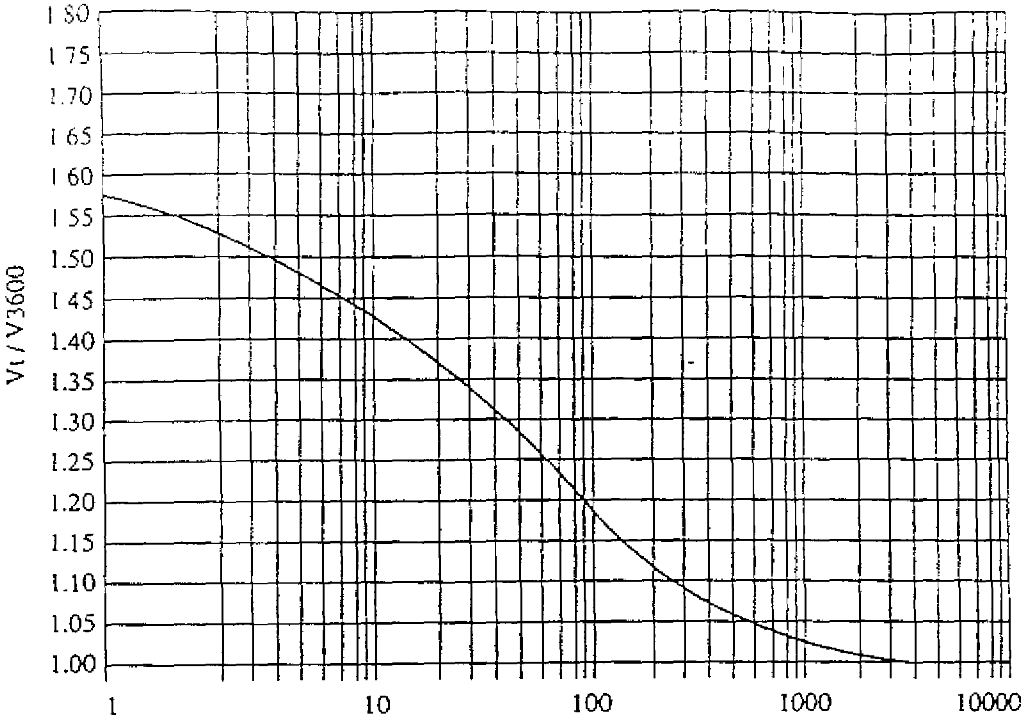
Table C6-5

Calculated Values	
V	132 ft/s
$\bar{z}$	360 ft
$I_{\bar{z}}$	0.302
$L_{\bar{z}}$	594.52 ft
Q^2	0.589
$\bar{V}_{\bar{z}}$	87.83 ft/s
$\hat{V}_{\bar{z}}$	136.24 ft/s
N_1	1.354
R_n	0.111
η	1.047
R_B	0.555
η	6.285
R_h	0.146
η	3.507
R_L	0.245
R^2	0.580
G	1.055
K	0.502
m_1	745,400 slugs
g_R	3.787

Along Wind Response - Example

Table C6-6

z (ft)	$\phi(z)$	X_{max} (z)	Rms.Acc. (ft/sec^2)	Rms. Acc. (milli-g)	Max. Acc. (ft/sec^2)	Max. Acc. (milli-g)
0	0.00	0.00	0.00	0.00	0.00	0.00
60	0.10	0.07	0.02	0.6	0.07	2.2
120	0.20	0.15	0.04	1.2	0.14	4.5
180	0.30	0.22	0.06	1.8	0.22	6.7
240	0.40	0.30	0.08	2.4	0.29	8.9
300	0.50	0.37	0.10	3.0	0.36	11.2
360	0.60	0.45	0.11	3.5	0.43	13.4
420	0.70	0.52	0.13	4.1	0.50	15.7
480	0.80	0.60	0.15	4.7	0.58	17.9
540	0.90	0.67	0.17	5.3	0.65	20.1
600	1.00	0.75	0.19	5.9	0.72	22.4



Gust Duration, Sec.

Fig. C6-1. Ratio of Probable Maximum Speed Averaged Over *t* sec to Hourly Mean Speed

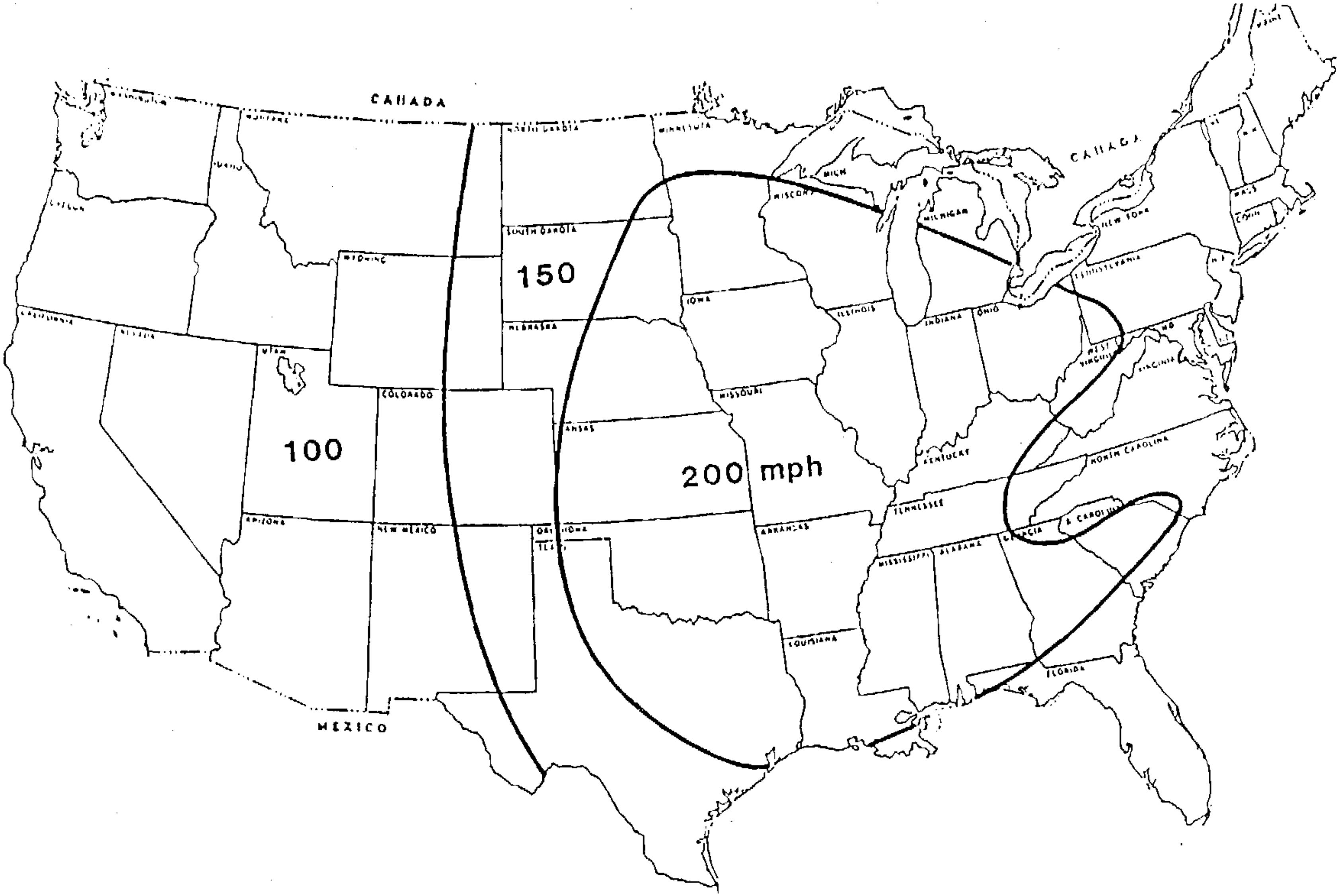
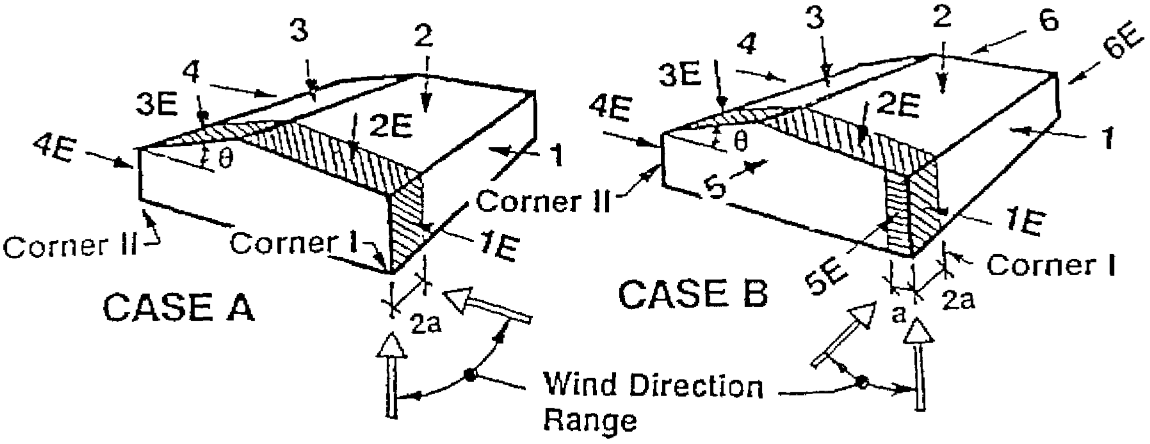
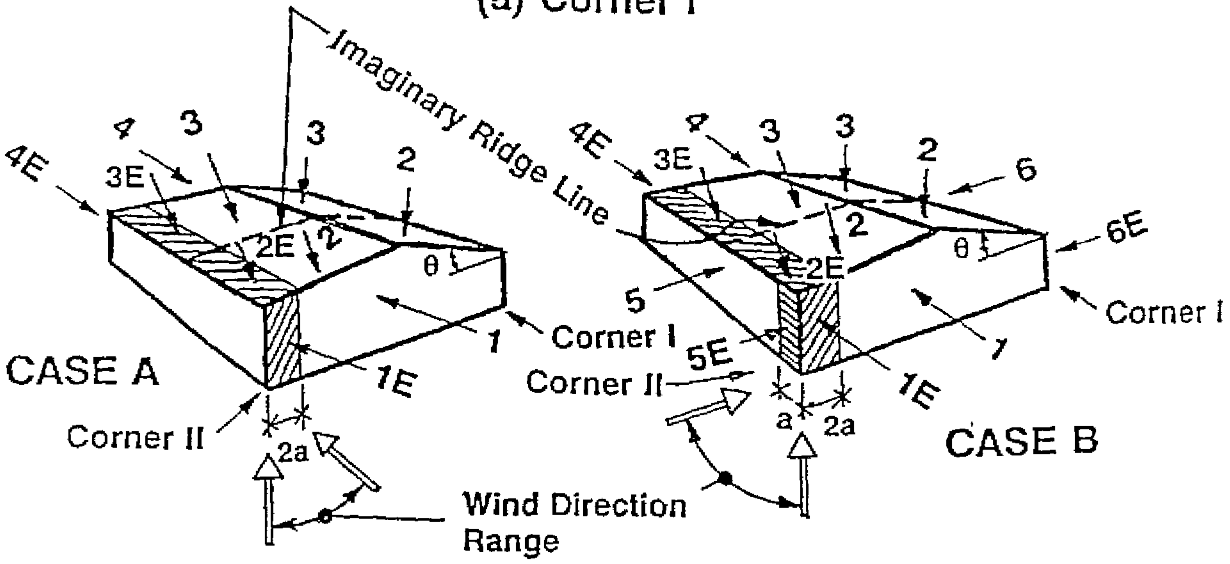


FIG. C6-1A. Tornadic Gust Wind Speed Corresponding to Annual Probability of 10^{-5} (Mean Recurrence Interval of 100,000 Years) (from ANSI/ANS 1983)



(a) Corner I



(b) Corner II (assume θ = 0°)

Fig. C6-2. Application of Load Cases for Two Windward Corners

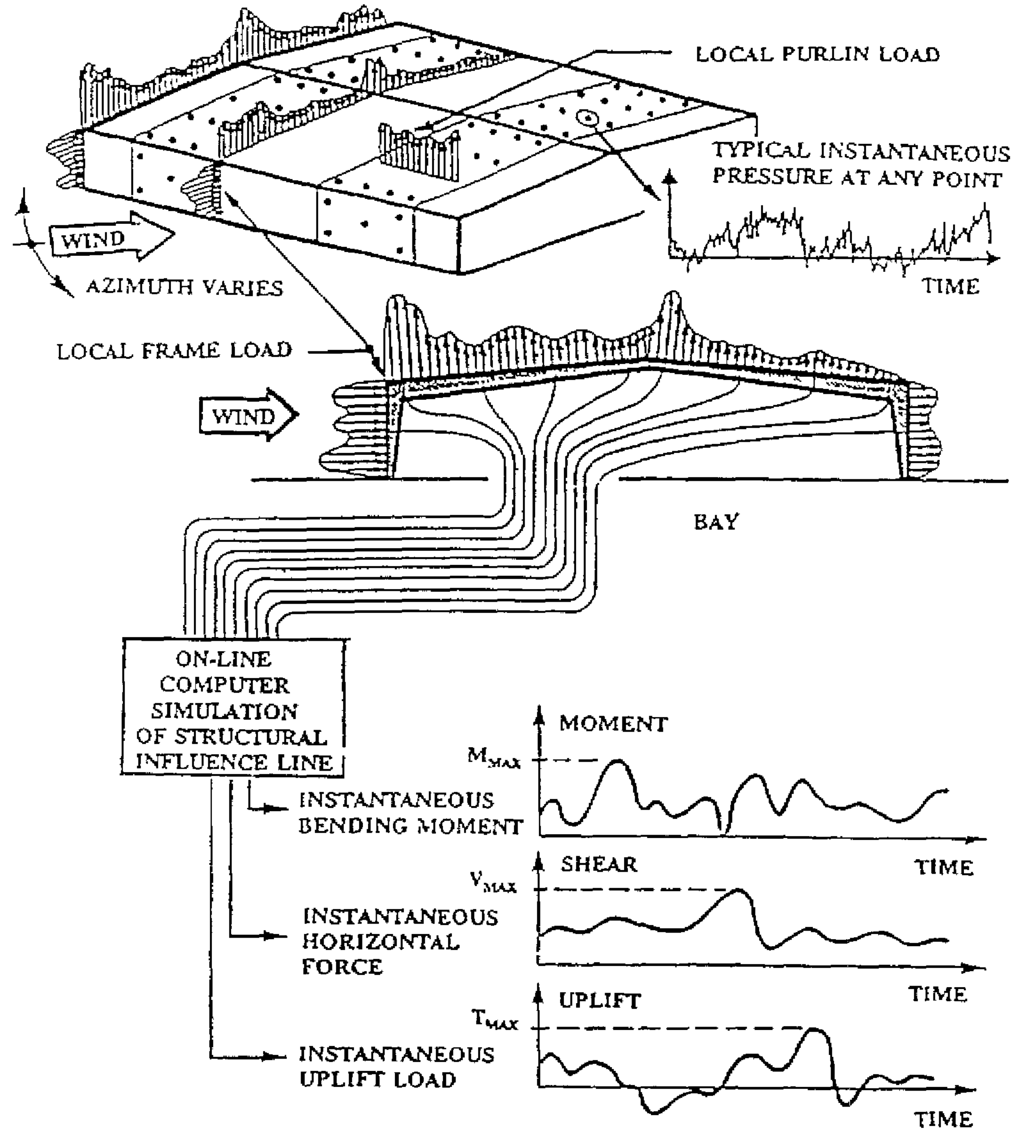


FIG. C6-3. Unsteady Wind Loads on Low Building for Given Wind Direction (after [11])

C7. Snow Loads

Methodology. The procedure established for determining design snow loads is as follows:

1. Determine the ground snow load for the geographic location (7.2 and the Commentary's C7.2).
2. Generate a flat roof snow load from the ground load with consideration given to (a) roof exposure (7.3.1 and the Commentary's C7.3 and C7.3.1), (b) roof thermal condition (7.3.2 and the Commentary's C7.3 and C7.3.2); (c) occupancy and function of structure (7.3.3 and the Commentary's C7.3.3)
3. Consider roof slope (7.4 through 7.4.5 and the Commentary's C7.4).
4. Consider partial loading (7.5 and the Commentary's C7.5).
5. Consider unbalanced loads (7.6 through 7.6.4 and the Commentary's C7.6).
6. Consider snow drifts: (a) on lower roofs (7.7 through 7.7.2 and the Commentary's C7.7) and (b) from projections (7.8 and the Commentary's C7.8).
7. Consider sliding snow (7.9 and the Commentary's C7.9).
8. Consider extra loads from rain on snow (7.10 and the Commentary's C7.10).
9. Consider ponding loads (7.11 and the Commentary's C7.11).
10. Consider existing roofs (7.12 and the Commentary's C7.12).
11. Consider other roofs and sites (the Commentary's C7.13)
12. Consider the consequences of loads in excess of the design value (immediately following).

Loads in Excess of the Design Value. The philosophy of the probabilistic approach used in this standard is to establish a design value that reduces the risk of a snow load-induced failure to an acceptably low level. Since snow loads in excess of the design value may occur, the implications of such "excess" loads should be considered. For example, if a roof is deflected at the design snow load so that slope to drain is eliminated, "excess" snow load might cause ponding (as discussed in the Commentary's C7.11) and perhaps progressive failure.

The snow load/dead load ratio of a roof structure is an important consideration when assessing the implications of "excess" loads. If the design snow load is exceeded, the percentage increase in total load would be greater for a lightweight structure (that is, one with a high snow load/dead load ratio) than for a heavy structure (that is, one with a low snow load/dead load ratio). For example, if a 40-lb/ft^2 (1.92 kN/m^2) roof snow load is exceeded by 20 lb/ft^2 (0.96 kN/m^2) for a roof having a 25-lb/ft^2 (1.19 kN/m^2) dead load, the total load increases by 31% from 65 to 85 lb/ft^2 (3.11 to 4.07 kN/m^2). If the roof had a 60-lb/ft^2 (2.87 kN/m^2) dead load, the total load would increase only by 20% from 100 to 120 lb/ft^2 (4.79 to 5.75 kN/m^2)

C7.2 Ground Snow Loads. The snow load provisions were developed from an extreme-value statistical analysis of weather records of snow on the ground [1]. The log normal distribution was selected to estimate ground snow loads, which have a 2% annual probability of being exceeded (50-year mean recurrence interval).

Maximum measured ground snow loads and ground snow loads with a 2% annual probability of being exceeded are presented in Table C7-1 for 204 National Weather Service (NWS) "first-order" stations at which ground snow loads have been measured for at least 11 years during the period 1952-1992.

Concurrent records of the depth and load of snow on the ground at the 204 locations in Table C7-1 were used to estimate the ground snow load and the ground snow depth having a 2% annual probability of being exceeded for each of these locations. The period of record for these 204 locations, where both snow depth and snow load have been measured, averages 33 years up through the winter of 1991-92. A mathematical relationship was developed between the 2% depths and the 2% loads. The nonlinear best-fit relationship between these extreme values was used to estimate 2% (50-year mean recurrence interval) ground snow loads at about 9200 other locations at which only snow depths were measured. These loads, as well as the extreme-value loads developed directly from snow load measurements at 204 first-order locations, were used to construct the maps.

In general, loads from these two sources were in agreement. In areas where there were differences, loads from the 204 first-order locations were considered to be more valuable when the map was constructed. This procedure ensures that the map is referenced to the NWS observed loads and contains spatial detail provided by snow-depth measurements at about 9200 other locations

The maps were generated from data current through the 1991-92 winter. Where statistical studies using more recent information are available, they may be used to produce improved design guidance.

However, adding a big snow year to data developed from periods of record exceeding twenty years will usually not change 50-year values much. As examples, the data bases for Boston and Chattanooga were updated to include the winters of 1992-93 and 1993-94 since record snows occurred there during that period. In Boston, 50-year loads based on water equivalent measurements only increased from 34 to 35 psf (1.63 to 1.68 kN/m^2) and loads generated from snow depth measurements remained at 25 psf (1.20 kN/m^2) In Chattanooga, loads generated from water equivalent measurements increased from 6 to 7 psf (0.29 to 0.34 kN/m^2) and loads generated from snow depth measurements remained at 6 psf (0 29 kN/m^2)

The following additional information was also considered when establishing the snow load zones on the map of the United States (Fig. 7-1)

1. The number of years of record available at each location.
2. Additional meteorological information available from NWS, Soil Conservation Service (SCS) snow surveys and other sources.
3. Maximum snow loads observed there.
4. Regional topography.
5. The elevation of each location.

The map is an updated version of those in the 1993 edition of this Standard and is the same as that in the 1995 edition.

In much of the south, infrequent but severe snowstorms disrupted life in the area to the point that meteorological observations were missed. In these and similar circumstances more value was given to the statistical values for stations with complete records. Year-by-year checks were made to verify the significance of data gaps.

The mapped snow loads cannot be expected to represent all the local differences that may occur within each zone. Because local differences exist, each zone has been positioned so as to encompass essentially all the statistical values associated with normal sites in that zone. Although the zones represent statistical values, not maximum observed values, the maximum observed values were helpful in establishing the position of each zone

For sites not covered in Fig. 7-1 design values should be established from meteorological information, with consideration given to the orientation, elevation, and records available at each location. The same method can also be used to improve upon the values presented in Fig. 7-1. Detailed study of a specific site may generate a design value lower than that indicated by the generalized national map. It is appropriate in such a situation to use the lower value established by the detailed study. Occasionally a detailed study may indicate that a higher design value should be used than the national map indicates. Again, results of the detailed study should be followed

The area covered by a site-specific case study will vary depending on local climate and topography. In some places, a single case study will suffice for an entire community, but in others, varying local conditions limit a "site" to a much smaller area The area of applicability usually becomes clear as information in the vicinity is examined for the case study

As suggested by the footnote, it is not appropriate to use only the site-specific information in Table C7-1 for design purposes. It lacks an appreciation for surrounding station information and, in a few cases, is based on rather short periods of record. The map or a site-specific case study provide more valuable information.

The importance of conducting detailed studies for locations not covered in Fig. 7-1 is shown in Table C7-2.

For some locations within the CS areas of the northeast (Fig. 7-1), ground snow loads exceed 100 lb/ft^2 (4 79 kN/m^2). Even in the southern portion of the Appalachian Mountains, not far from sites where a 15-lb/ft^2 (0.72 kN/m^2) ground snow load is appropriate, ground loads exceeding 50 lb/ft^2 (2 39 kN/m^2) may be required Lake-effect storms create requirements for ground loads in excess of 75 lb/ft^2 (3 59 kN/m^2) along portions of the Great Lakes. In some areas of the Rocky Mountains, ground snow loads exceed 200 lb/ft^2 (9.58 kN/m^2).

Local records and experience should also be considered when establishing design values.

The values in Table 7-1 are for specific Alaskan locations only and generally do not represent appropriate design values for other nearby locations They are presented to illustrate the extreme variability of snow loads within Alaska. This variability precludes statewide mapping of ground snow loads there.

Valuable information on snow loads for the Rocky Mountain states is contained in references [2] through [12].

Most of these references for the Rocky Mountain states use annual probabilities of being exceeded that are different from the 2% value (50-year mean recurrence interval) used in this standard. Reasonable, but not exact, factors for converting from other annual probabilities of being exceeded to the value herein are presented in Table C7-3.

For example, a ground snow load based on a 3 3% annual probability of being exceeded (30-year mean recurrence interval) should be multiplied by 1.18 to generate a value of p_g for use in Eq. 7-1.

The snow load provisions of several editions of the National Building Code of Canada served as a guide in preparing the snow load provisions in this standard. However, there are some important differences between the Canadian and the United States data bases. They include:

1. The Canadian ground snow loads are based on a

3.3% annual probability of being exceeded (30-year mean recurrence interval) generated by using the extreme-value, Type-I (Gumbel) distribution, while the normal-risk values in this standard are based on a 2% annual probability of being exceeded (50-year mean recurrence interval) generated by a log-normal distribution.

2. The Canadian loads are based on measured depths and regionalized densities based on 4 or less measurements per month. Because of the infrequency of density measurements, an additional weight of rain is added. [13] In this Standard the weight of the snow is based on many years of frequently-measured weights obtained at 204 locations across the United States. Those measurements contain many rain-on-snow events and thus a separate rain-on-snow surcharge load is not needed except for some roofs with a slope less than 1/2 in./ft (2.38°).

C7.3 Flat-Roof Snow Loads, p_f. The live load reductions in 4.8 should not be applied to snow loads. The minimum allowable values of p_f presented in 7.3 acknowledge that in some areas a single major storm can generate loads that exceed those developed from an analysis of weather records and snow load case studies.

The factors in this standard that account for the thermal, aerodynamic, and geometric characteristics of the structure in its particular setting were developed using the National Building Code of Canada as a point of reference. The case study reports in references [14] through [22] were examined in detail.

In addition to these published references, an extensive program of snow load case studies was conducted by eight universities in the United States, by the Corps of Engineers' Alaska District, and by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) for the Corps of Engineers. The results of this program were used to modify the Canadian methodology to better fit United States conditions. Measurements obtained during the severe winters of 1976-77 and 1977-78 are included. A statistical analysis of some of that information is presented in [23]. The experience and perspective of many design professionals, including several with expertise in building failure analysis, have also been incorporated.

The minimum values of p_f account for a number of situations that develop on roofs. They are particularly important considerations where p_g is 20 lb/sq ft (0.96 kN/m^2) or less. In such areas, single storms result in loadings for which Eq. 7-1 and the C_e and C_t values in Tables 7-2 and 7-3, respectively, underestimate loads.

C7.3.1 Exposure Factor, C_e. Except in areas of aerodynamic shade,' where loads are often increased by snow drifting, less snow is present on most roofs than on the ground. Loads in unobstructed areas of conventional flat roofs average less than 50% of ground loads in some parts of the country. The values in this standard are above-average values, chosen to reduce the risk of snow load-induced failures to an acceptably low level. Because of the variability of wind action, a conservative approach has been taken when considering load reductions by wind.

The effects of exposure are handled on two scales. First Eq. 7-1 contains a basic exposure factors of 0.7. Second, the type of terrain and the exposure of the roof are handled by exposure factor C_e. This two-step procedure generates ground-to-roof load reductions as a function of exposure that range from 0.49 to 0.91.

Table 7-2 has been changed from what appeared in a prior (1988) version of this Standard to separate regional wind issues associated with terrain from local wind issues associated with roof exposure. This was done to better define categories without significantly changing the values of C_e.

Although there is a single "regional" terrain category for a specific site, different roofs of a structure may have different exposure factors due to obstruction provided by higher portions of the structure or by objects on the roof. For example in terrain category C, an upper level roof could be fully exposed ($C_e = 0.9$) while a lower level roof would be partially exposed ($C_e = 1.0$) due to the presence of the upper level roof, as shown in Example 3 in the commentary.

The adjective "windswept" is used in the "mountainous areas" terrain category to preclude use of this category in those high mountain valleys that receive little wind.

The normal, combined exposure reduction in this standard is 0.70 as compared to a normal value of 0.80 for the ground-to-roof conversion factor in the 1990 National Building Code of Canada. The decrease from 0.80 to 0.70 does not represent decreased safety but arises due to increased choices of exposure and thermal classification of roofs (that is, six terrain categories, three roof exposure categories and four thermal categories in this standard versus three exposure categories and no thermal distinctions in the Canadian code).

It is virtually impossible to establish exposure definitions that clearly encompass all possible exposures that exist across the country. Because individuals may interpret exposure categories somewhat differently, the range in exposure has been divided into several categories rather than just two or three. A difference of opinion of one category results in about a 10% "error" using these several categories and an "error" of 25% or more if only three categories are used

C7.3.2 Thermal Factor, C_t. Usually, more snow will be present on cold roofs than on warm roofs. An exception to this is discussed below The thermal condition selected from Table 7-3 should represent that which is likely to exist during the life of the structure Although it is possible that a brief power interruption will cause temporary cooling of a heated structure, the joint probability of this event and a simultaneous peak snow load event is very small. Brief power interruptions and loss of heat are acknowledged in $C_t = 1.0$ category. Although it is possible that a heated structure will subsequently be used as an unheated structure, the probability of this is rather low. Consequently, heated structures need not be designed for this unlikely event

Some dwellings are not used during the winter Although their thermal factor may increase to 1 2 at that time, they are unoccupied, so their importance factor reduces to 0.8 The net effect is to require the same design load as for a heated, occupied dwelling

Discontinuous heating of structures may cause thawing of snow on the roof and subsequent refreezing in lower areas Drainage systems of such roofs have become clogged with ice, and extra loads associated with layers of ice several inches thick have built up in these undrained lower areas The possibility of similar occurrences should be investigated for any intermittently heated structure.

Similar icings may build up on cold roofs subjected to meltwater from warmer roofs above. Exhaust fans and other mechanical equipment on roofs may also generate meltwater and icings.

Icicles and ice dams are a common occurrence on cold eaves of sloped roofs They introduce problems related to leakage and to loads. Large ice dams that can prevent snow from sliding off roofs are generally produced by heat losses from within buildings. Icings associated with solar melting of snow during the day and refreezing along eaves at night are often small and transient. Although icings can occur on cold or warm roofs, roofs that are well insulated and ventilated are not commonly subjected to serious icings at their eaves Because ice dams can prevent load reductions by sliding on some warm ($C_t = 1.0$) roofs, the "unobstructed slippery surface" curve in Figure 7-2a now only applies to unventilated roofs with a thermal resistance equal to or greater than 30 $ft^2 \cdot hr \cdot F°/Btu$ (5.3 $K \cdot m^2/W$) and to ventilated roofs with a thermal resistance equal to or greater than 20 $ft^2 \cdot hr \cdot F°/Btu$ (3.5 $K \cdot m^2/W$). Roofs that are well insulated and ventilated have been given a $C_t = 1.1$ in Table 7-3. This increases their flat roof snow load p_f These provisions have been changed from the 1995 version of this Standard to cause a partial increase in loads when $C_t = 1.1$ instead of the "full" increase at both $C_t = 1$ 1 and 1 2. Methods of minimizing eave icings are discussed in [24] through [29]

Glass, plastic, and fabric roofs of continuously heated structures are seldom subjected to much snow load because their high heat losses cause snow melt and sliding For such specialty roofs, knowledgeable manufacturers and designers should be consulted The National Greenhouse Manufacturers Association [30] recommends use of C_t = 0 83 for continuously heated greenhouses and $C_t = 1.00$ for unheated or intermittently heated greenhouses. They suggest a value of I = 1.0 for retail greenhouses and I = 0.8 for all other greenhouses. To qualify as a continuously heated greenhouse, a production or retail greenhouse must have a constantly maintained temperature of 50°F (10°C) or higher during winter months. In addition it must also have a maintenance attendant on duty at all times or an adequate temperature alarm system to provide warning in the event of a heating system failure. Finally, the greenhouse roof material must have a thermal resistance, R-value, less than 2 $ft^2 \cdot hr \cdot F°/Btu$ (0.4 $K \cdot m^2/W$). In this standard, the C_t factor for such continuously heated greenhouses is set at 0 85 An unheated or intermittently heated greenhouse is any greenhouse that does not meet the requirements of a continuously heated single or double glazed greenhouse. Greenhouses should be designed so that the structural supporting members are stronger than the glazing If this approach is used, any failure caused by heavy snow loads will be localized and in the glazing This should avert progressive collapse of the structural frame. Higher design values should be used where drifting or sliding snow is expected.

Little snow accumulates on warm air-supported fabric roofs because of their geometry and slippery surface However, the snow that does accumulate is a significant load for such structures and should be considered Design methods for snow loads on air structures are discussed in [31] and [32].

The combined consideration of exposure and thermal conditions generates ground-to-roof factors that range from a low of 0 49 to a high of 1 09 The equivalent ground-to-roof factors in the 1990 National Building Code of Canada are 0.8 for sheltered roofs, 0.6 for exposed roofs and 0 4 for exposed roofs in exposed areas north of the tree line, all regardless of their thermal condition.

Reference [33] indicates that loads exceeding those calculated using this Standard can occur on roofs that receive little heat from below. Limited case histories for freezer buildings suggest that the C_t factor may be larger than 1.2.

C7.3.3 Importance Factor, I. The importance factor I has been included to account for the need to relate design loads to the consequences of failure. Roofs of most structures having normal occupancies and functions are designed with an importance factor of 1.0, which corresponds to unmodified use of the statistically determined ground snow load for a 2% annual probability of being exceeded (50-year mean recurrence interval)

A study of the 204 locations in Table C7-1 showed that the ratio of the values for 4% and 2% annual probabilities of being exceeded (the ratio of the 25-year to 50-year mean recurrence interval values) averaged 0.80 and had a standard deviation of 0.06. The ratio of the values for 1% and 2% annual probabilities of being exceeded (the ratio of the 100-year to 50-year mean recurrence interval values) averaged 1.22 and had a standard deviation of 0.08. On the basis of the nationwide consistency of these values it was decided that only one snow load map need be prepared for design purposes and that values for lower and higher risk situations could be generated using that map and constant factors.

Lower and higher risk situations are established using the importance factors for snow loads in Table 7-4. These factors range from 0.8 to 1.2. The factor 0.8 bases the average design value for that situation on an annual probability of being exceeded of about 4% (about a 25-year mean recurrence interval) The factor 1.2 is nearly that for a 1% annual probability of being exceeded (about a 100-year mean recurrence interval)

C7.3.4 Minimum Allowable Values of p_f for Low Slope Roofs. These minimums account for a number of situations that develop on low slope roofs They are particularly important considerations where p_g is 20 lb/ft^2 (0.96 kN/m^2) or less. In such areas, single storms can result in loading for which the basic exposure factor of 0.7 as well as the C_e and C_t factors do not apply.

C7.4 Sloped-Roof Snow Loads, p_s. Snow loads decrease as the slopes of roofs increase. Generally, less snow accumulates on a sloped roof because of wind action Also, such roofs may shed some of the snow that accumulates on them by sliding and improved drainage of meltwater. The ability of a sloped roof to shed snow load by sliding is related to the absence of obstructions not only on the roof but also below it, the temperature of the roof, and the slipperiness of its surface. It is difficult to define "slippery" in quantitative terms. For that reason a list of roof surfaces that qualify as slippery and others that do not, are presented in the Standard itself. Most common roof surfaces are on that list. The slipperiness of other surfaces is best determined by comparisons with those surfaces. Some tile roofs contain built-in protrusions or have a rough surface which prevents snow from sliding. However, snow will slide off other smooth-surfaced tile roofs. When a surface may or may not be slippery the implications of treating it either as a slippery or non-slippery surface should be determined.

Discontinuous heating of a building may reduce the ability of a sloped roof to shed snow by sliding, since meltwater created during heated periods may refreeze on the roof's surface during periods when the building is not heated, thereby 'locking' the snow to the roof.

All these factors are considered in the slope reduction factors presented in Fig. 7-2 which are supported by references [33,34,35,36]. The thermal resistance requirements have been added to the "unobstructed slippery surfaces" curve in Figure 7-2a to prevent its use for roofs on which ice dams often form since ice dams prevent snow from sliding Mathematically the information in Fig. 7-2 can be represented as follows.

1. Warm roofs (C_t = 1.0 or less)

   (a) Unobstructed slippery surfaces with $R \geq 30$ ft^2·hr·F°/Btu (5.3 K•m^2/W) if unventilated and $R \geq 20$ ft^2·hr·F°/Btu (3.5 K•m^2/W) if ventilated

0-5° slope	$C_s = 1.0$
5-70° slope	$C_s = 1.0 - (\text{slope} - 5°)/65°$
>70° slope	$C_s = 0$

   (b) All other surfaces:

0-30° slope	$C_s = 1.0$
30-70° slope	$C_s = 1.0 - (\text{slope} - 30°)/40°$
>70° slope	$C_s = 0$

2. Cold Roofs (C_t = 1.2):

   (a) Unobstructed slippery surfaces:

0-15° slope	$C_s = 1.0$
15-70° slope	$C_s = 1 - (\text{slope} - 15°)/55°$
>70° slope	$C_s = 0$

   (b) All other surfaces:

0-45° slope	$C_s = 1.0$
45-70° slope	$C_s = 1.0 - (\text{slope} - 45°)/25°$
>70° slope	$C_s = 0$

If the ground (or another roof of less slope) exists near the eave of a sloped roof, snow may not be able to slide completely off the sloped roof. This may result in the elimination of snow loads on upper portions of the roof and their concentration on lower portions. Steep A-frame roofs that nearly reach the ground are subject to such conditions Lateral as well as vertical loads induced by such snow should be considered for such roofs.

C7.4.3 Roof Slope Factor for Curved Roofs. These provisions have been changed from those in the 1993 edition of this Standard to cause the load to diminish along the roof as the slope increases.

C7.4.4 Roof Slope Factor for Multiple Folded Plate, Sawtooth, and Barrel Vault Roofs Because these types of roofs collect extra snow in their valleys by wind drifting and snow creep and sliding, no reduction in snow load should be applied because of slope

C7.4.5 Ice Dams and Icicles Along Eaves. The intent is to consider heavy loads from ice that forms along eaves only for structures where such loads are likely to form It is also not considered necessary to analyse the entire structure for such loads, just the eaves themselves.

C7.5 Unloaded Portions. In many situations a reduction in snow load on a portion of a roof by wind scour, melting, or snow-removal operations will simply reduce the stresses in the supporting members However, in some cases a reduction in snow load from an area will induce heavier stresses in the roof structure than occur when the entire roof is loaded. Cantilevered roof joists are a good example, removing half the snow load from the cantilevered portion will increase the bending stress and deflection of the adjacent continuous span. In other situations adverse stress reversals may result

The intent is not to require consideration of multiple "checkerboard" loadings.

Separate, simplified provisions have been added for continuous beams to provide specific partial loading requirements for that common structural system.

C7.6 Unbalanced Roof Snow Loads. Unbalanced snow loads may develop on sloped roofs because of sunlight and wind Winds tend to reduce snow loads on windward portions and increase snow loads on leeward portions Since it is not possible to define wind direction with assurance, winds from all directions should generally be considered when establishing unbalanced roof loads.

C7.6.1 Unbalanced Snow Loads on Hip and Gable Roofs. The unbalanced uniform snow load on the leeward side was 1.5 p_s/C_e and 1.3 p_s/C_e in the 1993 and 1995 editions of this standard In this edition, a 1993 approach is prescribed for roofs with small eave to ridge distances and the 15° cutoff is eliminated. For moderate to large roof slopes (i e. roof slopes between $275\beta p_f/\gamma W$ and 70°), the unbalanced snow load on the leeward side varies between 1.5 p_s/C_e and 1.8 p_s/C_e as a function of β. The gable roof drift parameter, β, quantifies the likelihood of wind induced drifting across the ridge line. That is, for small values of L/W one expects significant leeward drifts only for wind essentially perpendicular to the ridge line, while for larger values of L/W one gets significant drifts for a larger range of wind directions. For these moderate to large roof slopes, the maximum leeward side drift load tends to occur between the ridge and the eave For these cases, a uniform load intensity of $1.2(1 + \beta/2)p_s/C_e$ is prescribed.

For smaller roof slopes the load at the eave is limited to the "balanced" portion, 1.2 p_f/C_e, plus γh_e where h_e is the elevation difference between the ridge and eave. The balanced portion, $1.2p_f/Ce$, nominally corresponds to the ground load if the structure is unheated (i.e. $C_t = 1.2$). For very small roof slopes the aerodynamic shade region fills, resulting in the top of the leeward snow being nominally horizontal

The angle, $275\beta p_f/\gamma W$, corresponds to the case where the maximum leeward side snow load occurs at the midpoint between the ridge and the eave As sketched in Fig C7-1, it is calculated by equating the area of snow transported from the windward side

$$A_w = \frac{\beta}{2}\,(1.2\,\frac{p_f}{\gamma})\,W \qquad \text{C7-1}$$

with the area of a triangular surcharge drift on the leeward side.

$$A_d = \frac{1}{2}\,(\frac{W}{2})\,(\frac{W}{2}\,\tan\theta) \qquad \text{C7-2}$$

Using the small angle approximation (i e. $\theta \cong \tan\theta$) for angles in radians and converting from radians to degrees,

$$\theta = 275\beta p_f/\gamma W \qquad \text{C7-3}$$

The gable roof drift parameter β is based upon an analysis of case histories presented in [56].

The design snow load on the windward side for the unbalanced case, 0.3 P_f (or 0.3 P_s) is based upon case histories presented in [21] and [56]. The lower limit of $\theta = 70/W + 0.5$ is intended to exclude low slope roofs, such as membrane roofs, on which significant unbalanced loads have not been observed [57].

The provisions of the Standard and this Commentary correspond to the case where the gable or hip roof, in plan, is symmetric about the ridge line, specifically roofs for which the eave to ridgeline distance, W, is the same for both sides. For asymmetric roofs, the unbalanced load for the side with the smaller W should be increased to account for the larger snow source area on the opposite side, following the procedures discussed in [56]

C7.6.2 Unbalanced Snow Loads for Curved Roofs. The method of determining roof slope is the same as the 1995 edition of this standard. C_s is based on the actual slope not an equivalent slope. These provisions do not apply to roofs that are concave upward. For such roofs, see Section 7.13.

C7.6.3 Unbalanced Snow Loads for Multiple Folded Plate, Sawtooth, and Barrel Vault Roofs. A minimum slope of 3/8 in./ft (1.79°) has been established to preclude the need to determine unbalanced loads for most internally-drained, membrane roofs which slope to internal drains. Case studies indicate that significant unbalanced loads can occur when the slope of multiple gable roofs is as low as 1/2 in./ft (2.38°)

The unbalanced snow load in the valley is 2 p_f/C_e to create a total unbalanced load that does not exceed a uniformly distributed ground snow load in most situations

Sawtooth roofs and other "up-and-down" roofs with significant slopes tend to be vulnerable in areas of heavy snowfall for the following reasons:

1. They accumulate heavy snow loads and are therefore expensive to build.
2. Windows and ventilation features on the steeply sloped faces of such roofs may become blocked with drifting snow and be rendered useless.
3. Meltwater infiltration is likely through gaps in the steeply sloped faces if they are built as walls, since slush may accumulate in the valley during warm weather. This can promote progressive deterioration of the structure.
4. Lateral pressure from snow drifted against clerestory windows may break the glass.
5. The requirement that snow above the valley not be at an elevation higher than the snow above the ridge may limit the unbalanced load to less than 2 p_f/C_e.

C7.6.4 Unbalanced Snow Loads for Dome Roofs. This provision is based on a similar provision in the 1990 National Building Code of Canada

C7.7 Drifts on Lower Roofs (Aerodynamic Shade). When a rash of snow-load failures occurs during a particularly severe winter, there is a natural tendency for concerned parties to initiate across-the-board increases in design snow loads. This is generally a technically ineffective and expensive way of attempting to solve such problems, since most failures associated with snow loads on roofs are caused not by moderate overloads on every square foot (square meter) of the roof but rather by localized significant overloads caused by drifted snow.

It is extremely important to consider localized drift loads in designing roofs. Drifts will accumulate on roofs (even on sloped roofs) in the wind shadow of higher roofs or terrain features. Parapets have the same effect. The affected roof may be influenced by a higher portion of the same structure or by another structure or terrain feature nearby if the separation is 20 feet (6.1 meters) or less. When a new structure is built within 20 feet (6.1 meters) of an existing structure, drifting possibilities should also be investigated for the existing structure. The snow that forms drifts may come from the roof on which the drift forms, from higher or lower roofs or, on occasion, from the ground.

The leeward drift load provisions are based on studies of snow drifts on roofs [37 through 40]. Drift size is related to the amount of driftable snow as quantified by the upwind roof length and the ground snow load. Drift loads are considered for ground snow loads as low as 5 lb/ft^2 (0.24 kN/m^2). Case studies show that, in regions with low ground snow loads, drifts 3 to 4 ft (0.9 to 1.2 meters) high can be caused by a single storm accompanied by high winds.

A change from a prior (1988) edition of this Standard involves the width w when the drift height h_d from Fig. 7-9, exceeds the clear height h_c. In this situation the width of the drift is taken as 4 h_d^2/h_c with a maximum value of 8 h_c. This drift width relation is based upon equating the cross-sectional area of this drift (i.e., 1/2 h_c x w) with the cross-sectional area of a triangular drift where the drift height is not limited by h_c (i.e., 1/2 h_d x 4 h_d). The upper limit of drift width is based on studies by Finney [41] and Tabler [42] which suggest that a "full" drift has a rise-to-run of about 1:6.5, and case studies [43] which show observed drifts with a rise-to-run greater than 1:10.

The drift height relationship in Figure 7-9 is based on snow blowing off a high roof upwind of a lower roof. The change in elevation where the drift forms is called a "leeward step." Drifts can also form at "windward steps." An example is the drift that forms at the downwind end of a roof that abuts a higher structure there. Figure 7-7 shows "windward step" and "leeward step" drifts.

For situations having the same amount of available snow (i.e. upper and lower roofs of the same length) the drifts which form in leeward steps are larger than those which form in windward steps. In the previous version of the Standard, the windward drifts height was given as 1/2h_d from Fig. 7-9 using the length of the lower roof for l_u. Based upon recent case history experience in combination with a prior study [45], a value of 3/4 is now prescribed.

Depending on wind direction, any change in elevation between roofs can be either a windward or leeward step. Thus the height of a drift is determined for each wind direction as shown in Example 3, and the larger of the two heights is used as the design drift.

The drift load provisions cover most, but not all, situations References [41] and [46] document a larger drift than would have been expected based on the length of the upper roof. The larger drift was caused when snow on a somewhat lower roof, upwind of the upper roof, formed a drift between those two roofs allowing snow from the upwind lower roof to be carried up onto the upper roof then into the drift on its downwind side It was suggested that the sum of the lengths of both roofs could be used to calculate the size of the leewind drift.

In another situation [47] a long "spike" drift was created at the end of a long skylight with the wind about 30 degrees off the long axis of the skylight The skylight acted as a guide or deflector which concentrated drifting snow. This caused a large drift to accumulate in the lee of the skylight This drift was replicated in a wind tunnel.

As shown in Figure 7-8, the clear height, h_c, is determined based on the assumption that the upper roof is blown clear of snow in the vicinity of the drift. This is a reasonable assumption when the upper roof is nearly flat. However, sloped roofs often accumulate snow at eaves as illustrated in Figures 7-3 and 7-5 For such roofs, it is appropriate to assume that snow at the upper roof edge effectively increases the height difference between adjacent roofs. Using half the depth of the unbalanced snow load in the calculation of h_c produces more realistic estimates of drift loads.

Tests in wind tunnels [48 and 49] and flumes [44] have proven quite valuable in determining patterns of snow drifting and drift loads. For roofs of unusual shape or configuration, wind tunnel or water-flume tests may be needed to help define drift loads.

C7.8 Roof Projections. Drifts around penthouses, roof obstructions and parapet walls are also of the "windward step" type since the length of the upper roof is small or no upper roof exists.Solar panels, mechanical equipment, parapet walls, and penthouses are examples of roof projections that may cause "windward" drifts on the roof around them. The drift-load provisions in 7.7 and 7.8 cover most of these situations adequately, but flat-plate solar collectors may warrant some additional attention. Roofs equipped with several rows of them are subjected to additional snow loads. Before the collectors were installed, these roofs may have sustained minimal snow loads, especially if they were windswept. Since a roof with collectors is apt to be somewhat "sheltered" by the collectors, it seems appropriate to assume the roof is partially exposed and calculate a uniform snow load for the entire area as though the collectors did not exist. Second, the extra snow that might fall on the collectors and then slide onto the roof should be computed using the `cold roofs-all other surfaces' curve in Fig 7-2b This value should be applied as a uniform load on the roof at the base of each collector over an area about 2 feet (0 6 meters) wide along the length of the collector The uniform load combined with the load at the base of each collector probably represents a reasonable design load for such situations, except in very windy areas where extensive snow drifting is to be expected among the collectors. By elevating collectors several feet (a meter or more) above the roof on an open system of structural supports, the potential for drifting will be diminished significantly Finally, the collectors themselves should be designed to sustain a load calculated by using the `unobstructed slippery surfaces' curve in Fig. 7-2a. This last load should not be used in the design of the roof itself, since the heavier load of sliding snow from the collectors has already been considered The influence of solar collectors on snow accumulation is discussed in [50] and [51]

C7.9 Sliding Snow. Situations that permit snow to slide onto lower roofs should be avoided [52] Where this is not possible, the extra load of the sliding snow should be considered. Roofs with little slope have been observed to shed snow loads by sliding. Consequently, it is prudent to assume that any upper roof sloped to an unobstructed eave is a potential source of sliding snow

The dashed lines in Figs. 7-2a and 7-2b should not be used to determine the total load of sliding snow available from an upper roof, since those lines assume that unobstructed slippery surfaces will have somewhat less snow on them than other surfaces because they tend to shed snow by sliding. To determine the total sliding load available from the upper roof, it is appropriate to use the solid lines in Fig 7-2a and 7-2b. The final resting place of any snow that slides off a higher roof onto a lower roof will depend on the size, position, and orientation of each roof [35] Distribution of sliding loads might vary from a uniform load 5 feet (1.5 meters) wide, if a significant vertical offset exists between the two roofs, to a 20-foot (6 1 meters)-wide uniform load, where a low-slope upper roof slides its load onto a second roof that is only a few feet (about a meter) lower or where snow drifts on the lower roof create a sloped surface that promotes lateral movement of the sliding snow.

In some instances a portion of the sliding snow may be expected to slide clear of the lower roof. Nevertheless, it is prudent to design the lower roof for a substantial portion of the sliding load in order to account for any dynamic effects that might be associated with sliding snow.

Snow guards are needed on some roofs to prevent roof damage and eliminate hazards associated with sliding snow [53]. When snow guards are added to a sloping roof, snow loads on the roof can be expected to increase. Thus, it may be necessary to strengthen a roof before adding snow guards. When designing a roof that will likely need snow guards in the future, it may be appropriate to use the "all other surfaces" curves in Figure 7-2 not the "unobstructed slippery surfaces" curves.

C7.10 Rain on Snow Surcharge Load. The ground snow-load measurements on which this standard is based contain the load effects of light rain on snow. However, since heavy rains percolate down through snowpacks and may drain away, they might not be included in measured values. Where p_g is greater than 20 psf (0.96 kN/m^2), it is assumed that the full rain-on-snow effect has been measured and a separate rain-on-snow surcharge is not needed. The temporary roof load contributed by a heavy rain may be significant. Its magnitude will depend on the duration and intensity of the design rainstorm, the drainage characteristics of the snow on the roof, the geometry of the roof, and the type of drainage provided. Loads associated with rain on snow are discussed in [54] and [55]

Water tends to remain in snow much longer on relatively flat roofs than on sloped roofs. Therefore, slope is quite beneficial, since it decreases opportunities for drain blockages and for freezing of water in the snow

For a roof with a 1/4-in./ft (1 19°) slope, where $p_g = 20$ lb/ft^2 (0.96 kN/m^2), $p_f = 18$ lb/ft^2 (0 86 kN/m^2), and the minimum allowable value of p_f is 20 lb/ft^2 (0.96 kN/m^2), the rain-on-snow surcharge of 5 lb/ft^2 (0.24 kN/m^2) would be added to the 18-lb/ft^2 (0 86 kN/m^2) flat roof snow load to generate a design load of 23 lb/ft^2 (1.10 kN/m^2).

C7.11 Ponding Instability. Where adequate slope to drain does not exist, or where drains are blocked by ice, snow meltwater and rain may pond in low areas. Intermittently heated structures in very cold regions are particularly susceptible to blockages of drains by ice. A roof designed without slope or one sloped with only 1/8 in./ft (0.6°) to internal drains probably contains low spots away from drains by the time it is constructed When a heavy snow load is added to such a roof, it is even more likely that undrained low spots exist. As rainwater or snow meltwater flows to such low areas, these areas tend to deflect increasingly, allowing a deeper pond to form. If the structure does not possess enough stiffness to resist this progression, failure by localized overloading can result. This mechanism has been responsible for several roof failures under combined rain and snow loads.

It is very important to consider roof deflections caused by snow loads when determining the likelihood of ponding instability from rain-on-snow or snow meltwater.

Internally drained roofs should have a slope of at least 1/4 in /ft (1.19°) to provide positive drainage and to minimize the chance of ponding. Slopes of 1/4 in./ft (1.19°) or more are also effective in reducing peak loads generated by heavy spring rain on snow Further incentive to build positive drainage into roofs is provided by significant improvements in the performance of waterproofing membranes when they are sloped to drain.

Rain loads and ponding instability are discussed in detail in Section 8 of this standard.

C7.12 Existing Roofs. Numerous existing roofs have failed when additions or new buildings nearby caused snow loads to increase on the existing roof. A prior (1988) edition of this Standard mentioned this issue only in its Commentary where it was not a mandatory provision. The 1995 edition moved this issue to the Standard.

The addition of a gable roof alongside an existing gable roof as shown in Figure C7-2 most likely explains why some such metal buildings failed in the South during the winter of 1992-93. The change from a simple gable roof to a multiple folded plate roof increased loads on the original roof as would be expected from Section 7.6.3. Unfortunately, the original roofs were not strengthened to account for these extra loads and they collapsed.

If the eaves of the new roof in Figure C7-2 had been somewhat higher than the eaves of the existing roof, the exposure factor C_e, for the original roof may have increased thereby increasing snow loads on it. In addition, drift loads and loads from sliding snow would also have to be considered.

C7.13 Other Roofs and Sites. Wind tunnel model studies, similar tests employing fluids other than air, for example water flumes, and other special experimental and computational methods have been used with success to establish design snow loads for other roof geometries and complicated sites [44, 48 and 49]. To be reliable, such methods must reproduce the mean and turbulent characteristics of the wind and the manner in which snow particles are deposited on roofs then redistributed by wind action. Reliability should be demonstrated through comparisons with situations for which full-scale experience is available.