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Publisher's version / Version de l'éditeur:

Canadian Journal of Civil Engineering, 12, 2, pp. 334-343, 1985-06

National Research Council Canada
Conseil national de recherches Canada

SNOW LOADS ON SLOPING ROOFS: TWO PILOT STUDIES IN THE OTTAWA AREA

by D. A. Taylor

Reprinted from
Canadian Journal of Civil Engineering
Vol. 12 No. 2, 1985

DBR Paper No. 1282
Division of Building Research

Price $1.00 OTTAWA NRCC 24432

Snow loads on sloping roofs: two pilot studies in the Ottawa area

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Received November 28, 1983

Revised manuscript accepted December 27, 1984

The results of two pilot studies are presented: one concerning snow on farm roofs in the Ottawa area carried out in 1966, and the other an eight-winter investigation of the influence of surface roughness and slope on snow accumulation on nine 2.4 m × 2.4 m unheated, north-facing experimental roofs built in a sheltered woods at the National Research Council Canada in Ottawa. The results indicate a trend towards reduced snow density as slopes increase and a smaller accumulation of snow on smooth (metal) surfaces than on rough shingled roofs as slopes increase. More data on full-sized roofs across Canada are required to verify this. It is suggested that a less conservative slope-reduction relation might be considered for smooth roofs in the Ottawa area and for other areas with similar climate.

Key words: snow loads, sliding snow, sloping roofs, snow depths, snow densities, surface roughness, pilot survey.

Les résultats de deux études pilotes sont présentés: La première traite de la neige sur les toits de ferme dans la région d'Ottawa, étude complétée en 1966. La deuxième porte sur des enquêtes tenues au cours de huit hivers considérant l'influence de la rugosité de la surface et de la pente du toit sur l'accumulation de neige sur neuf toits de 2,4 m × 2,4 m, non chauffés, orientés vers le nord et construits dans un boisé du Conseil national de recherches Canada d'Ottawa. Les résultats indiquent une tendance vers une réduction de la densité de neige à mesure que les pentes augmentent et une quantité moindre de neige sur les surfaces lisses (métal) que sur les toits de bardeaux rugueux à mesure que les pentes augmentent. Plus de données sur des toits de grandeurs réelles à travers le Canada sont nécessaires pour vérifier cette théorie. Il est suggéré qu'une relation moins conservatrice des réductions de pente soit considérée pour les toits lisses dans la région d'Ottawa et autres régions soumises à des conditions climatiques similaires.

Mots clés: charges de neige, neige glissante, toits inclinés, épaisseurs de neige, densités de neige, rugosité de la surface, enquête pilote.

[Traduit par la revue]

Can. J. Civ. Eng. **12**, 334–343 (1985)

Introduction

Sloping roofs such as gables, sheds, valleys, and arches are traditional in Canada; as well, large, visually striking, inclined glass and metal surfaces have lately become fashionable on new buildings. The design of such roofs for winter conditions requires care, since they must be able to carry substantial weights of snow (Taylor 1979, 1980, 1981); in addition, they may release the snow suddenly, endangering people, vehicles, other roofs, and mechanical and electrical installations below (Taylor 1983) (Fig. 1).

To define the loads for which smooth inclined surfaces should be designed more measurements of snow on sloping roofs are required. With additional data it may be possible to improve the slope-reduction relation used for design in Canada and to examine whether it would be wise to allow a greater reduction for cold smooth roofs than for cold rough ones. The provisions in the National Building Code of Canada 1980 describing the relation between roof slope and snow load are based on a very small number of observations; the pilot studies described in this paper, although still not adequate, will improve the data base. The longer-running pilot study is continuing, with the addition in October 1983 of two glass roofs with slopes of 20° and 35°.

Mechanics of sliding

Figure 2 illustrates the forces on a mass of snow, A, tending to slide down a slope, θ. A is driven by the component, Q, of its own weight, W, resolved parallel to the roof surface, $Q = W \sin\theta$. It is restrained by F, the cohesive and static friction forces developed at the sliding surface, and by tensile and compressive forces, T and C. T comes from snow frozen to the roof or anchored over the ridge, and C from snow frozen to the eave. The cohesion and friction resistance under A varies widely, even from day to day, depending on climate, weather, heat loss, and roughness of the roof surface. Normally, heat loss from below causes the 0° isotherm to move into the insulating snow layer, resulting in breakdown of the resistance under mass A. Then a crack usually penetrates the snow cover near the ridge, reducing the tensile resistance, T, to zero. Following this, the compressive resistance at the eave is overwhelmed by the unrestrained snow mass pushing from above, and sliding occurs.

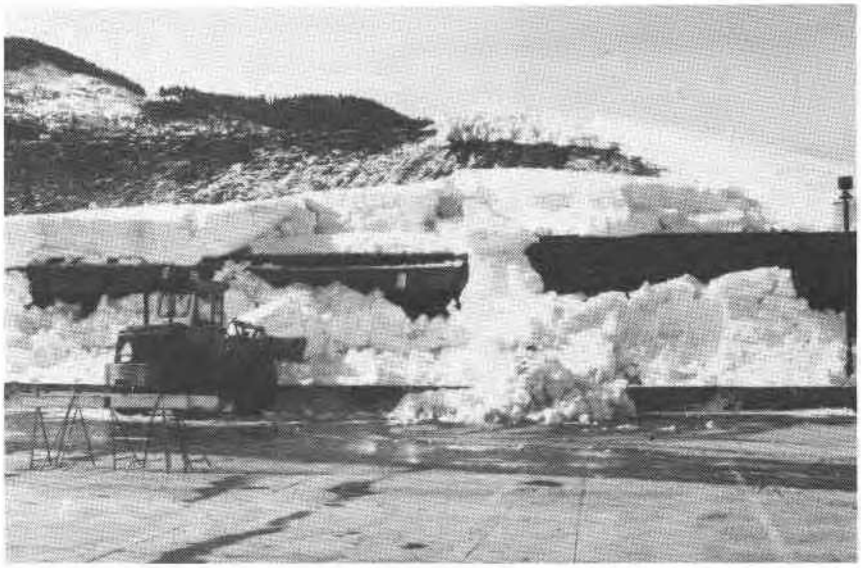

FIG. 1. Snow slide from a large 4-in-12 sloped roof covered with cedar shingles. The Glulam beam acting as a snow fence at the eave has collapsed. Whistler, B.C. (Photograph C. J. Stethem, Whistler, B.C.)

Obstructions to sliding

Sliding may be prevented or delayed by vents, chimneys, dormers, gutters, snow fences, parapets, and valleys (including valleys in L-shaped roofs). In some deep-snow areas with temperatures near and occasionally above 0°C, or where there is high heat loss through the roof, sliding has been known to shear chimneys or other projections at the roof surface (Fig. 3). If the designer wants snow to slide readily, he should locate chimneys and other projections at the top of the slope, or extending to it, to prevent significant accumulation behind them. Further, there should be enough space below the eaves to allow all the snow to slide off without any bridging between ground and roof, especially if reduced design loads due to sliding are assumed. When snow from a roof hits a lower surface (perhaps the roof of another building or a wall) the force may be substantial and should be considered in design (Perla *et al.* 1978; Nakamura *et al.* 1981).

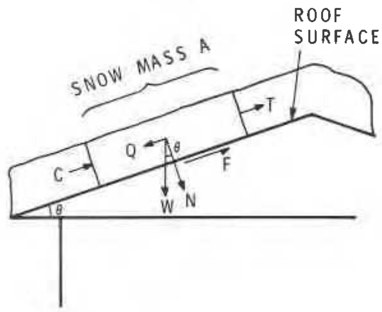

FIG. 2. Forces on mass of snow, *A*, on a sloping roof.

Slope-reduction factor

National Building Code

Beginning in 1941 the National Building Code of Canada (NBCC) permitted a reduction in snow loads with increasing roof slope. Originally determined on the basis of experience and judgement, largely in the absence of data, the Code provisions were changed as information from collapses and case histories of heavy and unusual snow accumulations became available. The first commentary on snow loads included a new slope-reduction relation derived, in part, from regular measurements of snow on inclined roofs during surveys conducted between 1956 and 1965 (Schriever and Peter 1965). The data base was restricted because the roofs all had slopes of less than 32° and many were exposed to wind, making it difficult to separate the effect of slope from that of drifting. That relation (Fig. 4), still used today (Supplement to the National Building Code of Canada 1980), is as follows:

$$C_s = 1.0, \qquad 0° \leq \alpha \leq 30°$$

$$C_s = 1.0 - \frac{\alpha - 30°}{40°}, \qquad 30° \leq \alpha \leq 70°$$

$$C_s = 0.0, \qquad 70° \leq \alpha \leq 90°$$

where C_s is the slope-reduction factor[1] and α is the slope. The expression is based on cold roof data and

[1]In the 1985 National Building Code, C_s will replace β, which was used in 1977 and 1980.

FIG. 3. Chimney sheared from sloping metal roof by heavy snow is lying in foreground. Mt. Washington, B.C.

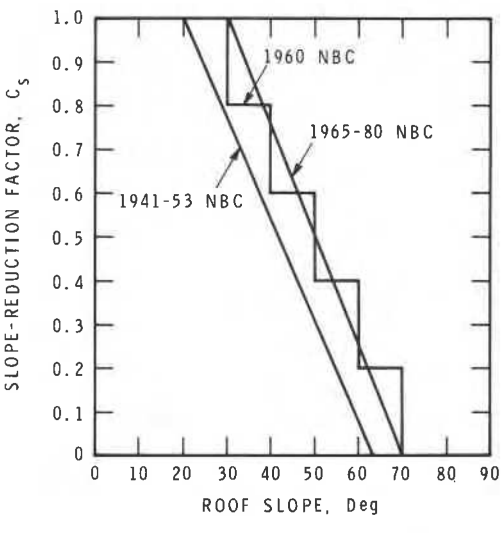

FIG. 4. Influence of roof slope on the minimum design snow load (National Building Code since 1941).

makes no distinction between rough (asphalt and wood shingles) and smooth (metal and glass) surfaces or heated and unheated buildings.

Other codes

Slope-reduction curves from some other countries (Ghiocel and Lungu 1975; ISO 1981) generally permit no reduction for slopes between 0° and 20°−30° and then a linear reduction falling to zero at 60°−75°, but within these limits there is wide variation in the computed C_s factors (Fig. 5). The new provisions in the U.S. model standard (ANSI 1982) are the most comprehensive, with different factors for warm and cold, smooth and rough roofs (Fig. 6). The curves in Figs. 5 and 6 appear to have been derived, like those in the National Building Code, from estimates based on judgement and data. O'Rourke *et al.* (1982) refer to data used to develop the 1982 ANSI standard (O'Rourke *et al.* 1983.)

Field measurements

Division of Building Research pilot study, 1966

In 1966 Halvor Høibø surveyed 50 farm buildings in the Ottawa area, most uninsulated, of which seven had mansard (gambrel) roofs and the rest gable or shed roofs. Although the barns were unheated, some were warmed by the heat from animals; the eight houses in the group were heated and insulated. The roofs were at a variety of slopes and orientations to sun and wind, with steel or aluminum roofing and asphalt or wood shingles. Most results were recorded immediately following 30 and 31 January, when a total of 49 cm (19.1 in.) of snow fell, by far the biggest fall of the winter. Wind speeds varied on the 30th from 11 km/h (E) to 55 km/h (NW) and temperatures from −18°C to −12°C. On the 31st the wind dropped from 53 km/h (NW) to 32 km/h (NW) through the day as temperatures rose from −12°C to −10°C. The two days were gusty and cold, with blowing and drifting snow. For this reason, snow-depth contours were plotted for each roof and the maximum average load on each for the winter was calculated and used in the graphs.

Division of Building Research pilot study, 1974−1982

A second study was started in 1974 to isolate the

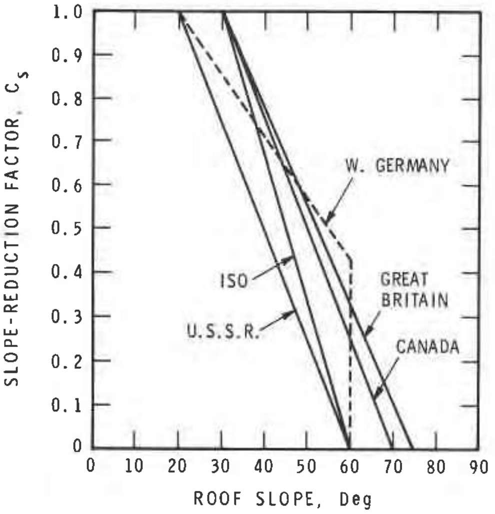

FIG. 5. Sample of slope-reduction curves currently in use (Ghiocel and Lungu 1975).

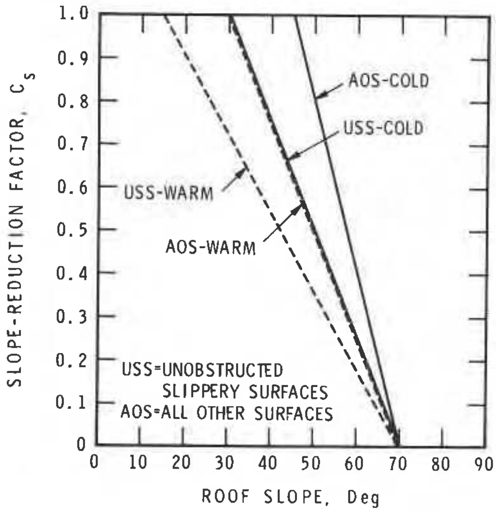

FIG. 6. Slope-reduction factor, C_s, used in ANSI A58.1-1982 for warm and cold surfaces, slippery and otherwise.

influence of slope from other factors such as wind and sunshine. This is a conservative situation since both wind and sunshine will generally cause a reduction in the load on shed roofs. Six north-sloping shed roofs were constructed in a sheltered bush area on National Research Council property. Each was 2.4 m × 2.4 m (8 ft × 8 ft), mounted on a frame (Fig. 7) that allowed for adjustment of slope, in 5° increments, up to 70°. Three were covered with light green asphalt shingles and three with prepainted steel roofing of approximately the same colour (Fig. 8). As the lowest edges were only 0.6 m (2 ft) above the ground, the snow was cleared from in front of each to permit unimpeded sliding. The roof was cleared whenever the snow was

FIG. 7. Detail of frame supporting one roof. The white-painted plywood to reflect sun away from the underside was installed later.

FIG. 8. Two covering materials: left—rough asphalt shingles, right—smooth prepainted steel roofing.

partially prevented from slipping because of bridging to the ground.

The three steel-covered roofs had slopes of 20°, 35°, and 50°, and the asphalt-shingled ones slopes of 35°, 50°, and 60°. Before the winter of 1977 a steel-covered 0° roof was built 1.1 m above the ground, and in October 1979 a 10° steel roof and a 20° shingled roof (minimum clearance of just over a metre) were built, giving nine roofs in all. The undersides of the roof joists were covered by white-painted plywood and vented to prevent heating from reflected sunlight.

Snow and ice thicknesses measured perpendicular to each roof surface were recorded weekly, nine per roof, then averaged, and converted to vertical depths. Because the roofs were small and taking core samples disturbed the snow cover (Fig. 9), densities were measured at longer intervals and then only one per roof. There were, therefore, relatively few density measurements. More should have been taken (and are in the continuing study) in spite of the disruption of the snow cover.

FIG. 9. Density sampling. Notice amount of snow disturbed in obtaining a good core sample.

Results of pilot studies

Influence of warm temperatures and rain

Climate information and snow depths on the 35° metal and shingled roofs over the first year of the 1974–1982 survey are plotted in Fig. 10. It is apparent that high temperatures and rain influenced the results. When the temperature was above 0°C the snow compacted and melted, and the meltwater drained off the slope. As well, the steel roof cleared during most rainfalls and periods of high temperature. As the 35° steel roof cleared a number of times and the comparable shingled roof did not, the snow on the shingled roof was older; because of compaction and the thermodynamic processes taking place as snow ages, older snow tends on average to be denser than new snow (i.e. its specific gravity is higher (Fig. 11)).

Depths and densities

Although loads are normally of most interest, they are not measured directly but are calculated from recorded depths (averaged, as explained before) and densities (not averaged). The average recorded depths from the prepainted steel roofs are shown in Fig. 12, while those from the asphalt-shingled roofs are shown in Fig. 13. Results from the flat roof are plotted on

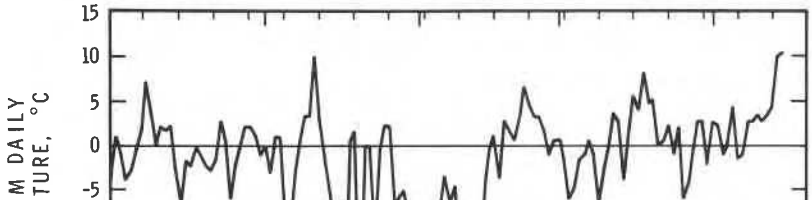

FIG. 10. Influence of temperature and rain on depth of snow on two roofs and on the ground during first winter of pilot survey, 1974–1975.

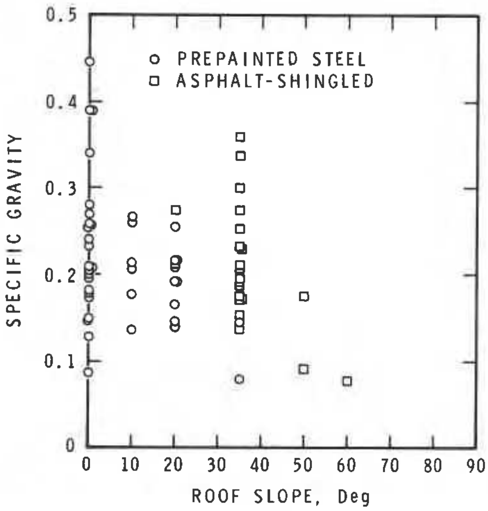

FIG. 11. Influence of slope on measured specific gravity of snow on experimental roofs at NRCC over eight winters. (The 10° and 20° steel roofs were in place for only three winters.)

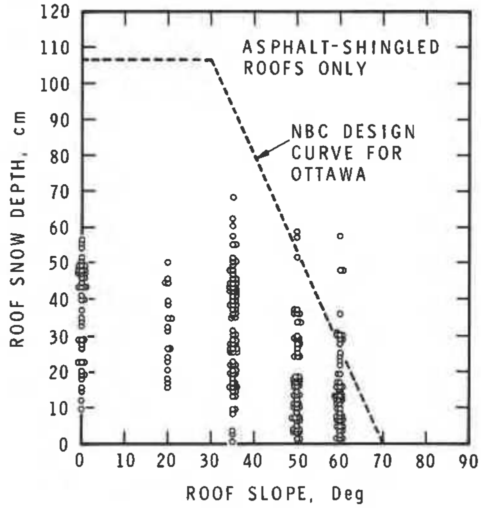

FIG. 13. Influence of slope on depth of snow on experimental roofs covered with asphalt shingles (8 years of observations).

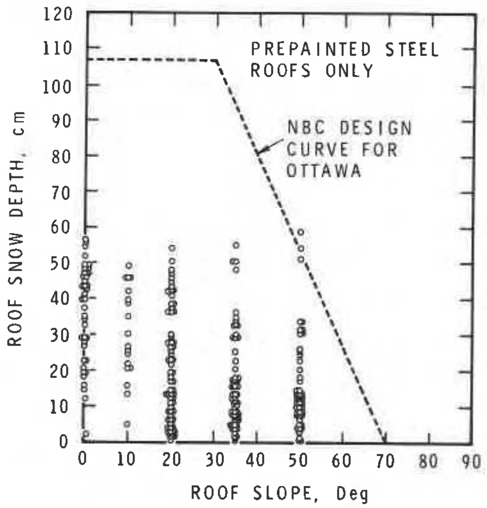

FIG. 12. Influence of slope on depth of snow on experimental roofs covered with prepainted steel (8 years of observations).

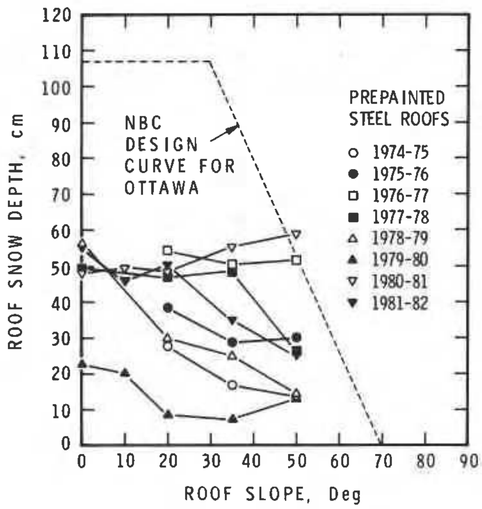

FIG. 14. Graph of maximum depth of snow on prepainted steel roofs for each of eight winters.

each. The dashed line on these figures shows the "design" depths computed from design loads given in the NBC for sheltered conditions. Figures 14 and 15 show maximum average depths recorded in each winter. It is clear from Figs. 12–15 that the average depths on steeply sloping roofs of 50° and 60° can be quite high. Figure 11, however, suggests that the specific gravities on the metal and asphalt-shingled roofs are less on steeper slopes, indicating why the loads drop dramatically while maximum measured depths do not. More density measurements are required on steep roofs to establish that this is a significant trend.

Although there are not yet enough density data to justify extensive analysis, certain trends can be identified. Figure 16 shows a typical plot of measured load versus specific gravity. It was drawn to obtain specific gravities corresponding to the maximum loads measured on the slopes, for plotting in Fig. 17. The largest specific gravities recorded were not used because they were often measured late in the season, after the period of maximum load. The resulting two (straight) lines in Fig. 17 illustrate the trend towards lower specific gravities as slopes increase (the minimum specific gravity probably should not be less than about 0.1, the average

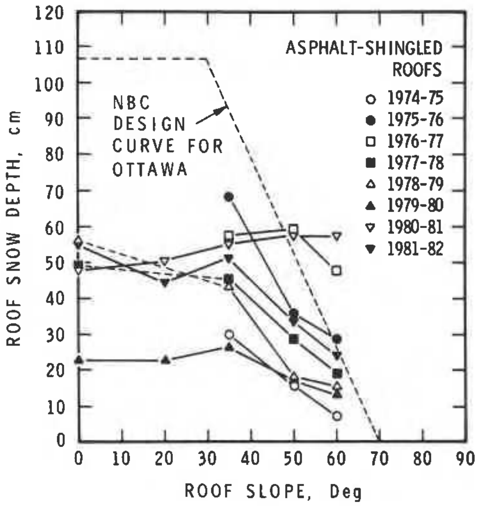

FIG. 15. Graph of maximum depth of snow on asphalt-shingled roofs for each of eight winters.

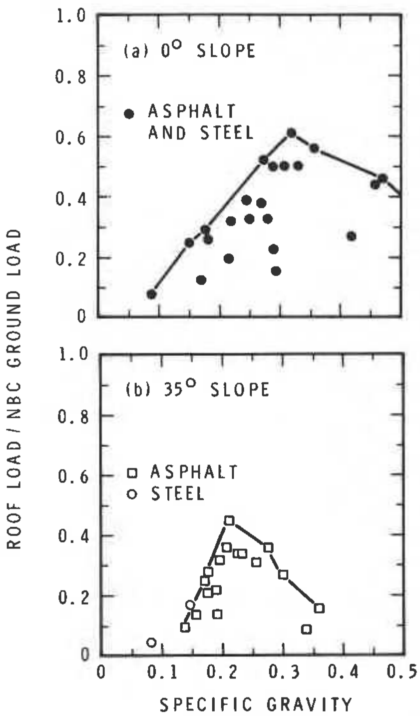

FIG. 16. Graphs to find specific gravity corresponding to maximum ratios of roof load to NBC ground load. Data from 8 year pilot survey, Ottawa: (*a*) specific gravity of snow and ice on flat roof; (*b*) specific gravity of snow and ice on roof with 35° slope.

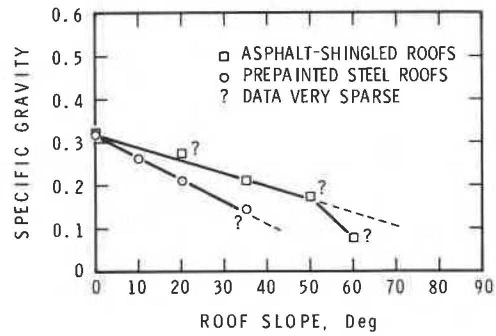

FIG. 17. Graph of specific gravities corresponding to maximum roof load to NBC ground load ratios for roofs of different slope. Data from 8 year pilot survey, Ottawa.

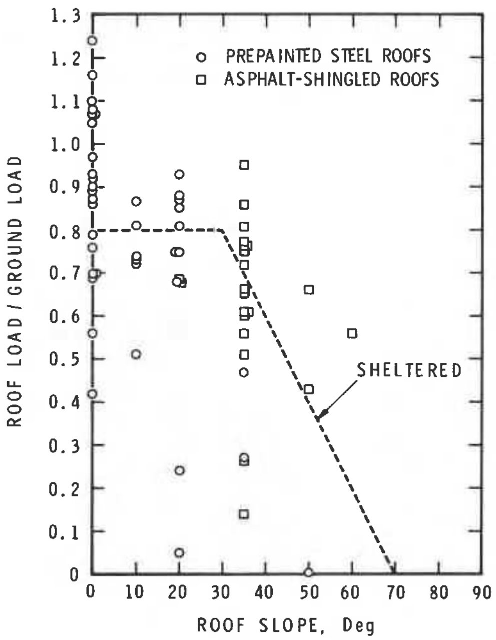

FIG. 18. Data from 1974–1982 pilot study at NRCC plotted as the ratio of roof-to-ground load (measured at the same time) versus roof slope. Note that at 50° there were many measurements of zero snow on the prepainted steel roofs.

figure for newly fallen snow (Goodison and Metcalfe 1981; MacNeil and O'Neill 1977; Potter 1965)). As it frequently slides off steeper slopes, the snow there will be newer and less dense at the time of readings. Enhanced drainage will also contribute to reduced density. There is, as well, another fundamental cause. The deformation of snow on flat surfaces results as time passes in settlement and increased density. On sloping roofs the component of deformation parallel to the slope becomes shearing, or creep deformation, possibly resulting in some minimal dilation; the component perpendicular to the slope contributes to increased density. Thus, the steeper the slope the less the increase in density due to settlement. If more measurements con-

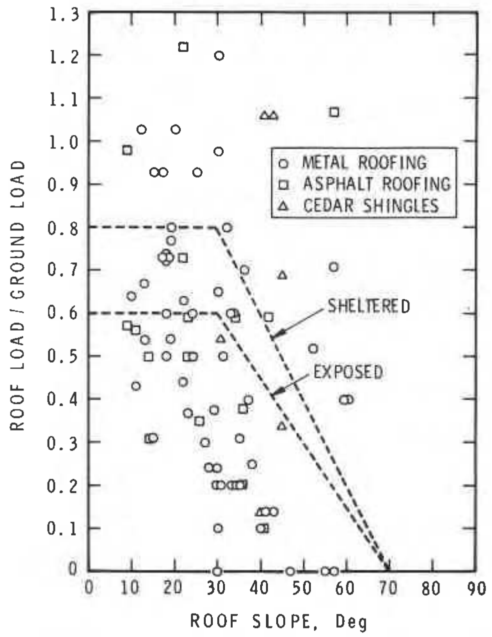

FIG. 19. Høibø's data from snow on farm buildings, plotted as the ratio of roof load to ground load (measured at the same time) versus roof slope.

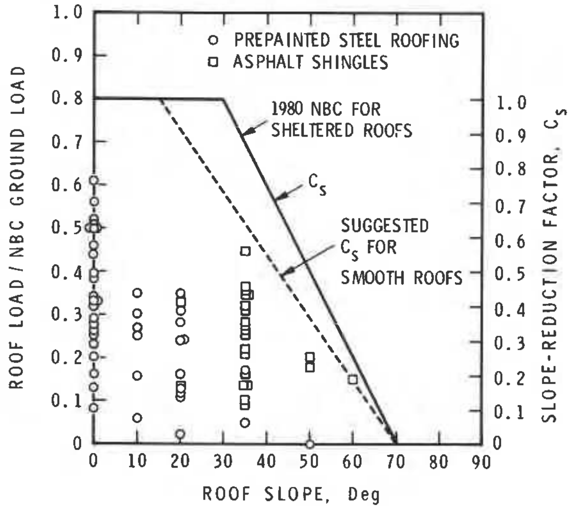

FIG. 20. Data from pilot study 1974–1982 plotted as ratio of roof load to NBC ground load versus slope. The axis on the right is the slope-reduction factor, C_s (solid line). Note that at 50° there were many measurements of zero snow on the prepainted steel roofs.

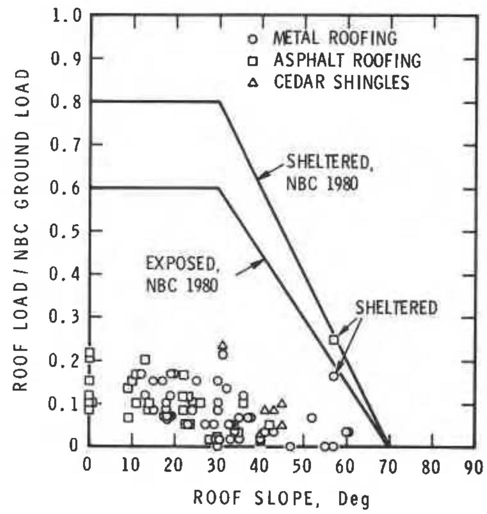

FIG. 21. Høibø's data from snow on farm buildings, Ottawa area, plotted as the ratio of measured roof load to NBC-recommended ground load versus slope.

firm the relation between slope and specific gravity shown in Fig. 17, observations of depths without densities can be put to use to compute loads, taking due account of the probable variation in density in Fig. 17.

Loads

Loads rather than densities and depths are normally of direct interest to designers. Those obtained during the author's (1974–1982) and Høibø's (1966) surveys are plotted in two forms in Figs. 18–21: in Figs. 18 and 19 as the ratio of roof-to-ground load (measured at the same time) versus slope, and in Figs. 20 and 21 as roof load to the 30 year return ground load, S_0 (used in the National Building Code) versus slope. Results of the longer survey, which covered a variety of conditions over eight winters, show that snow slides off smooth metal before it does off rough, shingled roofs (Figs. 18 and 20), and that loads on metal roofs decrease more rapidly than those on shingled surfaces as slopes increase. The effect was not apparent in Høibø's survey mainly because most of the measurements were made following one major fall; as well, the ground load at the time was relatively low, between 25% and 43% of S_0, and the weather conditions had little chance to go through normal fluctuations.

Although it is a popular way of presenting load data, use of the ratio of roof-to-ground load (measured at the same time) can lead to difficulties; most of the data in Figs. 18 and 19 are not for particularly high snow loads and do not, for the following reason, reflect what happens when loads approach those that affect structural design. As the roof load (W) increases, so too does the tendency for snow to creep and slide. Sliding or shearing resistance (F in Fig. 2) at the interface is composed of cohesion and friction. Though the frictional component, which is a function of the angle of internal friction of the snow, may increase with increased load, the cohesive resistance does not. The overall shear resistance will therefore increase less rapidly than the driving force, $Q = W \sin \theta$. The result is

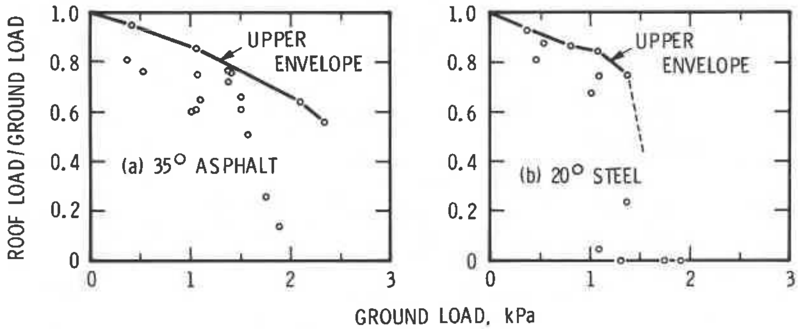

FIG. 22. Reduction in the ratio of roof-to-ground load as ground load increases.

that the ratio of roof-to-ground load tends to decrease as snow continues to fall (Fig. 22) and sliding reduces it to zero (Fig. 22*b*).

The results plotted in Figs. 20 and 21 are more useful for code users than those in Figs. 18 and 19. They are, in effect, plots of snow load versus slope because all the readings were taken in an area with the same 30 year return ground load, S_0. If data from other parts of Canada eventually become available, the roof loads will probably need to be nondimensionalized by a climate parameter that correlates with the load on sloping roofs. The maximum accumulation of ground snow between periods when air temperatures reach 0°C or 5°C, for example, or between rainfalls, may be adequate for this purpose. Such a factor would also reduce differences between locations where snow accumulates gradually as a result of many snowfalls and those where extreme loads result from a 1 or 2 day snowstorm.

Because the ground snow loads measured during these surveys were generally low, more data recorded in winters with heavy snow are required to confirm the trend shown in Fig. 20: that loads on unheated slippery (prepainted steel) roofs decrease more readily than those on cold rough (asphalt-shingled) roofs as slopes increase. The dashed line in Fig. 20 is included to show that even if an extremely conservative view were taken of the data the design load on slippery metal or glass roofs with slopes over 15° might be reduced in regions having a climate like Ottawa's, with occasional thaws and rain during the winter. Whether such a reduction could now be considered for regions where the design load is obtained from 1 or 2 day snowstorms is another matter, and very much depends on the temperature during the snowfalls. Local experience would have to guide the designer.

Since 1978, J. A. Munroe of the Engineering and Statistical Research Institute, Agriculture Canada, has been conducting a survey of snow on farm buildings at field stations across the country. Most are gable roofs, steel covered, and sloped at 18.4° (4 in 12). The data will help to determine whether there is a significant scale effect between 2.4 m × 2.4 m roofs and full-sized ones, and will introduce drifting and climatic effects differing from those in Ottawa. Similar projects need to be encouraged to assist the NBC committees to keep the Code and "Commentary on snow loads" up to date.

Conclusions

Observations of snow loads on sloping roofs in the Ottawa area indicate that the specific gravity of the snow tends to decrease as slope increases and that load decreases as slope increases and as roughness decreases. More data are required to establish these trends. Slope-reduction equations should account for surface conditions, especially roughness, by permitting reductions in design snow loads on slippery metal and glass roofs where warranted by local experience.

Experimental roofs that can be observed under controlled conditions, excluding wind and sun, should be set up and monitored weekly, perhaps in New Brunswick and British Columbia. Although further experiments are not critical or urgent because the National Building Code is fairly conservative, more data to support reductions for slippery roofs would assist the committees responsible for changes in the Code. Observations on existing buildings across Canada would also contribute to the data base; anyone with measurements (or photographs) of snow on sloping roofs is encouraged to contact the author.

Acknowledgements

The author is grateful for the record of careful observations by H. Høibø and for the assistance of P. J. Daly, who built the sloping roofs for the 8 year pilot survey in Ottawa and assisted with observations. He also wishes to thank J. D. Atkins, who helped with observations during the last two winters, and P. A. Schaerer and D. M. McClung of the Division of Building Research, National Research Council Canada, Vancouver, for useful discussions. In addition, he would like to acknowledge the assistance of all those who recorded case histories of snow accumulations on

sloping (and other) roofs and sent them to the Division.

This paper is a contribution from the Division of Building Research, National Research Council Canada.

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