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A SURVEY OF SNOW LOADS ON ROOFS OF ARENA-TYPE BUILDINGS IN CANADA

by D. A. Taylor

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A survey of snow loads on the roofs of arena-type buildings in Canada

D. A. TAYLOR

*Building Structures Section, Division of Building Research, National Research Council of Canada,
Ottawa, Ont., Canada K1A 0R6*

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The paper presents data on snow loads on three shapes of arena-type structures in Canada: the cylindrical arch, and the gable and Hipel roofs. Since there has never been a regular annual survey of snow on arenas, the data were compiled from a 4 year pilot study of snow on Quonset-type buildings, from case histories, and from newspaper clippings.

The data indicate that the maxima of the loads recommended for design in Commentary H on snow loads published in Supplement No. 4 to the National Building Code of Canada 1977 can be exceeded.

Further, it appears from the data that three loading cases should be considered in the design of curved roofs: uniformly distributed, unbalanced, and symmetrical loads. It is apparent also that the unbalanced loads recommended for gable roofs may be too conservative.

Cet article décrit les données disponibles sur les charges de neige pour trois types de toit d'aréas canadiens: la voûte cylindrique, le toit pignon et le toit en croupe. Puisqu'on n'a jamais systématiquement procédé à des relevés annuels des charges de neige sur les aréas, les données ont été tirées d'une étude pilote d'une durée de 4 ans et portant sur des bâtiments du type Quonset, puis de quelques études de cas, et enfin de découpages de journaux.

Les données ainsi recueillies indiquent que les charges maximales prévues par les prescriptions réglementaires peuvent être dépassées (commentaire H sur les charges de neige, Supplément No 4, Code national du Bâtiment, Canada 1977).

De plus, il ressort de ces données que trois cas de charge doivent être étudiés dans le calcul d'un toit courbé: la charge uniformément répartie, la charge dissymétrique et la charge symétrique. Il appert que les charges dissymétriques recommandées pour les toits pignons peuvent se révéler trop sévères.

[Traduit par la revue]

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Introduction

Snow loads used in the design of arenas in the period preceding the first National Building Code (NBC) in 1941 were often based on the experience of the designer, and in more populated areas, on local building codes. Since 1941, snow loads have been recommended in the NBC but very few data on arenas have been collected to substantiate them. Hence they were based on a few case histories and on the experience and judgement of engineers on the code committees. In the last 10-15 years more case histories, often of the snow on old arenas and arena-type buildings at the time of collapse or condemnation, have been recorded, and other research information has become available.

This paper presents data on snow on arenas, curling rinks, and arena-type buildings. It is not concerned with their strength or behaviour, as little is known about the structural design or condition of each. It is known, however, that many were not designed in accordance with building codes. A general discussion of the factors influencing the accumulation of snow on roofs can be found in Commentary H on snow

loads in the NBC¹ (National Building Code 1977a). These factors include the effect of: wind and shelter; geometry of the structure and its environment; specific gravity of the snow; heat loss and solar radiation; sliding; drainage; snow removal; and relative elevation above sea level.

Wind and Shelter: Influential Factors

The influence of wind and shelter warrants further discussion. The speed of the wind and its duration and direction are of primary importance. Snow falling during very light winds will tend to be distributed uniformly on roofs unless it slides off. Slightly higher winds, though not enough to cause scour of existing snow and saltation (transport along the surface), will affect the deposition of falling snow and result in moderate to low drifts, depending on the geometry. Winds above the saltation threshold may result in considerable redistribution of snow on the roof and in the accumulation of falling snow, forming large drifts. Very high winds, on the other hand, often

¹Henceforth referred to as Commentary H.

blow snow off roofs leaving them almost bare. However, the same winds may deposit large drifts on the ground or against structures and may result in the formation of snow ramps of such size that ground snow begins blowing onto the roofs.

The duration of winds of all speeds will determine the mass of snow deposited, shifted, or scoured away. Even low speeds of long duration may cause significant drifts and unbalanced loads larger than those caused by stronger winds of the same duration.

Since the quantity of snow tends to be reduced by solar radiation and perhaps heat loss, the drifts that build up over the winter are influenced by the rate of snowfall, its duration, and the time between snowfalls.

Shelter or obstructions cause turbulence or zones of 'aerodynamic shade' where the wind speed is reduced and the snow settles out. Hence, the orientation of a structure to the wind will create greater or lesser loads on the various structural elements, though structures such as arches or gable roofs will be most affected by winds at right angles to the crown or ridge. Depending on the kind and degree of shelter and the wind speed, snow may be deposited uniformly on roofs in the lee or in drifts on either side of the shelter. For example, a small roof on the lee- or windward side of a line of tall trees may be fairly uniformly covered whereas a larger roof may be only partially so.

Snow Load Surveys

Because of the significant variations of weather and snow conditions from one winter to another it is obviously impossible to draw too many conclusions from any survey lasting only one or two winters. Twenty-two years of field experience have indicated that the minimum duration of a systematic and adequate survey of snow on a particular roof shape is of the order of 10 years and that measurements must be made at representative locations across the country to include the effects of variations in climate and topography. Since budgets for such studies are limited, only one or two are conducted at any time. Arena-type roofs have not yet been surveyed in this fashion, in part because high, sloped snow-covered roofs are difficult to survey safely. The information presented in the following sections was obtained from a number of sources: case histories from the Division of Building Research, National Research Council of Canada; a pilot survey of snow on Quonset-type or stressed-skin buildings made from deeply corrugated sheet-steel sections bolted together to form cylindrical arches; a cross-country study of snow loads causing the collapse of Quonset-type buildings; and a newspaper clipping service to which the Division has subscribed for many years.

Three arena-type roofs (including roofs over curl-

FIG. 1. Types of curved roofs.

ing arenas) will be considered: curved, gable, and Hipel roofs.

Curved Cylindrical Roofs

These studies have supplied information about snow on 32 curved roofs of the varieties shown in Fig. 1. Of the 32, all except 3 'cathedral' types (for want of a better name) are circular (Table 1). Some of the roofs did not cover arenas or curling rinks but are included because they are the approximate size and shape of others that did. Considering the scarcity, it seems unduly conservative to disregard any good data. Table 1 shows the classification of the roofs and Table 2 contains the available information. Table 2 and Table 7, which deals with gable roofs, are the core of this paper and should prove to be a very useful reference for designers and researchers. In these, unless noted otherwise, the specific gravity of the snow was assumed to be 0.24, i.e., density = 15 pcf or 240 kg/m³.

Table 3 shows the distribution of the spans. Though some of the spans seem rather short, a sheet of curling ice is only 14 ft (4.3 m) wide, therefore a two-sheet rink need only be about 32–35 ft (10–11 m) wide. A regulation ice hockey rink on the other hand is 85 ft (26 m) wide and the building width is then typically about 110–130 ft (33–40 m).

Table 4, of prime interest, presents the loads on these roofs recorded either at collapse or under exceptional loading conditions (i.e., the data are biased towards heavy loads). C_s is the ratio of the snow load on the roof to the 30-year return ground load, g , recommended in the Climatic Supplement to the NBC (National Building Code 1977b). Reference to Table 2 will provide the details on geometry, shelter, and other important information available.

The information given in detail in Table 2 and summarized in Tables 3, 4, and 5 is not comprehensive and much is incomplete, but it is useful. In general, it shows that the peak values of the snow loads on curved roofs can be much higher than on gable roofs. Further, it illustrates that the maximum, $2g$, of the unbalanced load recommended for the design of

TABLE 1. Classification of curved roofs

Type	Number
Cathedral arch	3
Quonset arch	14
Other	15
Total	32

curved roofs (Fig. 2) can be exceeded. Indeed, although the data are biased towards heavy loads, it is significant that 3 out of 32 or 10% of all these roofs had maximum loads greater than twice the 30-year ground load, g ; of the 14 carrying unbalanced loads, 2 had maxima greater than $2g$ and 4 had maxima greater than $1.8g$ (Table 5).

The smaller arches with high rise/span ratios (Table 2, Nos. 15, 17) tended to accumulate unbalanced snow distributions similar to those in the 1977 Commentary (Fig. 2), whereas on the larger span arches (Nos. 13, 14, 19, 20, 21) except for No. 16, the drifts resembled those recommended for arches prior to 1977: a triangular load on the lee side varying linearly from 0 at the crown to $2g$ at the edge, the windward side being bare.

Although it would be instructive to provide a detailed explanation of cases 13 and 14, in which C_s was greater than 2.0, little can be added to the notes in Table 2. Nothing is known about the shelter, orientation, or span of the building in Halifax (No. 14) though somewhat more is known about the three arches, warehouses Nos. 4, 5, and 6 (cases 13, 19, and 16, respectively) in Sarnia. The wind was blowing at an angle of 70° to the axis of each warehouse, and warehouse No. 4 (case 13) was parallel to and 17 ft (5.2 m) downwind of warehouse No. 5 (case 19). The 17 ft (5.2 m) gap was covered over with a flat roof between the eaves of the two arches.

Note in Table 5 that the largest value of uniformly distributed load was $C_s = 0.78$ on a Quonset building sheltered by trees (Table 2, No. 1). This is close to the value 0.8 currently recommended. Values of C_s for ground drifts at the sides of the structure were also about 2.0 (Table 2, Nos. 8, 9). Commentary H recommends that these side drifts be considered but does not recommend design figures.

The designation 'symmetrical distribution' used in Table 5 includes a number of loading possibilities that can best be illustrated by reference to cases 8–12 in Table 2: light snow at the crown increasing to heavy at the base for cases 9 and 12; the opposite for case 10; and snow at the crown with sides bare and heavy snow at the base for cases 8 and 11.

Only general observations have been made because there are not enough data to define the snow distributions in any statistical way, nor enough to determine whether the maximum $2g$, which has been used for a long time to define the peak of the unbalanced loading condition, requires an increase. On the other hand, there seems to be no evidence to support a reduction.

Table 6 shows broadly the distribution of these loading cases. Little is known about the load distributions on 6 of the 32 roofs. However, it is clear from Table 6 that in the design of curved roofs at least two

loading cases should be examined: of the 26 known distributions, 27% had fairly uniform loads, 19% had symmetrical, and 54% had unbalanced loads.

Gable Roofs

There is even less information available on arenas or curling rinks with gable roofs. Table 7 contains most of the available data and Tables 8 and 9 provide a summary.

Of the 16 gable roofs, 2 were loaded uniformly, 1 with $0.67g$ (Table 7, No. 2) and the other with $0.79g$ (Table 7, No. 1). The latter value is for a sheltered roof and is very close to the figure of $0.8g$ recommended in Commentary H. Two others had unknown distributions with maxima of $0.82g$ and $0.94g$ and the remaining 12 carried unbalanced loads.

How do these unbalanced loads occur? If a heavy load covers a gable roof, it is possible that the snow will slide off one side when the sun shines on it. However, no cases have been reported of the situation in which a uniformly distributed load of 100% or even 80% of g has suddenly slipped off one side of a roof leaving the other fully loaded, and there is only one case (Tables 7 and 9, No. 11) with $0.6g$ on one side and 0 on the other. Though this case was almost certainly caused by sliding, large imbalances are more often caused by wind scour from one side and deposition on the other (Tables 7 and 9, No. 3).

Are the unbalanced loads recommended in the Commentary justified? The maximum load on one side and the average unbalance for each roof are shown in Table 9. With five of these cases having a maximum C_s equal to or greater than 1.0 and eight greater than 0.8, it would be difficult indeed to contemplate reducing the maximum recommended design loads below their current levels (Fig. 3). It may be that the unbalanced load recommended for design is too severe, but as there is not enough evidence to adequately define the relationship between the maximum or average values of C_s and roof slope or between the maximum average unbalance and slope, the question cannot be resolved now.

The data on unbalanced loads, from Table 9, and the recommendations of Commentary H, as described in the following, are illustrated in Fig. 4. The design snow load on roofs of slope less than 15° is a uniformly distributed load of $0.8g$, or $0.6g$ if the roof is fully exposed to the wind. Above 15° the load on the windward side decreases abruptly to 0 while on the other it increases linearly from 0.8 to $1.0g$ at 20° , remains constant between 20 and 30° , and reduces linearly to 0 at 70° . The overall impression from Fig. 4 is that the Commentary may be overconservative. This may be partly due to the fact that it does not acknowledge a difference between rough and slippery surfaces because of the lack of data on the one hand and pr-

TABLE 2. Snow loads on curved roofs

No.	Location	Type/use; date (yr-mo-day)	Span; height; length		Rise/span	1977 NBC* specified ground load, g		Maximum roof snow load		Load distribution	Notes
			(ft)	(m)		(psf)	(kPa)	(psf)	(kPa)		
1	Mary Lake, Ont.	Quonset (unheated) collapsed 71-03-28	31 — 40	9.5 — 12.2	—	77	3.7	60 $C_s = 0.78$	2.9	Fairly uniform	Snow 3-4 ft (90-120 cm) deep all over; building N-S orientation and sheltered by trees
2	Cranberry River, B.C.	Quonset garage collapsed 72-03-11	40 19.2 60	12.2 5.8 18.3	0.48	61	2.9	30 $C_s = 0.49$	1.4	Fairly uniform	Snow up to 2 ft (30 cm) deep; load 25-30 psf (1.2-1.4 kPa); load shovelled off 10 ft (3 m) at each end of building and slid off steep sides
3†	Ancienne- Lorette, P.Q.	Arena collapsed 74-01-08	80 ~24 160	24.4 7.3 48.8	~0.05	79	3.8	37 $C_s = 0.47$	1.8	Fairly uniform	Block side walls 20 ft (6.1 m) high; snow and ice 22 in. (56 cm) deep
4	Salmo, B.C.	Quonset collapsed 75-01-18	40 — 42	12.2 — 12.8	—	67	3.2	30 $C_s = 0.45$	1.4	Fairly uniform	Measured snow load at failure was 30 psf (1.4 kPa); elevation of building above Salmo unknown
5†	Lytleton, N.B.	Quonset sawmill collapsed 76-01-09	40 ~20 140	12.2 6.1 42.7	~0.5	71	3.4	23 $C_s = 0.32$	1.1	Fairly uniform	Sheltered by trees; building collapsed under 18 in. (45 cm) of snow
6†	Powerview, Man.	Quonset arena collapsed 74-02-13	— — —	— — —	—	48	2.3	15 $C_s = 0.31$	0.7	Fairly uniform	The low-rise Quonset building, constructed by local people, was out of level and out of square and bolts were left out
7	Lake of Bays, Ont.	Curling rink collapsed 59-01-24	32 17 168	9.8 5.2 51.2	0.16	83	4.0	25 $C_s = 0.30$	1.2	Fairly uniform	Side walls of building 12 ft (3.7 m) high; roof covered with 17 in. (43 cm) of snow; measured snow density was 17.7 pcf (2.78 kN/m ³); roof supported by 22 timber trusses; sheathing was sheet metal
8	Embrun, Ont.	Quonset collapsed 71-02-25	40 — 100	12.2 — 30.5	—	58	2.8	120 $C_s = 2.07$	5.7	Symmetrical	Snow symmetrical, 8 ft (240 cm) deep at ground each side and 2½ ft (75 cm) deep on top over 5 ft (150 cm) width for half the length of building; building E-W orientation sheltered from the E wind by barn at E end
9	Nakusp, B.C.	Quonset aircraft hangar collapsed Jan. 1975	50 18 60	15.2 5.5 18.3	0.36	75	3.6	150 $C_s = 2.0$	7.2	Symmetrical	Snow load: 20 psf (1.0 kPa) at crown, 150 psf (7.2 kPa) at ground on each side

TABLE 2 (Continued)

No.	Location	Type/use; date (yr-mo-day)	Span; height; length		Rise/span	1977 NBC* specified ground load, g		Maximum roof snow load		Load distribution	Notes
			(ft)	(m)		(psf)	(kPa)	(psf)	(kPa)		
10	Portland, Ont.	Quonset boat storage building collapsed ~70-12-25	42 18.6 —	12.8 5.7 —	0.44	54	2.6	40 $C_s = 0.74$	1.9	Symmetrical	40 psf (1.9 kPa) at crown tapering to 5 psf (0.24 kPa) each side at edge; measured snow density was 15.4 pcf (2.4 kN/m ³)
11	Houston, B.C.	Quonset workshop collapsed Jan. 1974	40 22 60	12.2 6.7 18.3	0.55	50	2.4	30 $C_s = 0.60$	1.4	Symmetrical	Snow 20-24 in. (50-60 cm) deep over 12 ft (3.7 m) width at crown; snow slid off sides 15 h before collapse; snow fresh but wet and heavy; density ~15 pcf (2.4 kN/m ³)
12	Port Sydney, Ont.	Quonset collapsed 71-03-15	40 — 60	12.2 — 18.3	—	77	3.7	30 $C_s = 0.39$	1.4	Symmetrical	Building N-S orientation; trees to N; snow 1 ft (30 cm) on top and 2 ft (60 cm) at ground on each side
13	Sarnia, Ont.	Warehouse #4, no collapse 65-02-25	200 45 450	61.0 13.7 137	0.135	33	1.6	96 $C_s = 2.9$	4.6	Unbalanced	Snow density 12 pcf (1.9 kN/m ³); triangular unbalanced load on one side, max 8 ft (240 cm) deep at edge; other side clear; 18 ft (5.5 m) vertical side walls
14†	Halifax N.S.	Warehouse, collapsed 56-02-29	— — 500	— — 152	—	46	2.2	120 $C_s = 2.61$	5.7	Unbalanced	6-8 ft (180-240 cm) of snow on lee side of building; building had high side walls
15	Lethbridge Alta.	Cathedral arch, farm building, no collapse 60-04-26	~44 ~20 —	13.4 6.1 —	—	31	1.5	60 $C_s = 1.94$	2.9	Unbalanced	4 ft (120 cm) drift on one side of ridge; other side bare; top edge of drift parallel to ground and no higher than crown
16	Sarnia, Ont.	Warehouse #6, no collapse 65-02-25	200 45 700	61 13.7 213	0.135	33	1.6	60 $C_s = 1.82$	2.9	Unbalanced	18 ft (5.5 m) side walls; snow density 12 pcf (1.9 kN/m ³); max. snow depth 5 ft (150 cm), 15 ft (4.6 m) from edge of building; drift started 70 ft (21 m) from edge; windward side almost bare
17	Osgoode, Ont.	Quonset (unheated) shed, no collapse 77-02-23	39 14.5 81	11.9 4.4 24.7	0.37	60	2.9	105 $C_s = 1.75$	5.0	Unbalanced	Snow 7 ft (210 cm) deep on lee side at ground and 6 ft (180 cm) deep at ground on windward side; crown was bare but depth on lee side increased quickly to about 18 in. (45 cm), dropped slightly and increased to 7 ft (210 cm) at edge of structure; orientation of building is N-S, exposed to E-W winds

TAYLOR

TABLE 2 (Continued)

No.	Location	Type/use; date (yr-mo-day)	Span; height; length		Rise/span	1977 NBC* specified ground load, <i>g</i>		Maximum roof snow load		Load distribution	Notes
			(ft)	(m)		(psf)	(kPa)	(psf)	(kPa)		
18	Porquis, Ont.	Quonset collapsed 71-03-28	40 — 90	12.2 — 27.4	—	71	3.4	105 $C_s = 1.47$	5.0	Unbalanced	Building N-S orientation and sheltered on W and S by trees 40 ft (12 m) high, 100 ft (30 m) from building; snow shovelled off all top and about 1/3 down sides; 7 ft (215 cm) remained on W and 3 ft (90 cm) on E side; wind from S or SE
19	Sarnia, Ont.	Warehouse #5 collapsed 65-02-25	200 45 450	61 13.7 137	0.135	33	1.6	48 $C_s = 1.45$	2.3	Unbalanced	Windward side clear; on leeward side max. depth of snow was 4 ft (120 cm); measured snow density was 12 pcf (1.9 kN/m ³); side walls 18 ft (5.5 m) high
20	Azilda, Ont.	Quonset arena collapsed 70-03-08	118 22.7 220	36 6.9 67.1	0.19	63	3.0	90 $C_s = 1.43$	4.3	Unbalanced	Load increased regularly from 0 just upwind of the crown to 13 psf (0.6 kPa) at crown and finally to 90 psf (4.3 kPa) at edge of roof (ground) on lee side; no side walls
21	Listowel, Ont.	Arena collapsed 59-02-28	110 33 240	33.5 10.1 73.2	0.118	79	3.8	80 $C_s = 1.01$	3.8	Unbalanced	Snow load varied from near 0 at crown to a max. 80 psf (3.8 kPa) at edge of roof; side walls of building 20 ft (6.1 m) high; windward side almost bare
22	St. Catharines, Ont.	Bowling alley, no collapse 64-01-02	80 — 230	24.4 — 70.1	0.125	36	1.7	36 $C_s = 1.0$	1.7	Unbalanced	Windward side almost bare; max. load at edge where arch joined flat roof; a roughly triangular snow distribution
23	Ottawa, Ont.	Vehicle storage (unheated), no collapse 77-02-23	41.7 21 100.5	12.7 6.4 30.6	0.5	61	2.9	38 $C_s = 0.62$	1.8	Unbalanced	Building N-S orientation; drifts formed on W side due to E wind; other buildings within 300 ft (90 m) on all sides but site still windy; upper surface of drift almost horizontal, zero depth at crown, windward side bare
24	Morrisburg, Ont.	Cathedral arena collapsed 58-02-17	95 45 200	29.0 13.7 61.0	—	52	2.5	30 $C_s = 0.58$	1.4	Unbalanced	Building NE-SW orientation; roof supported by timber 'arch-trusses' and covered by sheet metal roofing; S side had drift ~1 ft (30 cm) deep near ventilators at peak to about 2 ft (60 cm) deep 20 ft (6 m) out from peak; snow density on roof 15.6 pcf (2.5 kN/m ³)
25	Kakabeka Falls, Ont.	Quonset unheated garage collapsed 76-03-19	40 15 80	12.2 4.6 24.4	0.38	71	3.4	30 $C_s = 0.42$	1.4	Unbalanced	Building E-W orientation; winds from NW; tree shelter along N side; approx. 18-24 in. (45-60 cm) snow all over except S side where about 1/3 of circumference was bare due to sliding and melting

TABLE 2 (Concluded)

No.	Location	Type/use; date (yr-mo-day)	Span; height; length		Rise/span	1977 NBC* specified ground load, g		Maximum roof snow load.		Load distribution	Notes
			(ft)	(m)		(psf)	(kPa)	(psf)	(kPa)		
26	Ottawa, Ont.	Equipment storage (unheated), no collapse 77-02-23	38.5 16.5 199	11.7 5.0 61.0	0.43	61	2.9	20 $C_s = 0.33$	1.0	Unbalanced	Building N-S orientation; sheltered on all sides by trees but exposed for about 300 ft (90 m) to E winds
27†	Crossfield, Alta.	Cathedral roof, curling rink collapsed 66-04-26	— — —	— — —	—	23	1.1	21 $C_s = 0.91$	1.01	Unknown	17 in. (43 cm) wet snow on roof; building exposed all sides; roof covering was asphalt shingles
28†	Huntsville, Ont.	Curling rink collapsed 72-03-15	~60 ~30 ~160	18.3 9.1 48.8	0.5	84	4.0	75 $C_s = 0.89$	3.6	Unknown	Snow from 2-5 ft deep (60-150 cm); snow at crown was from 0-2 ft (0-60 cm) deep; building collapsed after firemen tried to hose snow off roof; building covered with metal siding
29†	Chatsworth, Ont.	Arena collapsed 59-02-12	— — —	— — —	—	77	3.7	60 $C_s = 0.78$	2.9	Unknown	Snow up to 4 ft (120 cm) deep on roof supported by fairly shallow trussed arch(?) on vertical side walls
30†	Moncton, N.B.	Arena, no collapse March 1958	— — —	— — —	~0.19	79	3.8	60 $C_s = 0.76$	2.9	Unknown	Up to 4 ft (120 cm) of snow on lamella arched roof
31†	Burnaby, B.C.	Roller skating rink collapsed 66-01-05	— — —	— — —	—	40	1.9	23 $C_s = 0.58$	1.1	Unknown	Average 18 in. (45 cm) of snow on roof with some deeper (?) drifts
32†	Rock Island, P.Q.	Arena collapsed 69-01-18	~100 ~30 —	30.5 9.1 —	~0.14	56	2.7	30 $C_s = 0.54$	1.4	Unknown	Metal-covered roof; snow more than 2 ft (60 cm) deep in some places

NOTE: C_s = snow load/g.

*National Building Code, Supplement No. 1, 1977.

†Taken from newspaper clippings.

TABLE 3. Distribution of spans of curved roofs

ft	No. of roofs	m	No. of roofs
30 < span ≤ 40	12	9.1 < span ≤ 12.2	12
40 < span ≤ 50	4	12.2 < span ≤ 15.2	4
50 < span ≤ 60	1	15.2 < span ≤ 18.3	1
60 < span ≤ 70	0	18.3 < span ≤ 21.3	0
70 < span ≤ 80	2	21.3 < span ≤ 24.4	2
80 < span ≤ 90	0	24.4 < span ≤ 27.4	0
90 < span ≤ 100	2	27.4 < span ≤ 30.5	2
100 < span ≤ 120	2	30.5 < span ≤ 36.6	2
span = 200	3	span = 61.0	3
span unknown	6	span unknown	6
Total	32	Total	32

TABLE 4. Maximum snow load coefficient C_s for load distributions on curved roofs

	No. of roofs
2.50 < C_s ≤ 3.00	2
2.00 < C_s ≤ 2.50	1
1.75 < C_s ≤ 2.00	3
1.50 < C_s ≤ 1.75	1
1.25 < C_s ≤ 1.50	3
1.00 < C_s ≤ 1.25	1
0.80 < C_s ≤ 1.00	3
0.60 < C_s ≤ 0.80	5
0.50 < C_s ≤ 0.60	4
0.00 < C_s ≤ 0.50	9
Total	32

TABLE 5. Maximum snow load coefficient C_s for the curved roofs, arranged according to load distribution

Uniform	Unbalanced	Symmetrical	Unknown
0.78	2.90	2.07	0.91
0.49	2.61	2.00	0.89
0.47	1.94	0.74	0.78
0.45	1.82	0.60	0.76
0.32	1.75	0.39	0.58
0.31	1.47		0.54
0.30	1.45		
	1.43		
	1.01		
	1.00		
	0.62		
	0.58		
	0.42		
	0.33		

dence on the other. Reductions due to heat loss are not considered wise; slippery roofs that are cold, or upon which freezing rain has fallen prior to snow, have been known to accumulate substantial snow loads.

Hipel-type Roofs

Construction of Hipel-shaped arenas, barn-like

WINDWARD SIDE

$$C_s = 0$$

LEEWARD SIDE

$$C = \frac{\gamma h_x}{g} = \frac{15 h_x}{g}$$

WHEN $C > 2.0$ USE $C = 2.0$

THEN $C_s = C \cdot \beta$

FOR $\frac{h}{l} \leq \frac{1}{10}$ USE CASE I ONLY

FOR $\frac{h}{l} > \frac{1}{10}$ USE CASES I & II

FIG. 2. Arch loading in Commentary H, snow loads. The factor β , which describes the reduction of design snow load with increasing slope (α), is defined as follows: $\beta = 1.0$ (where $0 < \alpha \leq 30^\circ$); $\beta = 1.0 - (\alpha - 30^\circ)/40^\circ$ (where $30^\circ < \alpha \leq 70^\circ$); and $\beta = 0.0$ (where $70^\circ < \alpha \leq 90^\circ$).

TABLE 6. Distribution of loading cases on curved roofs

	No. of roofs
Uniformly distributed	7
Symmetrical	5
Unbalanced	14
Unknown	6
Total	32

structures supported by distinctive 'trusses', was common in Ontario in the 1930's-1950's. These roofs had two slopes, about 20° on each side of the ridge changing to 45-50° about 11 ft (3.4 m) from the side

TABLE 7. Snow loads on gable roofs

No.	Location	Building use; Date (yr-mo-day)	Span; height (max); length		Slope (deg)	1977 NBC* specified ground load, g		Maximum roof snow load		Load distribution	Notes
			(ft)	(m)		(psf)	(kPa)	(psf)	(kPa)		
1	Bells Corners, Ont.	Hockey arena, partial collapse 72-03-17	120 26 216	36.6 7.9 65.8	4.8	61	2.9	48 $C_s = 0.79$	2.3	Fairly uniform	Pre-engineered steel building with haunched frames, built 1965; 9-12 in. (23-30 cm) of ice at eave caused purlin to fail; failure of purlins spread to ridge via sag rods; then one frame with no lateral support from purlins collapsed; building sheltered by trees; average snow depth 4 ft (120 cm)
2†	Drummond- ville, P.Q.	Curling club collapsed 71-02-22	35 ~21 165	10.7 6.4 50.3	32	67	3.2	45 $C_s = 0.67$	2.2	Fairly uniform	Maximum snow depth 3 ft (90 cm) on both sides but average only ~2 ft (60 cm) on each side; building built in 1935; roof support by timber trusses
3	Kenaston, Sask.	Hockey and curling rink, partial collapse 78-02-07	~60 ~22 —	18.3 6.7 —	18.4	36	1.7	87 $C_s = 2.42$ max. $C_s = 0.92$ avg. on lee side of arena plus shed; $C_s = 1.56$ avg. on lee side of arena only	4.2	Unbalanced	Arena 60 ft span, gable roof, 12 ft (3.7 m) to eaves; curling rink 30 ft (9 m) span shed roof continuation of gable roof on lee side; measured density was 25.3 pcf (3.98 kN/m ³) average; maximum load was 87 psf (4.2 kPa); average load on lee side (gable plus shed) was 33 psf (1.6 kPa) and average on lee side of gable arena only, 56 psf (2.7 kPa); windward side clear; sheltered by houses and row of 30 ft (9 m) high poplar trees on lee side
4	Fraser Lake, B.C.	Arena, no collapse 72-02-24	120 36 —	36.6 11.0 —	18.4	52	2.5	76 $C_s = 1.46$	3.6	Unbalanced	Snow density = 13.3 pcf (2.09 kN/m ³); average snow load 29 psf (1.4 kPa) on one side and 36 psf (1.7 kPa) on other; maximum depth one side was 69 in. (175 cm)
5	Montreal (Forum), P.Q.	Arena, no collapse 71-03-12	170 — —	51.8 — —	20	56	2.7	75 $C_s = 1.34$	3.6	Unbalanced	Average snow load about 2½ ft (75 cm) on the west side and ½ ft (15 cm) on east of central gable; maximum depth 5 ft (150 cm); W-shaped roof
6	Bells Corners, Ont.	Arena, no collapse winter 1971	120 26 216	36.6 7.9 65.8	4.8	61	2.9	68 $C_s = 1.11$	3.3	Unbalanced	Up to 4½ ft (137 cm) of snow on one side; snow load on other side unknown; building sheltered by tall trees
7	Edmonton, Alta.	Turkey barn collapsed 71-01-30	40 — —	12.2 — —	17.4	31	1.5	31 $C_s = 1.00$	1.5	Unbalanced	Measured snow density = 14.7 pcf (2.31 kN/m ³); average load 11 psf (0.5 kPa) on windward side and 22 psf (1.1 kPa) on lee side; maximum snow load was 31 psf (1.5 kPa) on lee side

TABLE 7 (Concluded)

No.	Location	Building use; Date (yr-mo-day)	Span; height (max); length		Slope (deg)	1977 NBC* specified ground load, <i>g</i>		Maximum roof snow load		Load distribution	Notes
			(ft)	(m)		(psf)	(kPa)	(psf)	(kPa)		
8	St. Basile, N.B.	Arena, partial collapse 77-02-27	115 38 220	35.1 11.6 67.1	22.6	73	3.5	62 $C_s = 0.85$	3.0	Unbalanced	Density 20 pcf (3.14 kN/m ³); snow 15 ft (4.6 m) from eave was 62 psf (3.0 kPa) and at peak was 50 psf (2.4 kPa); other side unknown
9†	Chatham, N.B.	Curling club collapsed 67-03-09	60 — 150	18.3 — 45.7	33	71	3.4	60 $C_s = 0.85$	2.9	Unbalanced	L-shaped building covered with sheet steel roof; one leg of L collapsed; average snow depth 2 ft (60 cm) on one side and 1 ft (30 cm) on the other
10	Regina, Sask.	Ice rink collapsed 74-03-05	~50 ~20 ~160	15.2 6.1 48.8	~22	36	1.7	30 $C_s = 0.83$	1.4	Unbalanced	Maximum snow depth 2 ft (60 cm) on one side or 20 in. (50 cm) average; other side, 8 in. (20 cm) average
11	Montreal, P.Q.	Curling rink collapsed March 1971	62 20 185	18.9 6.1 56.4	18	56	2.7	33 $C_s = 0.59$	1.6	Unbalanced	One side clear; other side 20 in. (50 cm) of heavy wet snow; assumed snow density was 20 pcf (3.14 kN/m ³)
12†	Winnipeg, Man.	Curling club collapsed 66-03-05	~30 — —	9.1 — —	~30	44	2.1	25 $C_s = 0.57$	1.2	Unbalanced	Snow on windward side 6-8 in. (15-20 cm) deep; on leeward 16-20 in. (40-50 cm) deep
13†	Golden, B.C.	Curling rink collapsed 72-03-13	~45 ~21.5 ~160	13.7 6.5 48.8	~27	79	3.8	45 $C_s = 0.57$	2.2	Unbalanced	Snow ~3 ft (90 cm) on one side and 6-8 in. (15-20 cm) on other; roof supported by open web steel joists
14†	Elora, Ont.	Arena, no collapse 69-01-14	~100 — ~220	30.5 — 67.0	25-30	79	3.8	30 $C_s = 0.38$	1.4	Unbalanced	2 ft (60 cm) of snow on north side, unknown but lesser quantity on south
15†	Pierrefonds, P.Q.	Arena, no collapse winter 1971	— — —	— — —	—	56	2.7	53 $C_s = 0.94$	2.5	Unknown	Prefabricated, pre-engineered arena; six men shovelled 42 in. (107 cm) of snow off roof over 10 days to relieve sagging purlins
16†	Walkerton, Ont.	Fair building, partial collapse 77-01-20	35 — 75	10.7 — 22.9	—	73	3.5	60 $C_s = 0.82$	2.9	Unknown	4 ft (120 cm) of snow in some places; a 20 ft × 25 ft (6 m × 8 m) section of roof collapsed; roof supported by wood beams (trusses?)

NOTE: C_s = snow load/*g*.
 *National Building Code, Supplement No. 1, 1977.
 †Taken from newspaper clippings.

TABLE 8. Gable roofs: summary of spans and slopes

ft	(m)	No. of roofs	deg	No. of roofs
0 ≤ span < 50 (15.2)		5	slope = 4.8	2
50 ≤ span < 75 (22.9)		4	17 ≤ slope < 20	4
75 ≤ span < 100 (30.5)		0	20 ≤ slope < 25	3
100 ≤ span < 125 (38.1)		5	25 ≤ slope < 30	2
span > 125 (38.1)		1	30 ≤ slope ≤ 33	3
span unknown		1	slope unknown	2
Total		16	Total	16

walls (Fig. 5). Although neither of the two roofs discussed in this paper was supported by Hipel trusses, both had the characteristic external shape of Hipel roofs.

Table 10 summarizes the data from these structures. One in Almonte, Ontario, had snow on the 20° slope on one side weighing 30–40 psf (1.4–1.9 kPa) or $C_s = 0.5$ –0.67 while all the other slopes were bare. It was condemned because of sagging of some roof trusses under these loads. The other, in Lakefield, Ontario, had loads at collapse as shown in Fig. 5. There is no indication that Hipel roofs could not be adequately designed using the recommendations in Commentary

H for gable roofs. However, it is probably only the checking of structural adequacy and the maintenance of existing Hipel roofs that are important since few are now being built.

Conclusions

(1) The maximum of the uniformly distributed loads for both gable and curved roofs sheltered from the wind was approximately 80% of the specified ground load, the value recommended in Commentary H on snow loads.

(2) The largest unbalanced loads appear to be caused by drifting rather than sliding.

(3) The peak value, 2g, of the unbalanced load recommended in Commentary H for the design of curved roofs was exceeded on 2 of the 14 roofs carrying unbalanced loads. However, there are not enough data available to decide whether the figure 2g should be changed, or enough data to determine statistically a new value or the effect of the factors controlling that value. Indeed, revised peak values and the factors controlling them cannot be determined rationally, in a statistical sense, until more comprehensive field observations are obtained.

TABLE 9. Unbalanced loads on gable roofs

Roof No. (see Table 7)	Roof slope (deg)	Maximum load on one side (C_s)	Average C_s		Average unbalance loads C_s
			Side 1	Side 2	
3	18.4	2.42	0.92*	0	0.92
4	18.4	1.46	0.69	0.56	0.13
5	20	1.34	0.67	0.13	0.54
6	4.8	1.11	—	—	—
7	17.4	1.00	0.70	0.35	0.35
8	22.6	0.85	0.77	—	—
9	33	0.85	0.42	0.21	0.21
10	22	0.83	0.69	0.28	0.41
11	18	0.59	0.59	0	0.59
12	30	0.57	0.51	0.20	0.31
13	27	0.57	0.57	0.11	0.46
14	25–30	0.38	0.38	—	—
Average†			0.64	0.20	0.44

*See comments in Table 7, No. 3.

†Averages do not include roofs Nos. 8 and 14.

TABLE 10. Snow loads on Hipel roofs

Location	Date	Span (ft (m))	Height to eave (ft (m))	Slopes (deg)	1977 NBC* specified ground load, g (psf (kPa))	Maximum unbalanced loads (psf (kPa))
Almonte, Ont., hockey arena	No collapse 70–12–23	90 (27.4)	16 (4.9)	20/50	61 (2.9)	30–40 (1.4–1.9)
Lakefield, Ont., hockey arena	Collapse 71–02–14	90 (27.4)	16 (4.9)	22/45	61 (2.9)	44 (2.1)

NOTE: Values in parentheses are SI units.

*National Building Code, Supplement No. 1, 1977.

FIG. 3. Recommended design loads on gable roofs in Commentary H, snow loads. The factor β , which describes the reduction of design snow load with increasing slope (α), is defined as follows: $\beta = 1.0$ (where $0 < \alpha \leq 30^\circ$); $\beta = 1.0 - (\alpha - 30^\circ)/40^\circ$ (where $30^\circ < \alpha \leq 70^\circ$); and $\beta = 0.0$ (where $70^\circ < \alpha \leq 90^\circ$).

(4) There is even less information available on the shape of the unbalanced snow load distribution for curved roofs than there is on the peak value, and much more is needed!

(5) For the design of curved roofs, the data indicate that at least two and probably three loading cases should be considered: uniformly distributed, unbalanced, and symmetrical loads. However, to be precise, the symmetrical loads were observed only on the steel-clad arches of high rise/span ratios.

(6) The peak value of the snow load on curved roofs can be much greater than on simple gable roofs.

(7) The trend of the limited data on unbalanced loads on gable roofs indicates that Commentary H may be too conservative (Figs. 3, 4). However, more field observations of snow load distributions are necessary before a statistical reevaluation supporting a reduction in design loadings can be undertaken.

(8) There remains the need to identify the most probable extreme distributions consistent with the

FIG. 4. Unbalanced snow loads on gable roofs of arena-type structures. (Commentary H requirements for full and partial loading not included.)

FIG. 5. Lakefield arena.

constraints of economy and safety. To do this, more surveys should be conducted and many more case histories of snow on arena-type roofs collected.

It is hoped that any readers who have further information on the cases recorded in Tables 2 and 7, or on any other arenas, will contact the author. By this means more rapid advances can be made in supplying a rational statistical basis for load recommendations in the Commentary on snow loads of the National Building Code. Indeed, data on snow loads on any shape of roof would be useful.

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