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NOTE

Unbalanced snow distributions for the design of arch-shaped roofs in Canada

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This note examines in some detail the design snow loads on simple arches and curved roofs recommended in the 1977 *Commentary on Snow Loads* of the National Building Code of Canada. Empirical modifications that give more appropriate unbalanced snow loads for large-radius arches and that will alleviate the problems caused by some overconservative aspects of the 1977 design loads are presented. They have been accepted for inclusion in the 1980 commentary.

Cette communication donne certains détails du calcul des surcharges dues à la neige sur toits en voûte simples recommandé dans le *Commentaire sur les surcharges dues à la neige* 1977 du Code national du bâtiment. Des modifications empiriques qui donnent des surcharges de neige non équilibrées plus appropriées pour les toits en voûte à grand rayon et qui allègent les problèmes causés par certains aspects trop conservateurs du calcul des surcharges 1977 sont présentées. Ces calculs ont été acceptés pour le Commentaire 1980.

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Introduction

There were some significant changes in the recommended unbalanced snow loads for simple cylindrical arched and curved roofs in *Commentary H* to the National Building Code of Canada (NBC) 1977. Further recommendations appear in the 1980 edition of the commentary. The purpose of this note is to outline the thinking behind these changes.

In the 1977 *Commentary on Snow Loads* (NBC 1977) of the National Building Code of Canada a new unbalanced snow distribution was introduced for arched roofs to correct two unrealistic aspects of the triangular distribution used in the 1975 commentary (NBC 1975) (Fig. 1). Both tended to occur on short-radius highly curved roofs, e.g., Quonset-type roofs, and were: (i) the profile of the snow surface protruded unrealistically high above the crown of the arch; and (ii) the maximum snow load was located at the edge or eave of the roof regardless of the slope and without consideration of the fact that in some cases the slope was far too steep to retain snow.

Figure 2 from the 1977 commentary shows how the first problem was solved: the top surface of the drift was limited to the level of a horizontal line through the crown and the maximum load was limited to twice the 30 year return ground load, S_0.[1] The second problem was alleviated by multiplying the load

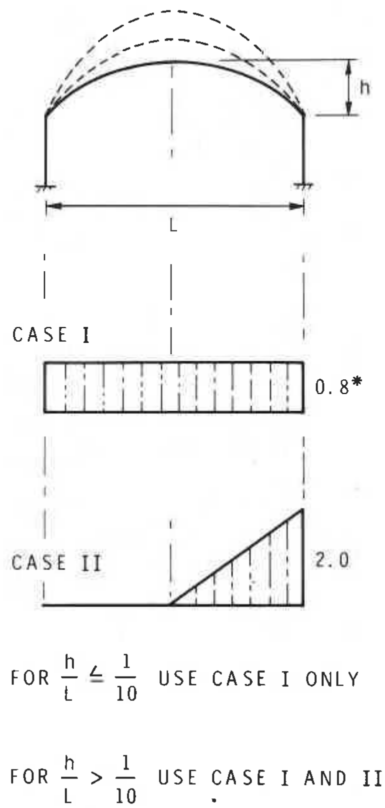

FIG. 1. Design snow loads on cylindrical arch-shaped roofs in the 1975 commentary. (For roofs exposed to the wind on all sides, all values of C_s marked with an asterisk (*) may be reduced by 25%.)

[1]In the 1980 NBC g is replaced by S_0 to avoid confusion with $g = 9.81$ m/s^2 (gravitational acceleration).

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obtained in this manner by the usual slope-reduction factor, β:

$$\beta = 1.0 \qquad 0 \leq \alpha \leq 30°$$

$$\beta = 1.0 - (\alpha - 30°)/40° \qquad 30° \leq \alpha \leq 70°$$

$$\beta = 0.0 \qquad 70° \leq \alpha \leq 90°$$

where α is the slope of the tangent to the surface at the point considered.

Despite the advantages of the 1977 over 1975 provisions for the common, approximately semicircular, cylindrical buildings, the 1977 recommendations proved to be rather conservative when applied to large-radius arches with wide spans in areas with low to moderate ground loads. This problem was exacerbated when these loads were applied in Ontario to existing arenas. Some curved roofs that were upgraded to satisfy the 1975 commentary might not have passed if checked again 2 years later against the 1977 loads. Of course, unless design loads are always revised downwards, there will inevitably be situations where new structures will be designed for more stringent conditions than existing structures. In this case, however, the 1977 changes were not introduced with the intention of increasing the design volume of snow on the roof. The data, although not plentiful, did not justify an increase; hence a further modification of the loads for the 1980 code appeared warranted.

Background

Most designers would agree that recommended snow distribution should remain relatively simple while approximating the distributions observed on curved roofs. Unfortunately, one of the difficulties is that there are very few field measurements of maximum accumulations. This is due mainly to the difficulty in obtaining such measurements, e.g., arriving at the site before snow slides off steeper roofs, obtaining measurements of depth and density safely on steep surfaces, and having the manpower and money to take such measurements across the country.

As there is a wide range of conditions that should be covered (climate, exposure, texture of roof surfaces, spans, and curvatures), field observations should be considered as guides only and must be complemented by judgement and a general understanding of air flow around buildings. Model tests (Isyumov 1971) in a water flume or wind tunnel using sand or some other substance as the "snow" may also be an important qualitative supplement but must be viewed with special caution, partly because of the difficulty of simulating cohesive snow. Information on simple arched and curved roofs has been summarized[2] (see also Taylor 1979).

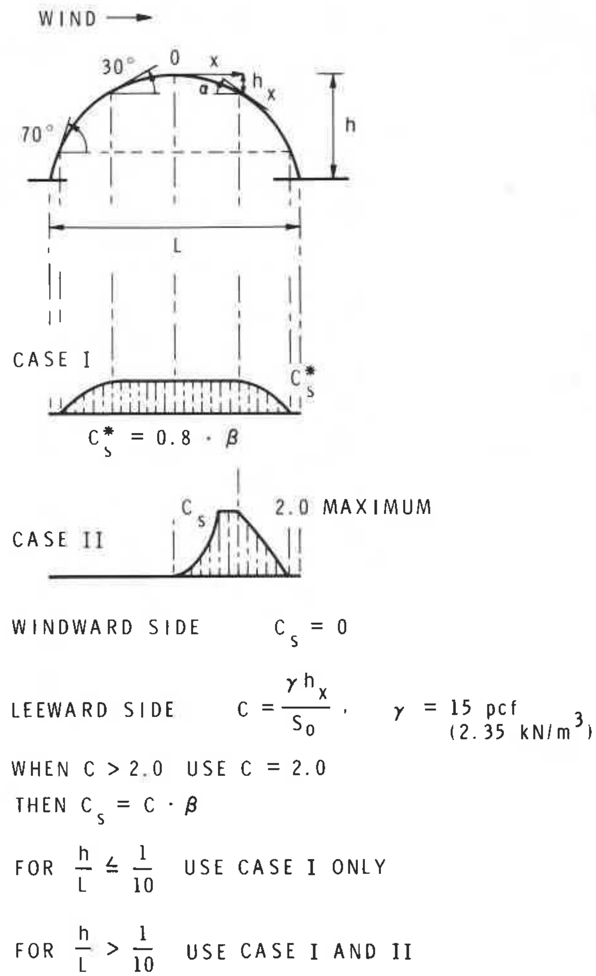


FIG. 2. Design snow loads on cylindrical arch-shaped roofs in the 1977 commentary. (For roofs exposed to the wind on all sides, all values of C_s marked with an asterisk (*) may be reduced by 25%.)

Discussion of Snow Loading in the 1977 Commentary

Before discussing modifications it is appropriate to examine the 1977 loading. Prior to 1977 the "uniformly distributed load" (Fig. 1, case I) was invariant across the span regardless of the slope, but this was changed in 1977 to reflect the influence of slope (Fig. 2). The significant change was to the unbalanced case II loading (Figs. 1, 2). Between 1965 and 1977 it was, as shown in Fig. 1, a triangle inde-

[2]Taylor, D. A. Snow loads for the design of cylindrical curved roofs in Canada, 1953–1980. (In preparation.)

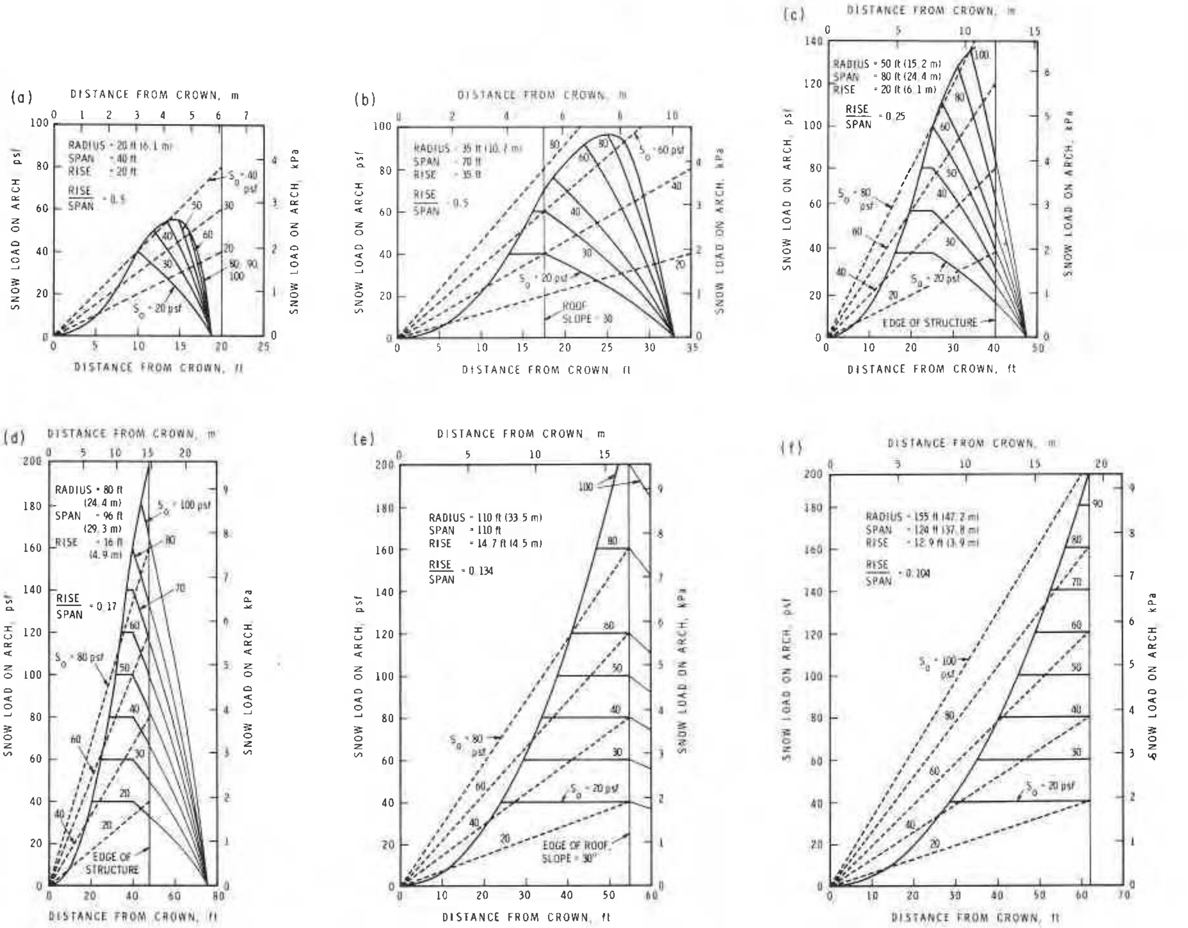


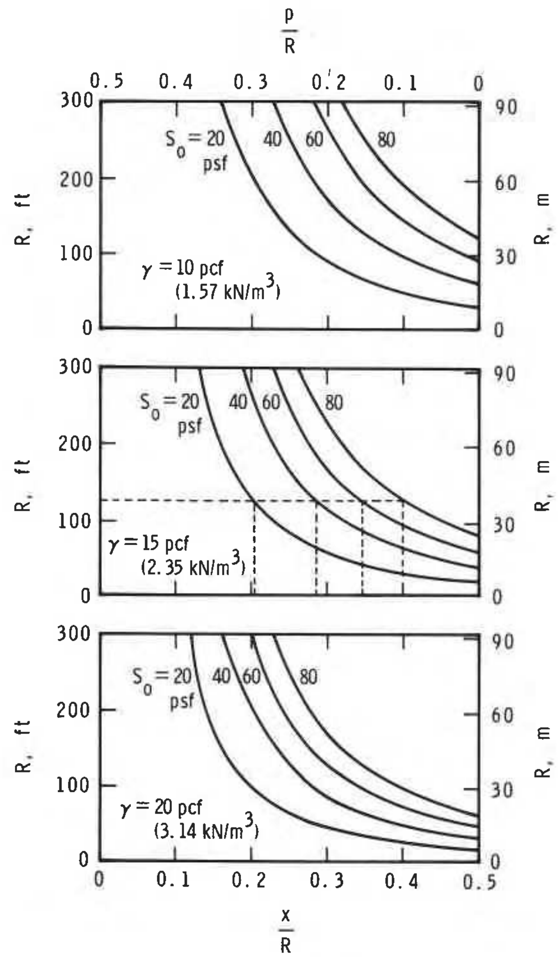
FIG. 3. Comparison of unbalanced snow load distributions according to the 1975 (- - -) and 1977 (—) commentaries. (20 psf ≈ 0.96 kPa.)

pendent of the shape of the curved surface: the maximum load, twice the 30 year return ground load (S_0), was always at the edge or eave of the roof regardless of the slope.

In 1977, however, the load distribution that applied to continuously curved arched roofs was made a function of the shape and slope of the roof, of S_0, and of the snow density, γ. In addition it was noted in the commentary for the first time that ground drifts at the base of the arch on either side or both sides of the structure should be considered. These ground drifts will not be considered here.

Figure 3 *a–f* illustrates the unbalanced snow loads on a variety of curved (circular arc) roofs. Figure 3*a* shows that for all values of S_0, the 1977 distribution gave lower volumes of snow than the 1975 distribution for the smaller Quonset-type (approximately semi-circular) roof. For a somewhat larger roof (Fig. 3*b*) this is true only for ground loads above 30 psf (1.4 kPa) and remains true for structures of increasingly larger spans for increasingly higher ground loads (Fig. 3 *c–f*). As the radii increase, a plateau of constant load, $2S_0$, appears first in Fig. 3*b* when $S_0 = 20$ and 30 psf (0.96 and 1.4 kPa) and for $S_0 = 20$, 30, and 40 psf (0.96, 1.4, and 1.9 kPa) in Fig. 3*c*, etc. It is this plateau that results in the increase over the 1975 loads for the larger spans in areas of low to moderate S_0. The longer the span and the lower the S_0, the heavier will be the extra load represented by the plateau.

Figure 4 shows the relationship between S_0, γ, and x, the distance measured horizontally from the crown to the point at which the load reaches $2S_0$. The *maximum possible* length of the load plateau is obtained from the same diagram assuming that the slope at the eaves is $\leq 30°$. For example, a hockey



$$\frac{x}{R} = \frac{2}{R}\sqrt{\frac{S_0}{\gamma}\left(R - \frac{S_0}{\gamma}\right)}$$

$$\frac{p}{R} = 0.5 - \frac{x}{R}$$

γ = SNOW DENSITY

x = DISTANCE FROM CROWN OF CIRCULAR ARCH TO POINT AT WHICH $C_s = 2.0$ IS REACHED USING CASE II IN THE 1977 NBC

p = LENGTH OF THE PLATEAU IN WHICH $C_s = 2.0$

R = RADIUS OF THE ARCH

S_0 = 30 YEAR RETURN GROUND LOAD (psf) (20 psf ≈ 0.96 kPa)

FIG. 4. A study of the onset and maximum possible length of the C_s = 2.0 load plateau using the 1977 distributions.

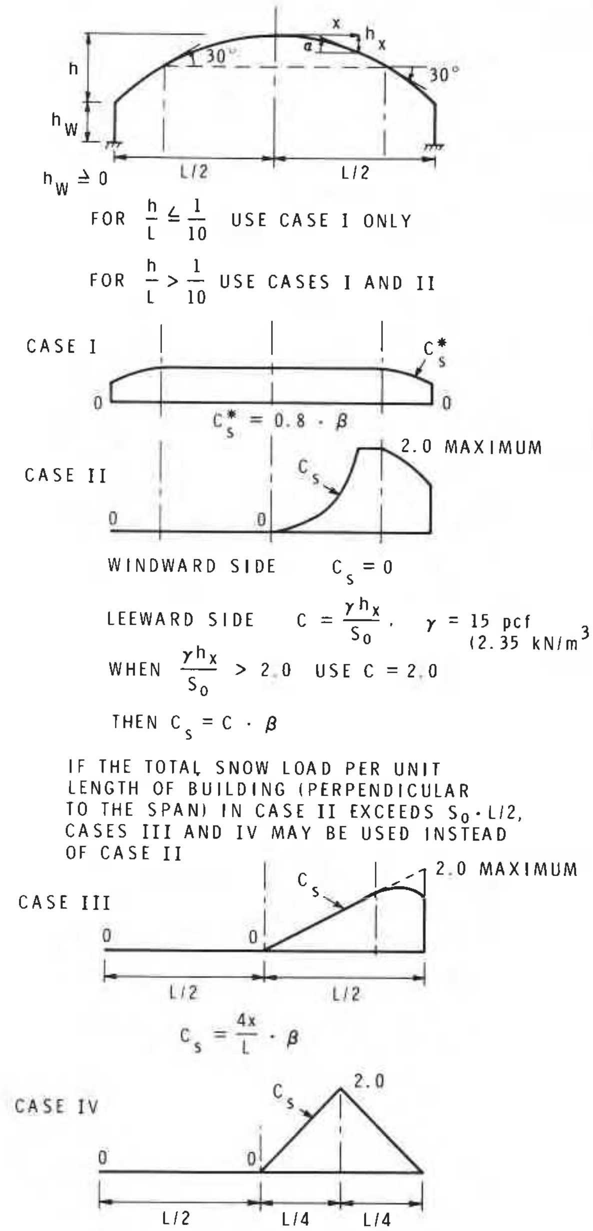


FIG. 5. Modified snow loads on arch-shaped roofs accepted for the 1980 commentary. (For roofs exposed to the wind on all sides, all values of C_s marked with an asterisk (*) may be reduced by 25%.)

arena might typically have a span, L, equal to the radius R of about 125 ft (38 m). If γ is 15 pcf (2.35 kN/m³), then the plateau length would vary from about $0.3R$ to $0.1R$ for S_0 = 20–80 psf (0.96–3.8 kPa), respectively.

Empirical Changes to the Unbalanced Loading in the 1977 Commentary

It appeared desirable to make empirical adjust-

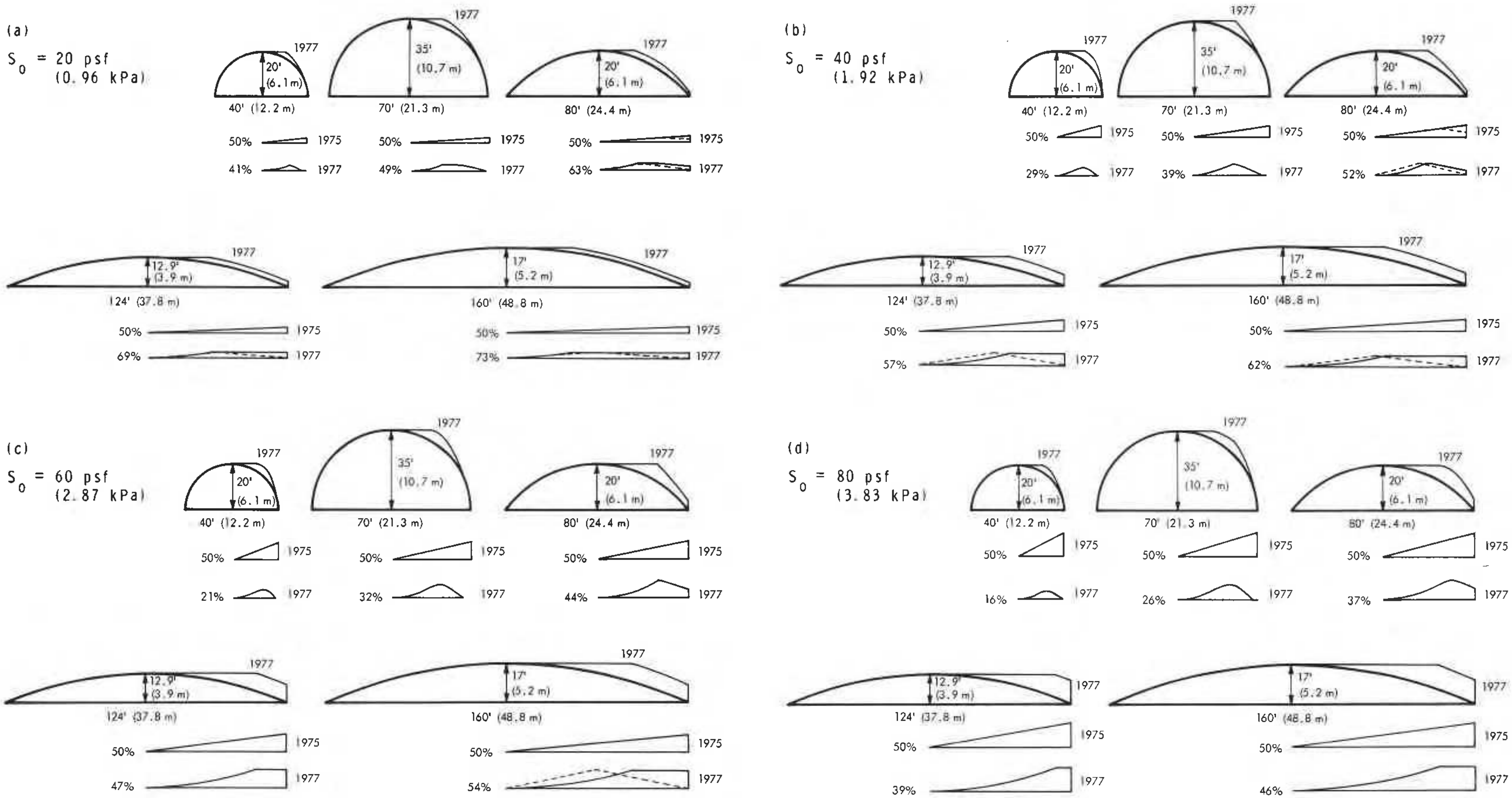


FIG. 6. Scaled drawings of the recommended design snow distributions on five arch-shaped roofs. (Broken lines represent 1980 distributions, cases III and IV. The total snow loads represented by each distribution (solid lines) are shown as a percentage of S_0L.)

ments for the 1980 commentary to reduce the size of this "plateau" rather than to wait many years for changes based on field data.

A number of ideas were checked by calculation using a linear elastic matrix analysis of two structures, a bow-string trussed arch with a radius and span of 118 ft (36 m) and rise of 16 ft (3.9 m) and a Quonset-type arch of radius and rise equal to 35 ft (10.7 m) and span 70 ft (21.4 m), both with $S_0 = 30$ and 60 psf (1.4 and 2.9 kPa).

From these calculations it seemed that any sophisticated solution would really be arbitrary and difficult to justify. The best approach at this stage seemed to be a simple addition in the commentary of one or two load cases that could be used in those situations in which the 1977 loading resulted in overconservatism (a long plateau at $2S_0$ resulting in a total load $> S_0L/2$). As available data indicate that the maximum load sometimes forms between the crown and edge of the roof, rather than along the edge, two new empirical loadings, cases III and IV, were proposed to the Standing Committee on Structural Design of the Associate Committee on the National Building Code. These new loadings limit the total volume of snow to the amount used prior to 1977 ($S_0L/2$), an amount that seems reasonable in the light of experience, and they can be used by the designer in lieu of case II. In this case, however, cases III and IV must be considered.

Case III (Fig. 5) is similar to the unbalanced loads recommended between 1965 and 1975 (Fig. 1, case II); the only difference is that the load decreases where the slope exceeds 30°, according to the slope-reduction factor β. Hence the total load is $\leq S_0L/2$.

The case IV distribution in Fig. 5, an isosceles triangle with the maximum load at $\frac{1}{4}$ span and with the load falling linearly to zero at the crown and the edge, results in a total load of $S_0L/2$. Hence, C_s is independent of β.

The decision to use cases III and IV was based on an evaluation of five roofs each for four different ground loads. The distributions are as shown in Fig. 6 *a–d*. From the figures the use of a total load of $S_0L/2$ to determine when to change from the case II to the case III/IV loading seemed appropriate. It follows that the total unbalanced snow load on these arch-shaped roofs will always be $\leq S_0L/2$.

Summary

To avoid the apparent overconservatism of the unbalanced snow loads of the 1977 commentary on some arch-shaped structures, the introduction of two new load cases (III and IV) and a limiting total load of $S_0L/2$ indicating when to use them is adequate for the time being. A more consistent approach giving the variation of design snow loads for the full range of sizes of curved roofs would be superior but will probably not be achieved until more data are collected. Model experiments simulating blowing snow in a wind tunnel or water flume may help, but field data collected throughout Canada will still be required.

Readers are encouraged to send to the authors case histories of snow accumulations on or against arch-shaped or, indeed, any shaped roof.

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

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