these developments.

In 1941 when the first National Building Code of Canada was published there were no routine measurements of the total depth or the water equivalent of the snow on the ground or on roofs. The daily snowfall was being measured and these values were added up month by month and averaged snowfalls computed for each month of the year. These were the only readily available snow statistics, and the problem was to find some way of using them to estimate ground snow loads. The snowfall in a severe winter would of course be much more than this average so they doubled the sum of the average snowfalls in January, February and March, added a bit to allow for rain and called that the design snow load. This procedure may have been rather crude but at least it was better than guessing.

That same year (1941) some weather stations started routine measurements of the total depth of snow on the ground. In 1952 Morley Thomas searched these records for the maximum reported depth at each station. He assumed a specific gravity of 0.2 for the snow, added the maximum one-day rainfall and called that the design snow load.

By 1961 there were enough data to make a statistical analysis feasible. The type I extreme value distribution was fitted to the annual maximum snow depths for each station and used to compute the 30-year return period snow depth. This was used instead of Thomas' "maximum recorded" value.

About this time the National Building Code of Canada first recognized that average roof loads were much less than ground loads but that for some roof shapes the roof loads were considerably greater. The ground snow load was therefore adjusted to provide more rational roof loads. These adjustments have been greatly improved over the last 15 years, and I expect Mr. Schriever will say something about this.

I shall deal only with the basic snow load on the ground. There are several problems in arriving at a reliable value. These include the value assumed for the specific gravity and the allowance for rain, but I believe the most important is the unreliability of many of the basic measurements of the depth of snow on the ground.

There are now over 30 years of data available for some stations, and this is very fortunate, but for most of the 500 stations the records are much shorter. At many stations the records are broken, that is they observe snow depths for part of a winter but miss one month which could be the month with maximum depth. It is thus often hard to decide whether to use a particular value.

In compiling tables of normal temperature or precipitation is is common practice to compute the averages for a standard 30-year period, such as 1941 to 70 and to discard years with significant amounts of missing data and to ignore stations with records much shorter than 30 years. If we applied the same criteria to depths of snow on the ground we would be discarding 70 to 80 per cent of the data.

At many locations where buildings are being constructed there are no measurements at all. Snow loads have been estimated for about 400 such locations but there is no way of telling how accurate they are except by waiting many years.

There is no reason to expect any sudden improvement in snow load computations in the future. Continuous measurements of snow depths (or better still, water equivalents) for many years will be necessary to provide really reliable ground snow loads. Computations based on daily snowfall, temperature, wind, humidity and solar radiation might provide reasonable estimates of the snow load on the ground if all these elements were available. However, the stations with records of all these elements are the same stations for which we already have the best and longest records of snow depths.

Measurements of water equivalents and a larger number of stations would be desirable, but more continuous records from the present stations would be even better. In the meantime we can only continue to make the best possible use of the available data by carefully considering the acceptability of every measurement.

SNOW LOADS ON BUILDING STRUCTURES – COMPARISON OF SELECTED U.S. STANDARDS, MODEL CODES AND U.S. FEDERAL STANDARDS

by Robert Crist

It would indeed be a formidable task to compare all of the building code provisions in the United States. It is possible, however, to make a reasonable comparison of the minimum load recommendations for snow loads by selecting frequently used source documents for the codes, the legal and binding documents adopted by regulatory agencies such as, state, city or the Federal government. Standards and model codes are source documents which are an assimilation of technical information that can be used for design and regulation. Many times model codes and standards are used directly by reference and other times by rewording or reformating to suit the needs and requirements of the code-writing body. Both standards and model codes will be used in this discussion.

The basic comparison document for this paper is the American National Standards Institute (ANSI) Standard A58.1-1972, Building Code Requirements for Minimum Design Loads in Buildings and Other Structures. In order to build the comparisons, the basic elements of the snow load provisions need to be discussed. The snow load provisions of this Standard are modelled after the National Building Code of Canada snow load provisions of 1965 with applicable modifications to the United States.

The ANSI A58.1-1972 Snow Load provisions consist of the following major elements:

1. <u>Minimum load table for roofs</u>

   This provides a simple reference for roofs the design of which is not generally controlled by snow load. However, the snow loads may not be less than the provisions of this table.

2. Ground snow load

Ground snow loads are presented in the form of isoline maps for three mean recurrence intervals, 25-, 50- and 100-years. The selection of the mean recurrence interval depends on the building use. The 25-year recurrence interval is specified for unoccupied buildings, the 50-year interval for permanent structures, and the 100-year interval for buildings with a high degree of hazard to life and property in case of failure. The isoline maps cover approximately 75% of the geographic area of the United States. Special consideration has to be given to the western part of the United States (Sierra Nevada and Rocky Mountain ranges) for snow accumulation in mountainous areas.

3. Transformation of ground snow load to load on the building structure

The transformation is the following form:

$$Q = C_S^* g$$

where Q is the transformed snow load, g is the ground snow load and C_S^* is a transformation factor that accounts for items such as thermal resistivity of the roof and melt off, wind exposure, roof geometry and unusual conditions such as sliding.

4. Load combinations

Loads in combination with snow load are specified in four different combinations as follows:

$$D + L$$
$$.75\,(D + L + W)$$
$$.75\,(D + L + T)$$
$$.66\,(D + L + W + T)$$

where

D = dead load
L = snow and occupancy load
W = wind load
T = thermal load

The coefficients applied to the load conbinations are probability factors. All load combinations are considered as working stress load combinations. There is no allowable increase for stress in the structures when a probability factor of less than unity is used.

For demonstrative purposes a comparison is made between the snow loading at Sault Ste Marie, Michigan as required by A58.1-1972 and by the National Building Code of Canada 1975. Table I shows the requirements for a flat roof for mean recurrence intervals of 25-, 50- and 100-years (ANSI A58.1-1972) and 30 years (National Building Code [NBC] of Canada 1975).

It is seen that the 30-year mean recurrence interval load of the NBC 1975 appears to correspond to the 100-year mean recurrence interval load of ANSI A58.1-1972. It should be noted, however, that the isolines of the NBC ground snow load incorporate a 1-day maximum rainfall (assumed to be frozen rain) superposed on the snow. This may account for a significant portion of the difference of the two loadings. Even though this single comparison is not conclusive, it does demonstrate the need for co-ordination and agreement in the concepts for snow loadings on building structures.

TABLE 1

COMPARISON OF ROOF LOADS

Reference	Mean Recurrence Interval Years	Ground Load (1) psf	Exposure			
			Shielded		Unshielded	
			C_s^*	Roof Load (1) psf	C_s^*	Roof Load (1) psf
A58.1-1972	25	45	0.8	36	0.6	27
NBC 1975	30	60	0.8	48	0.6	36
A58.1-1972	50	50	0.8	40	0.6	30
A58.1-1972	100	60	0.8	48	0.6	36

(1) 1 psf = 47.880337 N/m^2

For further comparative purposes, the following representative U.S. model building codes and U.S. Federal standards were selected.

Model Codes

1. Standard Building Code 1976 (Southern)
   (Southern Building Code Congress, International)

2. Uniform Building Code 1976 (UBC)
   (International Conference of Building Code Officials)

3. The BOCA Basic Building Code 1975 (BOCA)
   (Building Official and Code Administrators, International)

4. The National Building Code 1976 (AIA)
   (American Insurance Association)

Federal Standards

1. HUD Minimum Property Standards 1973 (MPS)
   (U.S. Department of Housing and Urban Development)

2. Design Manual – Structural Engineering NAVFAC DM-2 1970
   (U.S. Department of the Navy, Naval Facilities Engineering Command)

In this brief comparison, it would be difficult to show all differences between these documents and A58.1-1972. However, there can be pointed out some significant trends and major differences to provide perspective of the inconsistencies.

Three out of four of the model building codes use the principles and terminology of A58.1-1972. The UBC is the exception which does not give any specific provisions for snow loading and designates the responsibility of snow loading to the building official. The lack of loading criteria in the UBC is further complicated by the lack of ground snow load information in A58.1-1972 in the areas of the western United States (Sierra Nevada and Rocky Mountain regions) where the UBC is primarily used. One of the Federal standards, the MPS, uses A58.1-1972 by direct reference without exception. However, the NAVFAC DM-2 deviates in concept form the A58.1-1972 as it does not use the transformation of the ground load to the roof load. Five out of six of the standards and model codes provide minimum load tables which are similar to the A58.1-1972 minimum load table except that the UBC provides a more extensive table with an alternate loading procedure and special roof types. The NAVFAC DM-2, however, does not provide a minimum load table.

Some of the outstanding differences appear in the use of the mean recurrence interval. The BOCA specifies three mean recurrence intervals depending on occupancy type. The Standard and National Building Codes specify one mean recurrence interval. No mean recurrence interval is specifically given in the UBC. The NAVFAC DM-2 specifies a 25-year mean recurrence interval for all structures whereas the National Building Code uses 100-year mean recurrence interval for all structures. For the same mean recurrence interval (25-year), NAVFAC DM-2 and A58.1-1972 give different ground loads for the same geographic location.

Several different ways are used to present the ground snow load. The NAVFAC DM-2 presents tabulated loads for cities and mean recurrence interval isoline maps whereas all others present only mean recurrence interval isoline maps except for UBC which does not present ground snow load.

Transformation of ground snow load to roof snow load accounting for roof geometry varies considerably from one document to another. Roof geometries are treated differently in the A58.1-1972, NAVFAC DM-2 and UBC.

In this brief comparison the trend appears that the ANSI A58.1-1972 Standard is used as a resource document for the U.S. model building codes and Federal standards; however, there are some differences in the use of its principles. It appears that these differences can be classified into two areas:

1. The use of probabilistic methods and transformation of ground to roof load.
2. The assimilation of data have to result in the same load for the same geographical location.

Future plans involve inprovement of the ANSI A58.1-1972 snow load provisions by incorporating more up-to-date data. Statistical methods of analysis will be applied in assimilating data in a form readily applicable to the Standard user. It is important for all involved in providing data for snow loadings to consider presenting, as a minimum, mean values and standard deviations.

Also, if possible, probability distribution functions should be provided. Methods of presenting data should be carefully stipulated such as, characteristic values, nominal values, means of extremes, or means.

American National Standards Committee A58 will also be considering limit states and load factor approaches for all loads on building structures which will facilitate a consistent consideration of not only snow loads but others such as earthquake, wind, and gravity. It is our continuing goal in A58 to avoid complication and confusion but realize that we are solving complex problems. The user of a standard, the code writer, regulatory groups, and designers must always be kept in mind when assimilating a standard. Deriving standards is an evolutionary process and quantum jumps from one standard to another cannot be taken and have an effective use of a new standard.

RELATIONSHIP BETWEEN ROOF AND GROUND SNOW LOADS – NEW NBC SPECIFICATIONS – PROBLEM AREAS

by W. R. Schriever

Snow Load Surveys

About twenty years ago the Division of Building Research of NRC determined the actual load-carrying capacity of conventional roofs (rafter and joist roofs) by full-scale load tests in order to develop performance criteria for roof trusses. The tests revealed that some of the conventional roofs where not even able to carry the full design snow load. Was this because actual roof snow loads were less than the specified design snow loads? To answer this question, the Division initiated a survey of actual snow loads on house roofs.

This first survey was carried out with the help of volunteers all across Canada; it lasted for about ten years and covered, in addition to ordinary house roofs, a number of multi-level roofs of commercial buildings. The survey showed, among other things, the great influence of wind and also revealed the need to include the effects of wind in specifying design snow loads.

As is well known now, wind can either decrease or increase the snow load, depending on the exposure of a particular roof surface. On many simple house roofs the effect of the wind (and also of heat loss) was – in answer to the earlier question – definitely a decrease in load.

One objective of the measurements was to develop for the designer a set of snow load coefficients for the most common shapes of roofs. Supplement No. 4 to the National Building Code of Canada, (NBC) in its Commentary on Snow Loads, therefore contains a set of diagrams which allow decreases in loads on exposed areas to 0.8 or 0.6 of the ground load, depending on the exposure to wind, and require increases up to 3 times the ground load in those areas where drifts are likely to accumulate. Since the majority of roof areas are usually exposed, a considerable cost saving has resulted from these more realistic design snow loads.

Since then more specialized surveys have been continued by DBR, particularly of snow loads on flat roofs, sloped and curved roofs, mobile homes and, in the mountains of British Columbia, of the increase of ground loads with increasing elevation. Most of these are still in progress.

NBC 1977 Requirements for Curved Roofs

The commentary on snow loads in the forthcoming 1977 NBC will contain only a few changes compared to the 1975 edition; one of these is a revised distribution for unbalanced snow load for curved and arched roofs. The earlier requirement in the form of a triangular load with a coefficient of 0 at the peak and 2 at the eave was really intended for moderately curved large roofs, such as arena roofs, and resulted in unrealistic loads for the more highly curved roofs such as quonset huts, etc. The new coefficients will produce a more realistic load distribution on both types of curved roofs.

Complicating Factors

Predicting snow loads is always difficult both for the code writer and the designer. For a country like Canada, with its tremendous climate variations and limited number of weather stations, the ground load itself presents some problems. The coding of the roof load is made even more complicated by the great variety of roofs the designer encounters in his work. There are sometimes factors that could be taken into account in addition to those considered in the NBC Commentary. Of those other factors, I would consider aerodynamic and thermal considerations as the most important. Consider, for example, the effects of heat loss. Although in many conventional roofs, insulation and ventilation create an essentially 'cold' roof, there are roof types, such as glazed roofs, or membranes of air-supported structures where the long-term snow loads are significantly reduced by heat loss. Should the design loads be reduced for these roofs? If a reduced load is used for the design and the building were to remain unheated for a winter, the roof might be subject to the full load and collapse. In other words, sometimes the choice of an appropriate design snow load may be a philosophical question rather than a technical one.

UPDATE ON SNOW LOAD RESEARCH AT CRREL

by Wayne Tobiasson and Robert Redfield

Last year at the 33rd Eastern Snow Conference (ESC), snow load criteria established for Alaska in 1973(17) were reviewed and the extension of that work to the 'lower 48' states was described(18). At that time the CRREL computer was filled with the annual maximum depth of snow on the ground for each year of record at about 9000 National Weather Service (NWS) and USAF Air Weather Service (AWS) stations across the United States. Several statistical alternatives(4,5,6,7,8,9,16,17) were also being considered to forecast values for various return periods from the meterological information in the computer.

Since the conference, all candidate statistical alternatives were evaluated using data from 51 stations with long periods of record and the chi-square goodness-of-fit test. Four alternatives provided acceptable levels of fit, with the log-normal distribution yielding slightly better overall results. The average of the 25-year return period snow depths for the stations with long periods of record are presented in Table I.

Table I. Average values of 25-year return period ground snow depths for stations with long periods of record.

Distribution	Snow depth (in., cm.)	
Log-normal(1,16,17)	21.5	(54.6)
Double-exponential		
Gumbel's method(2,5,7,8)	21.6	(54.9)
Gringorten's method(6)	20.0	(50.8)
Lieblein's method(9)	19.8	(50.3)

The log-normal method and Gumbel's method using the double-exponential distribution produced essentially indentical average depths. Depths calculated using the methods of Gringorten and Lieblein were somewhat lower and therefore less conservative for design purposes. Accordingly, the depths of snow on the ground for return periods of 5, 25, 50 and 100 years were calculated for the 9000 locations using the log-normal distribution.

At 176 stations in the United States both depth and water equivalent measurements are available. Water equivalent records for these stations were analyzed in the same manner as the depth records. 'Conversion densities' were developed by dividing the 25 year water equivalent by the 25 year depth for each of these stations. The conversion densities were placed on a map of the United States and a single conversion density was established for each state except those in the Rocky Mountains. In the Rocky Mountain states conversion densities varied widely, even among neighboring stations, and state averages did not seem appropriate for that region. For the other states the conversion density ranged from 8 to 14 pcf (130 to 220 Kg/m^3) and averaged 10 pcf (160 Kg/m^3). By way of comparison, a nationwide conversion density of 12 pcf (190 Kg/m^3) augmented by rainfall is used in Canada.(2,3,5)

Snow load criteria have been developed for several of the Rocky Mountain states.(10,13,14,15,19,20) Soil Conservation Service (SCS) snow survey data, not NWS data, form the basis of those studies.

When NWS and SCS data for a typical Rocky Mountain state are analyzed and regression lines are drawn on a depth-load graph, a significant difference exists, as shown in Figure 1. The NWS straight line indicates a constant and rather low conversion density. The SCS curve indicates higher densities that increase significantly with increasing depth of snow on the ground. Most SCS measurements are made in unpopulated mountainous areas while most NWS observations are made in the vicinity of population centers. The SCS data seem appropriate for very deep snow but it is yet to be resolved which data source is best at shallower depths, which represent more common design situations. Unfortunately, at these depths the SCS ground snow load is about twice as heavy as the NWS load (Fig. 1). Efforts are underway to resolve this difference.

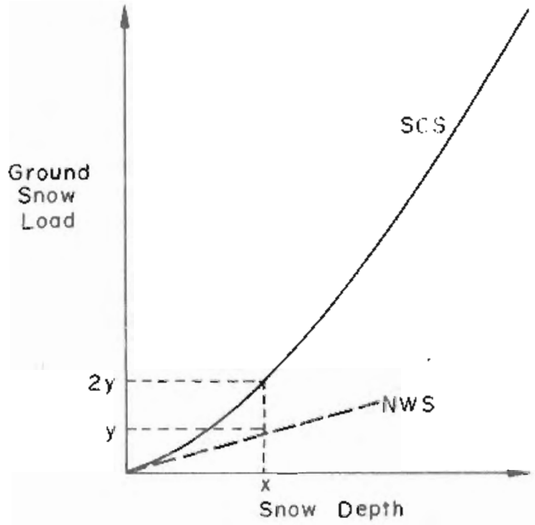

Figure 1. Comparison of National Weather Service (NWS) and Soil Conservation Service (SCS) data for a typical state in the Rocky Mountains

Once appropriate conversion densities are established for the Rocky Mountain states, ground snow loads for 5-, 25-, 50- and 100-year return periods will be developed for all stations in the United States. These data will not be presented as a few isolines on little maps of the U.S.A. As stressed at the 33rd ESC, such maps are considered overgeneralizations based on the magnitude of local variations in snow accumulation that exist just a few miles apart in may areas. Instead, all data will be tabulated alphabetically according to state and station name. The tabulation will also include the latitude, longitude and elevation of each station. A map of each state showing the location of all stations will supplement the tabulation. No snow load information will be presented on the state maps. The designer will be encouraged to determine the snow loads at several stations in the vicinity of the site in question. By considering local geographic features and station elevation, the designer will generate criteria for the site that take into consideration the magnitude of local variations to be expected. A little map with isolines would hide all this.

Defining an appropriate ground snow load is but the first step in determining a design roof snow load. Once the 9000-station tabulation is complete, the weak link in the system will be converting those values to appropriate roof loads. Interim factors which convert a ground snow load to a roof load with consideration given to the aerodynamic, geometric and thermal characteristics of the roof are being adopted from earlier CRREL work in Alaska(18), the National Building Code of Canada(3), and studies by the Division of Building Research, National Research Council of Canada(11,12). It can be argued that information in these references is not appropriate for much of the United States. This is acknowledged, and a program is underway to generate improved factors by conducting numerous snow load case studies across the nation.

Preliminary studies were conducted during the 1975-76 winter at Rensselaer Polytechnic Institute (RPI) in Troy, New York. During the past winter (1976-77) contracts for additional studies have been issued to the following institutions:

Rensselaer Polytechnic Institute
Rochester Institute of Technology
Michigan Technological University
South Dakota State University
Oregon State University
Washington State University

About 20 roofs are being studied at each institution. Roof selection was based on exposure, geometry and thermal characteristics. The depth and density of snow and ice on the ground and on these roofs are being periodically measured. Sliding snow, drifts, eave icings and other localized features are being defined. Results will be documented in reports similar to those prepared by the Division of Building Research, National Research Council of Canada(11,12).

The case study program will continue through the 1978-79 winter; other institutions will be involved. In addition, CRREL personnel will conduct case studies in areas heavily hit by snow. This winter two trips were made to Buffalo, New York where drift snow loads on roofs exceeding 200 psf (9.58 kPa) were measured.

In 1979 a comprehensive report analyzing all the case studies will be prepared. New snow load conversion factors will be generated and the ground snow load tabulations updated statistically to include data gathered since 1974. Publication of a final report is expect in 1980.

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ALTERNATIVE METHOD FOR PREDICTING ROOF SNOW LOADS AND THEIR VARIABILITY

by N. Isyumov

INTRODUCTION

As described in preceeding presentations by the panel, current roof snow load specifications rely on measurements of ground snow depths. That is the design load on a roof resulting from snow accumulation is taken as,

$$R = C_s g \tag{1}$$

where g is the regionally varying ground snow load for a specified recurrence interval obtained from annual maximum ground snow depths and an estimated snow density; and C_s is a snow load coefficient which translates the ground load to that on a roof.

Although snow deposits on both the roof and the ground are influenced by the same meteorological and climatological processes, the mechanisms of snow load formation need not be similar. Consequently, although the ground snow depth undoubtedly is a good measure of snowfall and its persistence over the course of winter, it does not,a priori,provide a reliable direct index of snow loads on roofs. While, the simplicity of using ground snow load data and climatically invariant ground to roof conversion factors is attractive, the absence of a physically consistent model of the formation of snow loads on roofs is a drawback. Two of the more important consequences are:

i) difficulties in extrapolating existing design snow loads to roof geometries and environments for which there is no previous experience; and

ii) problems in evaluating the inherent variability of roof snow loads required for limit states design formulations.

The objective of this presentation is to examine the snow loading problem from a researcher's point of view and to present an alternative approach towards the evaluation of snow loads on roofs. This approach; described in detail elsewhere (1,2), uses physical model studies carried out in a wind tunnel or a water flume and combines the model study findings with statistical information on the local climate to provide statistical data on roof snow loads.

ALTERNATIVE METHOD FOR EVALUATING ROOF SNOW LOADS

The use of wind tunnel model studies to evaluate the wind induced response of wind sensitive buildings and structures has become an accepted procedure. Similarly, wind tunnels and/or water flume model techniques, although in some respects more difficult, can provide effective means for studying snow deposition on roofs. It is important to note that physical modelling techniques are currently accepted as alternatives for establishing roof snow loads by the N.B.C. Unlike extreme wind loads which, apart from fatigue considerations, are determined by single events or storms, snow loads on roofs, with the exception of relatively mild winter climates, depend on the accumulation of snow over a period of time. As a result, snow loads depend on the time history of individual snowfalls and the interaction of various meteorological variables which tend to modify and/or reduce the roof snow deposit. Wind tunnel or water flume model studies can be effectively used to provide basic information on the deposition of snow on roofs resulting from particular snowfalls and the depletion of such deposits by wind action. Due to the accumulative and time dependent nature of snow loads however, this information by itself is not complete and must be combined with the statistics of the local climate in order to arrive at maximum snow load magnitudes likely to be experienced.

Thus in addition to model studies, a representative, physical model of the snow build-up process on the roof, is required to permit quantitative determination of maximum roof snow loads. This physical model of the snow build-up process must allow for the action of the various important meteorological and climatological parameters. Such a model, based on a mass balance approach, has been developed by the author(1,2,3) and was discussed at the 33rd Eastern Snow Conference. Using this model the roof snow load R(t) at time "t" during the course of winter becomes:

$$R(t) = \sum_{i=1}^{N(t)} \Delta R_i - \int_0^t \Delta r(\tau)\, d\tau \qquad (2)$$

where ΔR_i is the incremental roof snow load resulting from the i^{th} snowfall; $N(t)$ is the number of snowfalls up to time t; and $\Delta r(\tau)$ is the rate of snow load depletion by wind action and/or thermodynamic ablation at time τ.

The snow load on a particular roof given by equation (2) is the running sum of incremental loads added by individual snowfalls, and the depletion of the roof snow load by wind action and thermodynamic processes. Wind tunnel model studies can provide the basic information on snow deposition on roofs resulting from individual snowfalls of various magnitudes and durations accompanied by different wind conditions, and the depletion and/or modification of roof snow layers by wind action. This basic snow deposition and depletion data are then combined with the statistics of the local climate to simulate the history of the snow load on a particular roof over the course of a winter. Repeating this simulation over a large number of winters provides the necessary statistical base for the prediction of extreme snow loads for design purposes. The establishment of suitable statistical descriptions of such main meteorological variables as snowfall, wind speed and direction, and air temperature; and the development of the necessary methodology for the Monte Carlo simulation, which combines wind tunnel derived model data with the meteorological parameters of a particular area to provide statistical information on roof snow loads, were described at the 33rd Eastern Snow Conference(3).

PRACTICAL APPLICATIONS

In seeking improvements of design specifications, practical significance and cost effectiveness must be kept foremost in mind. The above described approach, which relies on physical model studies and a Monte Carlo simulation, which combines model derived data with the statistics of the local climate, is not suggested as an alternative to current code procedures for conventional roofs. The value of this approach is that it offers a method for establishing design snow loads for major roof systems which are potentially susceptible to large accumulations of snow. Furthermore, it provides a technique for parametric evaluations of the significance of the various variables involved. Calibrated by comparisons with full scale observations, this approach can be used to systematically evaluate the aerodynamic influence of the roof and its surroundings and to examine the dependence of the maximum roof snow load on various meteorological and climatic variables. The author has applied this approach to simple flat roofs in order to parametrically examine the dependence of maximum roof snow loads on the local climate(3). Used in this research role, this approach can supplement current code procedures in the following two areas:

i) improvement of the ground to roof conversion factor C_s; and

ii) evaluation of load factors required for limit states design formulations.

To include the influence of the properties of the roof and the local climate, the conversion factor C_s used by current code approaches in equation (1) should be adjusted to reflect the following:

i) roof geometry;
ii) exposure of the roof to wind action, including the roughness of the surrounding terrain, local shelter and the height of the roof above ground;
iii) the general windiness of the area and the orientation of the roof to the prevailing direction of wind speeds at which significant drifting can occur;
iv) the climate of the area including the distribution of individual snowfalls, the variation of the local air temperature, and the distribution of winter rainfalls; and
v) the thermal characteristics of the roof.

Attempts to reflect the influence of some of these variables on C_s have been made by Tobiasson and Redfield in their work on Alaskan Snow Loads(4).

VARIABILITY OF ROOF SNOW LOADS

Results obtained using the above described approach clearly show that the variability of roof snow loads is significantly larger than that of the ground snow loads. Typical statistical properties of simulated annual maximum ground and roof snow loads are presented in Table 1. The roof loads in this case are for an exposed 50–foot high flat roof located in a moderately rough or suburban terrain. Both simulated annual maximum ground and roof snow loads have been fitted with a Type I asymptotic extreme value distribution with mode U and a dispersion $1/a$. It is significant to note that the coefficient of variation of the annual extreme roof snow loads is more than twice that of the annual extreme ground values namely 0.57 as opposed to 0.26.

The load factor used in limit states design formulations is usually defined as the ratio of the extreme value exceeded only by 5 per cent of the extremes, to the characteristic value of the extremes. Using the conventional first - order second moment probability approach, the load factor is taken as:

$$a = 1 + 1.645\ V \tag{3}$$

Annual Extremes

Based on equation (3) annual extreme load factors become:

ground load:

$$a_g \quad 1 + 1.645 \times 0.26 = 1.43$$

TABLE 1

PARAMETERS OF SIMULATED ANNUAL
EXTREME GROUND AND ROOF SNOW LOADS

Parameter	Ground Snow Loads	Roof Snow Loads
Mode: U	37.3 psf	8.83 psf
Dispersion: $1/a$	8.48 psf	5.24 psf
Mean: $\mu \quad U + 0.577/a$	42.2 psf	11.9 psf
Stand. Dev.: $\sigma = \frac{\pi}{\sqrt{6}}\ 1/a$	10.9 psf	6.72 psf
Coef. of Var.: $V = \sigma/\mu$	0.26	0.57
30 year recurrence value: $R\,(30) \quad U + 1/a \ln 30$	66.1 psf	26.7 psf

roof load:

$$a_R = 1 + 1.645 \times 0.57 = 1.94$$

Consequently, following the code approach (as given by equation (1)) the use of a constant C_s leads to a significantly lower load factor; namely 1.43 as opposed to 1.94. To achieve a load factor of 1.94, while retaining the code approach and basing annual extreme roof loads on annual extreme ground values, requires that C_s also be treated as a stochastic variable. To obtain a load factor of 1.94 for $R = C_s g$, requires that C_s have a coefficient of variation of,

$$V_{C_s} = \sqrt{V_R^2 - V_g^2} \tag{4}$$

$$= \sqrt{0.57^2 - 0.26^2} = 0.51$$

Lifetime Extremes

The above arguments can be extended to estimate load factors for lifetime as opposed to annual extemes. Taking a 30 year design period, the characteristic values are taken as the 30 year return period roof and ground snow loads. From Table 1, these are 26.7 and 66.1 psf respectively. Coefficients of variation of the 30 year extreme roof and ground snow loads, based on the data presented in Table 1, become $V_R = 0.25$ and $V_g = 0.16$. Correspondingly the 30 year lifetime load factors become:

ground load:

$$a_g = 1 + 1.645 \times 0.16 = 1.26$$

roof load:

$$a_R = 1 + 1.645 \times 0.25 = 1.41$$

The above value of $a_R = 1.41$ is somewhat lower than the nominal value of 1.5 currently prescribed in the N.B.C. To achieve a roof snow load factor of 1.41, based on ground snow loads, requires that C_s is a stochastic variable with a coefficient of variation of:

$$V_{C_s} = \sqrt{0.25^2 - 0.16^2} = 0.19$$

SUMMARY:

The above described examples clearly demonstrate the value of the suggested approach of establishing roof snow loads, not only as a means for studying snow loads on ususual roof systems but also as a tool for improving our understanding of the snow load process within the framework of existing code specifications.

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2. Isyumov, N. and A. G. Davenport, "A Probabilistic Approach to the Prediction of Snow Loads". Canadian Jour. Civil Eng., Vol. 1, No. 1, 1974.

3. Isyumov, N. and M. Mikitiuk, "Climatology of Snowfall and Related Meteorological Variables with Application to Roof Snow Load Specifications", Canadian Jour. Civil Eng., Vol. 4, No. 2, 1977.

4. Tobiasson, W. and R. Redfield, "Alaskan Snow Loads", 24th Alaskan Science Conf. University of Alaska, Aug. 1973.

OPEN DISCUSSION

Comments by D. A. Taylor (Division of Building Research, National Research Council)

The importance of the ratio of the drift to ground load measured at any particular time should not be overstated. The formation of drifts is determined more by the wind, its duration, speed and orientation to the structure, by temperature, and by the "free" snow, the snow available for drifting, rather than the amount of snow lying on the ground. Much of the snow on the ground may be covered by hard crust.

In 1975 I observed in the Ottawa area, a large drift on a flat-roofed building at the lee end of a higher gable-roofed hockey arena. This triangular drift completely filled the 12'–9" maximum difference in elevation between the two roofs during a 4" to 6" snowfall. At the time the ratio of the maximum drift load to the ground load was 242/23 = 10.5, while the ratio of the maximum drift load to the 30 year ground load was 142/60 = 4.0. For this roof, very large drifts are apparently independent of the snow on the ground at the time and have formed even during the first snowfall of winter.

Further, in the Yukon and Northwest Territories, dry granular snow available for drifting may be almost unlimited and drifts have been known to ramp up to the top of two-storey buildings even in locations where the ground snow is quite low.

Response by W. R. Schriever

I agree with Dr. Taylor that the ratio of drift load to ground load can vary over a wide range and depends on many factors. It is therefore difficult to determine fixed limits for code use such as those recommended in the Commentary on Snow Loads of Supplement No. 4 to the NBC.

The maximum ratio of 3 of drift to ground load suggested for the lower roof of a multilevel in Figure H–5, for example, is I believe, sufficiently conservative for most conditions but might be not quite conservative enough when the upper roof is very large and in locations with arctic conditions.

The recommendations of the Commentary on Snow Loads should, therefore, be regarded exactly as that, i.e. recommendations. The designer should, always with the approval of the authority having jurisdiction (building official), use his own judgement, local experience, results of model tests or whatever other information is most appropriate to arrive at the best possible estimate of the snow load for the particular roof being designed.

Response by N. Isyumov

It is worth adding that although maximum snow loads on roofs in many cases result from snowfall and the action of wind over a portion of the winter, in warmer winter climates, maximum snow loads may occur largely as the result of extreme single snowfalls. Depending on wind conditions, snow loads resulting from a single snowfall, for many roof shapes, can be consistently larger than corresponding loads on the ground. This effect occurs at wind speeds which are insufficient to cause significant removal of snow by drifting and has been demonstrated by physical model tests. Consequently, in addition to roof geometry and drift formation by wind, local climatic conditions play on important role in determining the relationship between roof and ground snow loads.

Question by H. L. Ferguson (Environment Canada – Atmospheric Environment Service)

Are building designers concerned with maximum snow loads making use of relevant hydrometeorological studies?

There are a number of publications in the hydrometeorological literature dealing with methods of estimating "probable maximum precipitation" for various time periods. It should be possible to use these techniques to estimate extreme values of snowpack accumulations and storm rainfall and the combined probabilities or return periods for roof design purposes. One such study is "Critical Meteorological Conditions for Maximum Flows, the St. Francois and Chandiere River Basins, Quebec" by R. W. Gagnon, D. M. Pollock and D. M. Sparrow, published by the Atmospheric Environment Service, Downsview, Ontario, as Climatological Studies No. 16 (1970) which contains additional references.

Response by D. W. Boyd

In British Columbia the snow survey data are collected and published by the Water Investigations Branch. Occasionally they publish summaries in which all the records for one snow course are tabulated on one page. This arrangement makes it easy to pick out the annual maxima for any snow course for all the years of record. These data are frequently used to estimate snow loads at higher elevations or to estimate the rate of increase of snow loads with elevation. The results are mostly in unpublished correspondence.

In eastern North America I believe that the only published snow survey data are in the annual reports from the Eastern Snow Conference and the Atmospheric Environment Service. Abstracting annual maxima for only a few stations is very time comsuming and discourages their use.

Comments by S. Colbeck (U.S. Army CRREL)

I have tried to quantify the impact of rain on roof snow by constructing a computer program which routes the rainwater through the snow and off the roof. The program calculates the weight of both ice and water on the roof as a function of duration for any design basis rainstorm. The input to the program is:

i) a rainstorm of any return period expressed as

$$intensity = A\ (duration + B)^C$$

ii) the depth, ice density and permeability of the snow; and

iii) the size, shape, slope and drain size of the roof.

The output from the program is the total weight, fraction of total rainfall retained, weight of the unsaturated layer, weight of the saturated layer and depth of the saturated layer as a function of duration for the selected rainstorm. I should have this program completed and available for anyone who wants to determine the roof weight due to rain for roofs of simple shapes for any desired design basis rainstorm within six months.

Response by N. Isyumov

Mr. Colbeck's computer model is of considerable interest as the component of the design snow load due to assumed rain water retention can be significant for locations with relatively warm winter climates. For example, the National Building Code of Canada adds a "rain load" corresponding to the weight of the largest recorded 24-hour rainfall during the winter months when ground snow loads tend to be largest. This may be an overly conservative approach and Mr. Colbeck's work may help to rationalize this component of the design snow load.

In response to some questions on the details of his model, Mr. Colbeck replied that changes of phase and latent heat exchanges are not taken into account and that the snow layer is essentially treated as a porous medium.

Comments by D. W. Boyd

When deciding on the optimum strength of a roof one should take account of the initial cost, the probability of the roof load being exceeded during the expected useful life of the roof, and the cost of replacement in the event of a failure. These are economic factors that should lead to the owner getting the best value for his money.

In addition to economic considerations the designer should be concerned about the safety of the occupants of the building. No one wants the roof to fall on their head during their lifetime and therefore the risk that they are prepared to take in any one year is very small. Everyone is entitled to expect that the risk of building failure will be at some generally accepted low value. In Canada the chance of the snow load being exceeded in a particular winter has been arbitrarily set at 1 in 30, which, when combined with other factors in the design procedure, probably results in a risk of only about 1 in a million. This maximum risk or minimum safety should apply to all buildings to be used during the next winter whether they are temporary sheds on construction sites or head office buildings. Employees in both buildings are entitled to the minimum safety implied by the 30-year return period snow load.

Response by N. Isyumov

I agree with Mr. Boyd's comments that individuals should have the right to expect a high level of safety for different types of buildings including "temporary buildings", which for reasons of deterioration may have a shorter useful lifespan. Nevertheless, the expectation of a particular constant level of risk surely is only justified for buildings of similar occupancy designation. Indeed, philosophically it is not inconsistent to accept a higher level of risk in a building intended for low human occupancy; for example a farm shed; as opposed to one intended for high human occupancy. The importance factor , suggested for limit states design in the NBC, provides one means for adjusting the design load in accordance with the severity of the consequences of a failure. Furthermore, the use of 30 and 100 year return period reference velocity pressures in the NBC for "all" buildings and "post-disaster" buildings respectively, does set a precedent for distinguishing between different types of occupancy and consequently "importance". Consistent with this approach, it may be reasonable to use different return period design snow loads for buildings, not of different expected useful life span, but of different function or occupancy designation.

Comments by Michael O'Rourke (Rensselaer Polytechnic Institute, Troy, N.Y.)

A question was raised as to the desirability of using different design roof snow loads for structures with different operational lifetimes. Consider a hypothetical situation with two structures which are identical in every regard except that the operational lifetime of structure A is 5 years while the operational lifetime of structure B is 10 years. That is, it is planned that structure A will be in use for 5 years while structure B will be in operation for 10 years.

The maximum yearly snow load on the roof is a random variable with associated probabilities. For the sake of argument, let us assume that the yearly probability that the maximum snow load W_{max} will be larger than 40 PSF is 0.02. That is, the average recurrence interval for $W_{max} = 40\ PSF$ is 50 years and the probability that W_{max} is greater than 40 PSF during any particular year is one out of 50. With this information and assuming that W_{max} is independent, the probability that the maximum snow load will be greater than 40 PSF over a five or ten year period may be calculated.

$$Prob\ (W_{max} > 40/5\ year\ period) = 1 - (49/50)^5 = 0.0961$$

$$Prob\ (W_{max} > 40/10\ year\ period) = 1 - (49/50)^{10} = 0.1829$$

That is, since structure B is planned to be in operation for 10 years, it has a higher probability of being exposed to a snow load greater than 40 PSF during its lifetime.

Now consider two schemes for choosing roof snow loads for the two structures:

Scheme 1. Both structures are designed for the same roof snow loads.

Scheme 2. Structure B, which has a longer operational lifetime, is designed for a heavier roof snow load than structure A.

Note that I have disregarded the possibility of designing structure A for a larger snow load than structure B.

Using scheme 1 the yearly probabilities are the same but the lifetime probabilities are different. That is, for any given year when both structures A and B are in use, the probability that W_{max} is greater than 40 PSF are the same for both structures (i.e., 0.02) while the probability that 40 PSF will be exceeded in the lifetime of the structures are different (.096 versus .183).

A rational approach for scheme 2 would be to pick a design snow load (e.g. 48 PSF) for structure B such that the probability of exceeding 48 PSF in 10 years is the same as the probability of exceeding 40 PSF in 5 years.

$$P(W_{max} > 40/5 \text{ year period}) = 0.096$$

$$P(W_{max} > 48/10 \text{ years period}) = 0.096$$

As can be seen by this simple example, if you desire two structures to have the same probability of an overload over their entire lifetime, different design loads should be used.

Response by D. W. Boyd

I agree with everything that Mr. O'Rourke has said and I think that such calculations should be carried out to determine the best roof design from an economic point of view. I also think that the safety of the occupants of the buildings should be considered. Let us carry his example a little further. Company A accepts Mr. O'Rourke's arguments and constructs building A1 using the 40 psf design snow load and the corresponding 5-year risk of 0.096. Their employees work in this building for 5 years and then are transferred to a new but identical building A2 where they spend another 5 years. The risk of the snow load being exceeded at their place of work during the 10 years is $1 - (1-0.096)^2$ or 0.183. During the same 10 years the employees in building B were exposed to a risk of only 0.096. The employees of company A have, therefore, been exposed to almost twice the risk of the employees in building B. In this particular case both risks are less than what is commonly considered acceptable and there is no reason for objecting to company B constructing a building that is even safer than what is considered necessary. The danger lies in the other direction when it is argued that a temporary building should be designed using, say, a 5-year return period snow load, instead of using 30 years or more for all buildings.

Response by W. R. Schriever

Michael O'Rourke in his last sentence said that if one desires two structures with different life expectancies to have the same probability of an overload over their entire lifetime, different design loads should be used. If, however, a building code's main function is to look after the safety of the occupants, then one should use the same design load for both buildings. This would mean that a person entering a structure, say an arena for one hockey game would have the same chance of coming out alive whether the structure is a temporary or a permanent one, say an air-supported structure or a massive concrete or steel structure. None the less, there is some natural tendency to design a structure that is to last 50 or 100 years for a higher load than one that is to last a winter only, and engineers in the past have probably done a little bit of both principles mixed together. The National Building Code of Canada, however, philosophically at least, following the principle of protecting the public, would design the two structures for the same load.

Response by N. Isyumov

I share Mr. Schriever's view that the design load specified by a building code should not depend on the building's expected useful lifetime. In fact the definition of the lifetime of a building is a difficult one as so-called "temporary" structures often end up to be quite "permanent". Nevertheless, it may not be unreasonable to vary the design load in accordance to the function or occupancy designation of the building.