ROOF LOADS AND DRAINAGE

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1.0 SCOPE

This document provides recommendations for snow loads, roof live loads, rain loads, and roof drainage for the design of new roofs of buildings and other structures. It also provides recommendations for snow monitoring and removal plans.

1.1 Changes

October 2021. Interim revision. The following change was made:

A. Clarified the Human Factors section to allow emergency response other than snow removal.

July 2021. Interim revision. The following changes were made:

A. Moved guidance on snow monitoring and removal plans to Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*.

B. Added recommendations for specific design working life and consequence class for the Eurocode.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Design Loads and Methods

Unless otherwise noted in this data sheet, the recommended snow, rain, and roof live loads are allowable loads (characteristic loads); that is, they do not include any load factors.

2.2 Combinations of Loads

Design the roof to resist the effects of dead loads in combination with the more demanding of the following roof live or environmental (e.g., rain or snow) loads. However, ensure these loads do not result in a design that is less robust than required by the applicable building code.

A. The balanced (uniform) or unbalanced snow loads, including snow drift surcharge and rain-on-snow surcharge where applicable, in accordance with Section 2.4

B. The rain loads in accordance with Section 2.5 and precluding instability from ponding

C. Superimposed roof live loads, as specified, to account for the use and maintenance of the roof and the occupancy of the building/structure

D. A minimum unfactored (characteristic) roof live load of 20 psf (1.0 kN/m^2) except when a reduction in the minimum roof live load is appropriate, as described in Section 2.3

2.3 Roof Live Load

2.3.1 Reduction of Roof Live Load

Refer to Figure 2.3.1 for the determination of applicable roof live load reduction.

A. Reductions in the roof live load of 20 psf (1.0 kN/m^2), as specified in Section 2.3.2, may be used where permitted by applicable building codes and standards, as follows:

1. For all types of roof construction where the roof slope is at least 4 in 12 (18.4°), and for curved roofs with a rise of at least 1/8 the span.

2. For lightweight roof construction (which includes metal roofs, steel deck, boards-on-joists, plywood sheathing, and similar constructions) only where both of the following conditions are met:

a. The roof slope is at least 1/4 in 12 (1.2° or 2%), and

b. The roof snow load is zero, or the supported combined unfactored (characteristic) dead load plus resultant roof live load (reduced) is at least 28 psf (1.3 kN/m^2).

B. Do not use roof live load reduction for the following:

1. Roofs that can have an occupancy function, such as roofs on which an assembly or congregation of people is allowed or intended (e.g., some roof gardens, vegetated green roofs, and roofs that function as balconies, elevated terraces, or viewing platforms).

2. Roofs used for storage, including car parking garage roofs.

3. Roofs where the code-required unfactored (characteristic) live load is greater than 75 psf (3.6 kN/m^2).

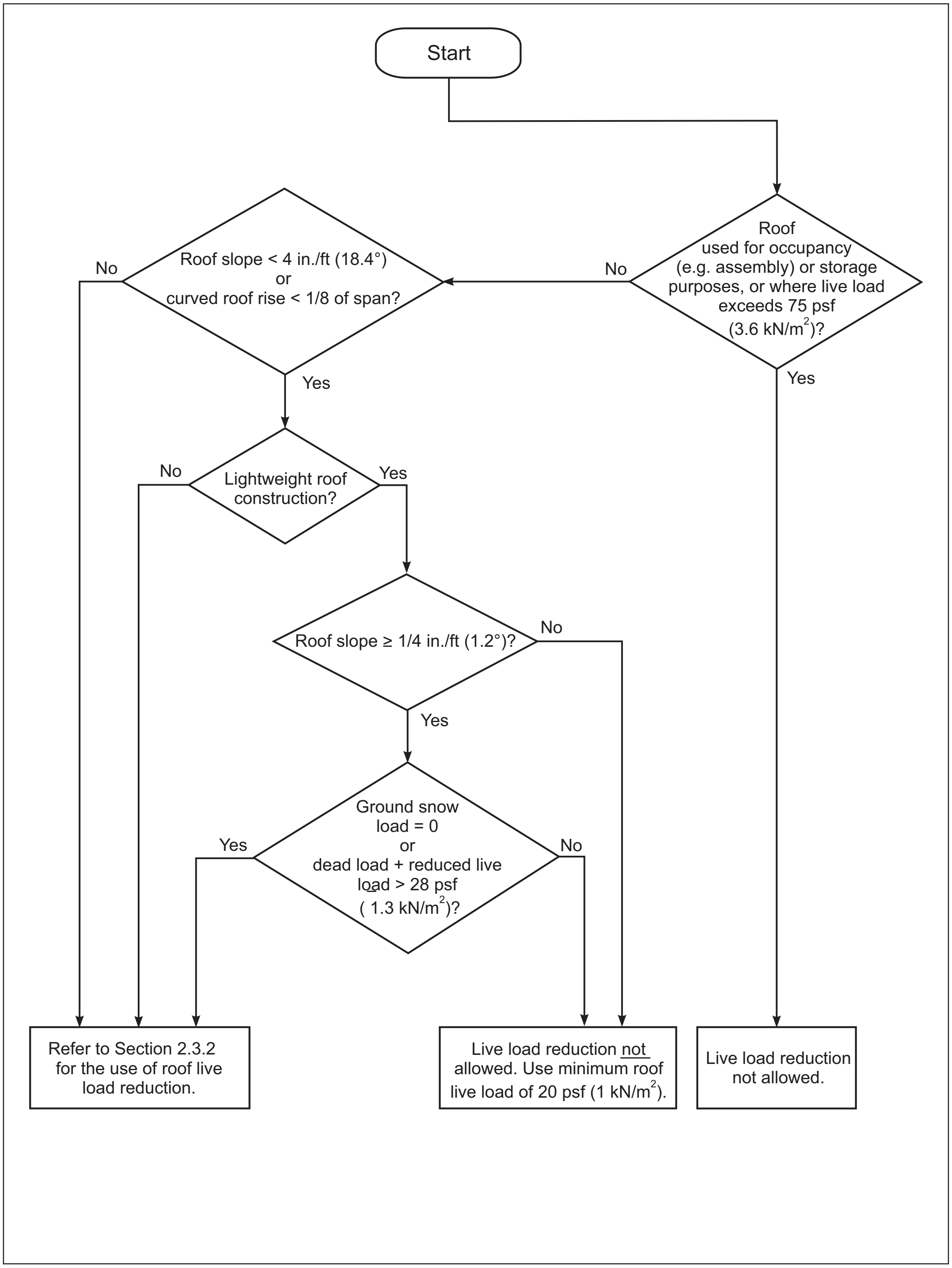


Fig. 2.3.1. Roof live load reduction flow chart

2.3.2 Reduced Roof Live Load Calculation

Where roof live load reduction is permissible under Section 2.3.1, use the following roof live load reduction procedure (TA = tributary area):

A. TA ≤ 200 ft^2 (19 m^2): No roof live load reduction allowed; use 20 psf (1.0 kN/m^2).

B. 200 ft^2 (19 m^2 < TA = < 600 ft^2 (56 m^2):

Roof live load (psf) = (1.2 - 0.001 [TA]) (20 psf).

or

Roof live load (kN/m^2) = (1.2 - 0.0108 [TA]) (1.0 kN/m^2).

C. TA > 600 ft^2 (56 m^2): Roof live load = 12 psf (0.6 kN/m^2).

For example, if TA = 400 ft^2 (37.5 m^2), then the minimum reduced roof live load is 0.8 x 20 psf (1.0 kN/m^2) = 16 psf (0.8 kN/m^2).

For a continuous structural roof system, such as a concrete slab, use a tributary length equal to the span (use the lesser span for a two-way slab system), and use a tributary width not greater than 1.5 x tributary span; in other words: TA = 1.5 (tributary span)^2. The same technique can be used for one-way systems such as metal roof deck, standing seam roofs, of lap seam roofs; however, based on typical spans, the TA will usually be less than 200 ft^2 (19 m^2) and therefore will not be eligible for roof live load reduction.

2.4 Snow and Ice Loads

2.4.1 General Methodology

2.4.1.1 Determination of Roof Design Snow Loads

Determine roof design snow loads using the recommendations of this section in conjunction with the combinations described in Section 2.2. For roofs of unusual shape or configuration, use wind-tunnel or analytical modeling techniques to help establish design snow loads.

Use the following steps to determine unfactored roof design snow loads. Refer to Section 2.8 for recommendations when using other codes and standards.

1. Determine the ground snow load (Section 2.4.2 and Appendix C).
2. Calculate the flat roof snow load (Section 2.4.3.1).
3. Adjust the flat roof snow load for geometry (Section 2.4.4).
4. Calculate the surcharge load from drift and sliding snow where applicable.
   a. Calculate drift loads (Section 2.4.5.1).
   b. Calculate the sliding snow load (Section 2.4.5.2).
5. Determine the Rain-on-Snow surcharge load where applicable (Section 2.4.3.2).

The scenarios of snow to examine depending upon the geometry of the roof layout. Scenarios may involve balanced and unbalanced load cases, and effects of orthogonal compass directions.

2.4.1.2 Snow Load Notation

C_e = exposure factor.

C_s = slope factor.

C_t = thermal factor.

D = snow weight density (pcf [kN/m^3]) of drifted snow.

h_b = height of balanced uniform snow load (ft [m]) (i.e., balanced snow load P_f or P_s divided by D).

h_c = clear height from top of balanced snow load (ft [m]) to the closest point(s) on adjacent upper roof; to the top of parapet; or to the top of a roof projection.

h_d = maximum height of snow drift surcharge above balanced snow load (ft [m]).

h_r = difference in height between the upper roof (including parapets) and lower roof or height of roof projection (ft [m]).

P_d = maximum intensity of drift surcharge load (psf [kN/m^2]).

P_f = flat-roof snow load (psf [kN/m^2]).

P_g = ground snow load (psf [kN/m^2]).

P_s = sloped-roof snow load (psf [kN/m^2]).

S = separation distance between buildings (ft [m]).

W_b = horizontal distance of roof upwind of drift (ft [m]), but not less than 25 ft (7.6 m). W_b equals the entire upwind fetch distance of roofs with multiple elevation differences, provided the predicted drift height at each elevation difference exceeds h_c.

W_d = width of snow drift surcharge (ft [m]).

W_p = width of rooftop projection (ft [m]).

W_s = width of sloped upper roof, from ridge to eave (ft [m]).

θ = roof slope from horizontal (degrees).

2.4.2 Ground Snow Load and Snow Density

Use ground snow loads based on a 50-year mean recurrence interval (MRI) and a nationally recognized building code or standard. Approximate multiplication factors for converting from lesser MRI ground snow loads to 50-year MRI ground snow loads are:

- 50-year = 2.25 x 5-year
- 50-year = 1.82 x 10-year
- 50-year = 1.20 x 25-year
- 50-year = 1.15 x 30-year

At locations where the elevation exceeds the limits indicated on the ground snow load maps, and in areas where local variation in ground snow loads is substantial enough to preclude meaningful mapping, refer to Section 2.4.2.6.

2.4.2.1 Ground Snow Loads in the United States

Ground snow loads (P_g) used in determining design snow loads for roofs are given in the two-part map for the contiguous United States in Figures C1 and C2. The maps are provided in the publication Minimum Design Loads and Associated Criteria for Buildings and Other Structures by the American Society of Civil Engineers/Structural Engineering Institute (ASCE/SEI 7-10 and 7-16). The maps present snow-load zones with estimated ground snow loads based on a 50-year MRI, and provide the upper elevation limit for the presented ground snow loads.

The United States ground snow load maps have regions designated “CS” (case studies) in which local variations in terrain and climate preclude accurate large-scale ground snow mapping. For CS regions, ground snow loads will be based on local data or snow studies. Refer to Section 2.4.2.6 for more details on recommended ground snow loads for these regions.

Ground snow loads are zero for Puerto Rico and most of Hawaii, although for mountainous regions in Hawaii, consult local building officials to verify ground snow load conditions.

Ground snow loads (P_g) for Alaska are presented in Table C1 for specific locations only and usually do not represent appropriate design values for other nearby locations. In Alaska, extreme local variations preclude statewide mapping of ground snow loads.

2.4.2.2 Ground Snow Loads in China

Use a snow load Importance Factor (I) of 1.2 for ground snow loads in China. Apply the 1.2 Importance Factor to the ground snow load values (P_g) from Figures C3 and C4, which represent the 50-year ground snow loads. Note that the P_g values for the various cities in Table C4 include the 1.2 Importance Factor. For example, for Dalian: From Figure C4, P_g = 0.53 kN/m^2; and from Table C4, P_g = 0.64 kN/m^2 (i.e., 0.53 kN/m^2 x 1.2 = 0.64 kN/m^2).

2.4.2.3 Ground Snow Loads in Europe

Use ground snow loads that are based on a 50-year MRI, including any National Annex for CEN member nations.

Refer to Section 2.8.2 for recommendations regarding the use of the Eurocode.

2.4.2.4 Ground Snow Loads in Canada

Use the 50-year MRI ground snow loads from 2005, 2010 or 2015 editions of the National Building Code of Canada (NBCC).

2.4.2.5 Ground Snow Loads in Russia

Use one of the sources for ground snow load in Russia:

- The Russian National Standard SP20.13330.2011: Loads and Effects (formerly SNiP 2.01.07-85), but increase the ground snow load to represent the 50-year MRI.
- The Russian National Standard SP20.13330.2016 which uses snow loads based on a 50-year MRI.

2.4.2.6 Ground Snow Loads Where Ground Snow Mapping is Inadequate

For some regions, the localized variation in ground snow conditions is substantial enough to preclude meaningful snow load mapping; these regions can include mountainous locations, or “lake effect” snow belts near large bodies of water.

For regions where an acceptable ground snow map is not available, regions on a ground snow map where snow loads are not provided (e.g., “CS” case studies regions as designated in Figures C1 and C2), or for regions where the elevation exceeds the limits on the ground snow map, consult the local building authority or code official having jurisdiction (authority having jurisdiction) to obtain a regional or site-specific snow study. Use the following guidelines to provide an acceptable level of assurance that the design snow load values in the regional snow study are accurate and reliable:

A. The snow load values are based on one of the following:

1. A study by a professional engineering (PE) organization, such as the Structural Engineer’s Association (SEA), of the particular state in question.

2. A study from a local university with credentialed (PhD or PE) authors.

3. A study by a federal, state, or county public safety/building agency with credentialed (PhD or PE) authors or reviewers.

B. The study uses a reputable source of raw data. For instance, U.S. National Weather Service (NWS) station data or similar for snow depths, and other national or state agency records, such as the U.S. Geological Survey (USGS), for topographical data.

C. The study indicates how snow loads are derived from snow depths (i.e., how the snow density is determined). The snow density should be reasonably close to the density provided in this data sheet.

D. The study indicates if the snow loads are for ground or roof.

E. The study indicates the intent is for structural loads.

F. The study is based on at least 25 years of data collection on average for the various locations, although a few scattered locations with roughly 15 years of data would be acceptable as a minimum.

G. The study indicates the snow load MRI (e.g., 50-year), as well as the statistical and fitting method (e.g., Log Pearson, least-squares regression, L-Moments) used to derive the MRI snow loads.

H. The study is peer reviewed by credentialed (PhD or PE) personnel.

2.4.2.7 Snow Density

Determine bulk snow density (to evaluate the heights of roof snow loads) (D) as a function of the ground snow load (P_g) according to Table 2.4.3.1 or the following formulas:

English Units:

D (pcf) = 0.13 P_g + 14 ≤ 30 where P_g in psf

Metric Units:

D (kN/m^3) = 0.43 P_g + 2.2 ≤ 4.7 where P_g in kN/m

2.4.3 Roof Snow Load

2.4.3.1 Flat Roof Snow Load

To determine the balanced (uniform) snow load (P_f) on a flat roof (i.e., any roof with a slope less than 5° [1 in 12 or 8%]), use Table 2.4.3.1 or the following formulas:

Where P_g ≤ 20 psf (1.0 kN/m^2): P_f = P_g

Where 20 psf < P_g ≤ 40 psf (1.0 < P_g ≤ 1.9 kN/m^2): P_f = 0.9 P_g, but not less than 20 psf (1.0 kN/m^2)

Where P_g > 40 psf (1.9 kN/m^2): Pf = 0.8 P_g, but not less than 36 psf (1.7 kN/m^2)

Table 2.4.3.1. Ground Snow Load (P_g) Versus Balanced Flat-Roof Snow Load (P_f), Density (D), and Height of Balanced Snow Load (h_b) for Flat and Low-sloped Roofs

English Units													
Ground Snow Load, P_g (psf) Balanced Flat-Roof Snow Load, P_f (psf)													
P_g	5	10	20	25	30	35	40	50	60	70	80	90	100
P_f	5	10	20	23	27	32	36	40	48	56	64	72	80
Density D, (pcf) Balanced Flat-Roof Snow Load Height, h_b, (ft)													
D	14.7	15.3	16.6	17.3	17.9	18.6	19.2	20.5	21.8	23.1	24.4	25.7	27.0
h_b	0.3	0.7	1.2	1.3	1.5	1.7	1.9	2.0	2.2	2.4	2.7	2.8	3.0
Metric Units													
Ground Snow Load, P_g (kN/m^2) Balanced Flat-Roof Snow Load, P_f (kN/m^2)													
	P_g	0.25	0.5	0.6	0.9	1.0	1.4	1.9	2.0	3.0	4.0	5.0	
	P_f	0.25	0.5	0.6	0.9	1.0	1.3	1.7	1.7	2.4	3.2	4.0	
Density D, (kN/m^3) Balanced Flat-Roof Snow Load Height h_b (m)													
	D	2.3	2.4	2.5	2.6	2.6	2.8	3.0	3.1	3.5	3.9	4.4	
	h_b	0.1	0.2	0.2	0.3	0.4	0.4	0.6	0.6	0.7	0.8	0.9	

Note: Linear interpolation is appropriate.

2.4.3.2 Rain-on-Snow Surcharge

Where 0 < P_g ≤ 20 psf (0.96 kN/m^2), use a uniform rain-on-snow surcharge load of 5 psf (0.24 kN/m^2) in combination with the balanced snow load for roofs based on the roof slope and W thresholds in Table 2.4.3.2.

Unbalanced, drifting, or sliding snow loads do not need to be combined with this rain-on-snow surcharge load.

Table 2.4.3.2. Rain-on-Snow Surcharge Load

Rain-on-Snow Surcharge					
W (ft)	Roof Slope				W
	in./ft	Rise: Run	Degrees	%	(m)
≤ 30	0.125	⅛: 12	0.6	1.0	≤ 9
45	0.1875	3/16: 12	0.9	1.6	14
60	0.25	¼: 12	1.2	2.1	18
90	0.375	⅜: 12	1.8	3.1	27
120	0.5	½: 12	2.4	4.2	37
150	0.625	⅝: 12	3	5.2	46
180	0.75	¾: 12	3.6	6.3	55
240	1.0	1: 12	4.8	8.4	73
300	1.25	1 ¼: 12	6	10.5	91
≥ 360	1.5	1 ½: 12	7.2	12.6	≥ 110

Notes:
1. For roof slopes less than those shown in the table, add a uniform design surcharge load of 5 psf (0.24 kN/m^2)to the uniform design snow load.
2. The 5 psf surcharge load need not be applied where the 50-year ground snow load is greater than 20 psf (0.96 kN/m^2).
3. The 5 psf surcharge load need not be applied where the 50-year ground snow load is zero.
4. The 5 psf surcharge load is applicable to balanced snow load cases only, and need not be used in combination with drift, sliding, or unbalanced snow load.
5. W = the horizontal distance from the roof ridge or valley to the eave.

2.4.3.3 Minimum Snow Loads for Low-Sloped Roofs

The minimum allowable snow loads are the balanced snow loads (P_f) of Section 2.4.3.1 or Table 2.4.3.1 and applied to shed, hip, and gable roofs with slopes less than 15°, and curved roofs where the vertical angle (see Fig. 2.4.4.4-1) from the eave to the crown is less than 10°. The formulas in Section 2.4.3.1 satisfy the following minimum snow load guidelines: For locations where the ground snow load (P_g) is 20 psf (1.0 kN/m^2 or less, the flat roof snow load (P_f) for such roofs is not less than the ground snow load (P_g); in locations where the ground snow load (P_g) exceeds 20 psf (1.0 kN/m^2), the flat-roof snow load (P_f) for such roofs is not less than 20 psf (1.0 kN/m^2).

In building codes, minimum roof live loads and live load reductions do not apply to snow loads. Snow loads greater than such live loads govern the determination of design loads.

2.4.4 Adjustment for Geometry

2.4.4.1 Sloped-Roof Snow Loads

A. Determine balanced (uniform) snow load (P_s) on sloped roofs, such as shed, hip, gable, and curved roofs, by multiplying the flat-roof load (P_f) by the roof slope factor (C_s): $P_s = C_s \times P_f$

Values of C_s are given in Table 2.4.4.1. Use cold roof values. The exception is warm roof values that apply for un-insulated glass or metal panel, plastic (e.g., acrylic or reinforced plastic panels), and fabric roofs with R-value less than 2.0 ft^2 x hr. x °F/Btu (0.4 m^2-°K/W) of buildings continuously heated above 50°F (10°C). To take advantage of warm roof slope factor values, ensure the building has a maintenance technician on duty at all times and a temperature alarm system battery back-up is in place to warn of heating failures.

B. Use “slippery surface” values only where the sliding surface is metal (aluminum, copper, galvanized or enameled steel panels, such as on all-metal buildings) and is unobstructed with sufficient space below the eaves to accept all sliding snow; if it is reasonable to assume snow guards could be installed (e.g., where a sloped roof overhangs a sidewalk) consider the roof obstructed. Note that for curved and domed roofs the “vertical angle” (see Fig. 2.4.4.4-1) is measured from the eave to the crown.

C. For fabric or membrane structures, refer to Data Sheet 1-59, *Fabric and Membrane Structures*, when determining the C_s factor.

Table 2.4.4.1. Roof Slope Factor C_s

Roof Slope, degrees (Rise:Run)	*C_s Values* [1,2]			
	Unobstructed Slippery Surfaces		All Other Surfaces	
	Cold Roof	Warm Roof	Cold Roof	Warm Roof
≤ 5° (1:12)	1.0	1.0	1.0	1.0
14° (3:12)	1.0	0.8	1.0	1.0
18.4° (4:12)	0.94	0.74	1.0	1.0
26.6° (6:12)	0.79	0.62	1.0	1.0
30° (7:12)	0.73	0.57	1.0	1.0
33.7° (8:12)	0.66	0.52	1.0	0.91
45° (12:12)	0.46	0.36	1.0	0.63
60°	0.19	0.14	0.4	0.25
70°	0	0	0	0

1. Use “cold roof” and “all other surfaces” values unless conditions in Section 2.3.7 apply.
2. Linear interpolation is appropriate within any column.

2.4.4.2 Unbalanced Roof Snow Loads

Consider balanced and unbalanced snow loads as separate load cases. Consider winds from all directions when establishing unbalanced snow loads. For design purposes, unbalanced and drifting snow due to orthogonal wind directions (90° to each other) are considered to occur simultaneously; however, winds from opposite directions, 180°, are not considered to occur simultaneously.

2.4.4.3 Hip and Gable Roofs

A. Unbalanced Snow Load

Consider the balanced snow load case for all roof slopes. The unbalanced snow load case need only be considered for roof slopes between 5° and 70° (1 in 12, and 33 in 12 slopes), inclusive. Balanced and unbalanced snow loading diagrams appear in Figure 2.4.4.3. Apply no reduction in snow load for roof slopes up to and including 15° (i.e., C_s = 1.0 and therefore $P_s = P_f$) and the snow surface above the eave need not be at a higher elevation than the snow surface above the ridge. Determine snow depths by dividing the snow loads by the appropriate snow density (D) from Table 2.4.3.1.

B. Ice Dam Load

For typical heated buildings that drain water from overhanging roof eaves, and where the roof assembly has an R-value of less than 25 ft^2 x hr x °F/Btu (4.4 m^2°K/W), apply a uniform snow load of $2P_f$ to the overhanging roof eaves; if the R-value of the roof assembly cannot be verified, assume the load $2P_f$ is applicable. The load $2P_f$ is intended to account for the effects of ice dams along the overhanging roof eave and need not be combined with any design load other than the dead load of the roof.

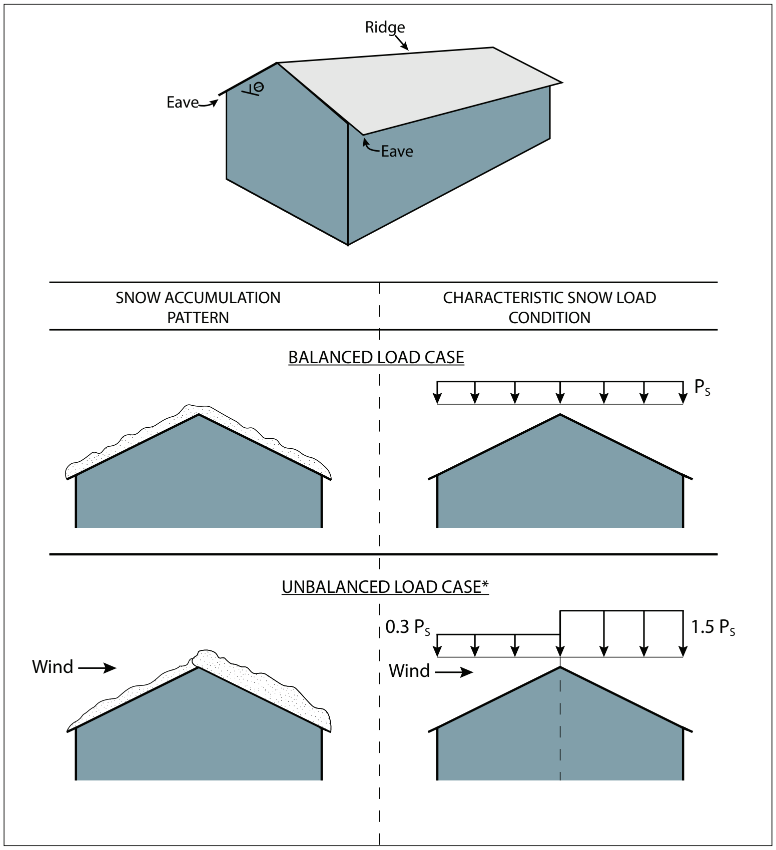


Fig. 2.4.4.3. Snow loads for hip and gable roofs

2.4.4.4 Curved and Domed Roofs

Consider unbalanced snow loads for slopes where the "vertical angle" from the eave to the crown is between 10° and 60°. Consider portions of curved roofs having a roof slope exceeding 70° free of snow; consider the point at which the roof slope exceeds 70° the "eave" for such roofs. Unbalanced loading diagrams, Cases I, II, and III, for curved roofs with roof slopes at the eave of less than 30°, 30° to 70°, and greater than 70°, appear in Figure 2.4.4.4-1. If another roof or the ground surface abuts a Case II or III curved roof at or within 3 ft (0.9 m) of the eave, ensure the snow load is not decreased between the 30° roof slope point and the eave, but remains constant at 2.0 Ps as shown by the dashed line.

For domed roofs, see Figure 2.4.4.4-2 for unbalanced snow load distribution with a single wind orientation. Note that since unbalanced snow loads due to orthogonal (90°) wind directions are assumed to act concurrently, consider also the load distribution with the unbalanced snow load on one-half the roof (180°), two linearly decreasing to zero snow zones of 22.5° each, and the remaining area (135°) free of snow. Determine the governing orientation of the unbalanced snow load based on the maximum demand on the structure.

2.4.4.5 Valley Roofs

Valleys are formed by multiples of folded plate, gable, saw-tooth, and barrel vault roofs. No reduction in balanced or unbalanced snow load is allowed for any roof slope (i.e., C_s = 1.0 and $P_s = P_f$). For valleys formed by roof slopes of 5° (1 in 12) and greater, consider unbalanced snow loads. The unbalanced snow load should increase from one-half the balanced load (0.5 P_f) at the ridge (or crown) to two times the balanced load at the valley (2.0 P_f) (see Fig. 2.4.4.5). The snow surface above the valley, however, need not be at a higher

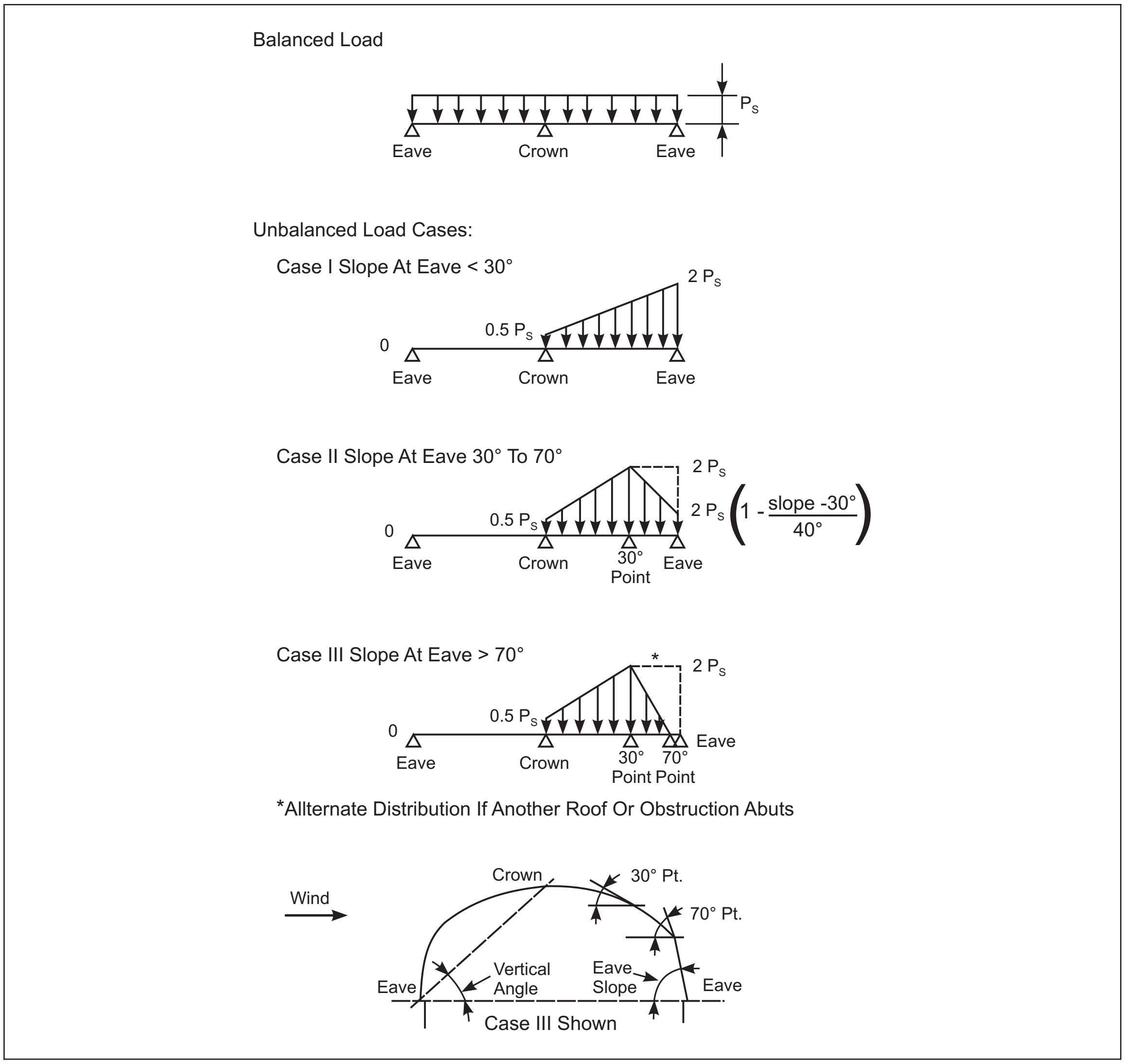


Fig. 2.4.4.4-1. Snow loads for curved and dome roofs

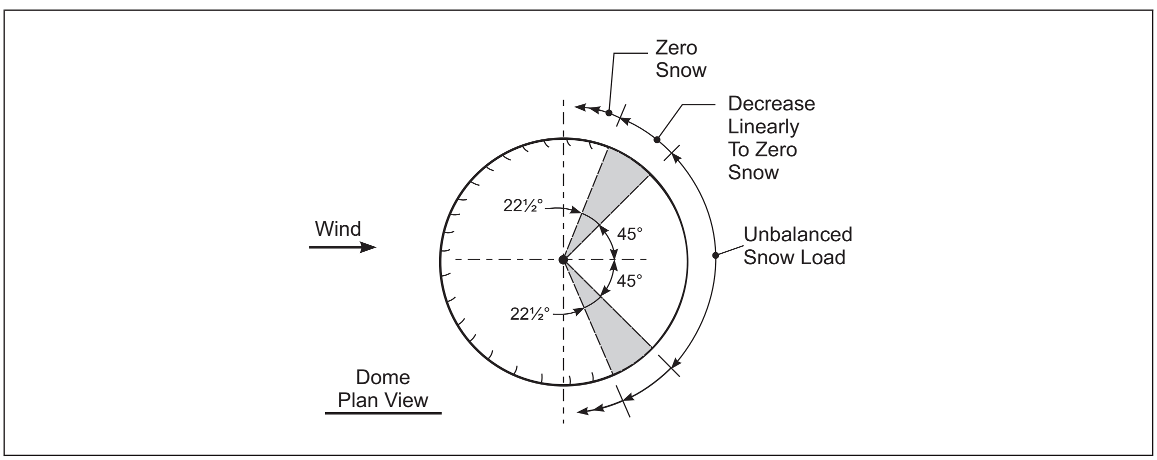


Fig. 2.4.4.4-2. Unbalanced snow load distribution on dome roofs

elevation than the snow surface at the ridge (or crown). Determine snow depths by dividing the snow loads by the appropriate snow density (D) in Table 2.4.3.1. The above snow load methodology is also applicable to multiple gable and barrel vault roofs.

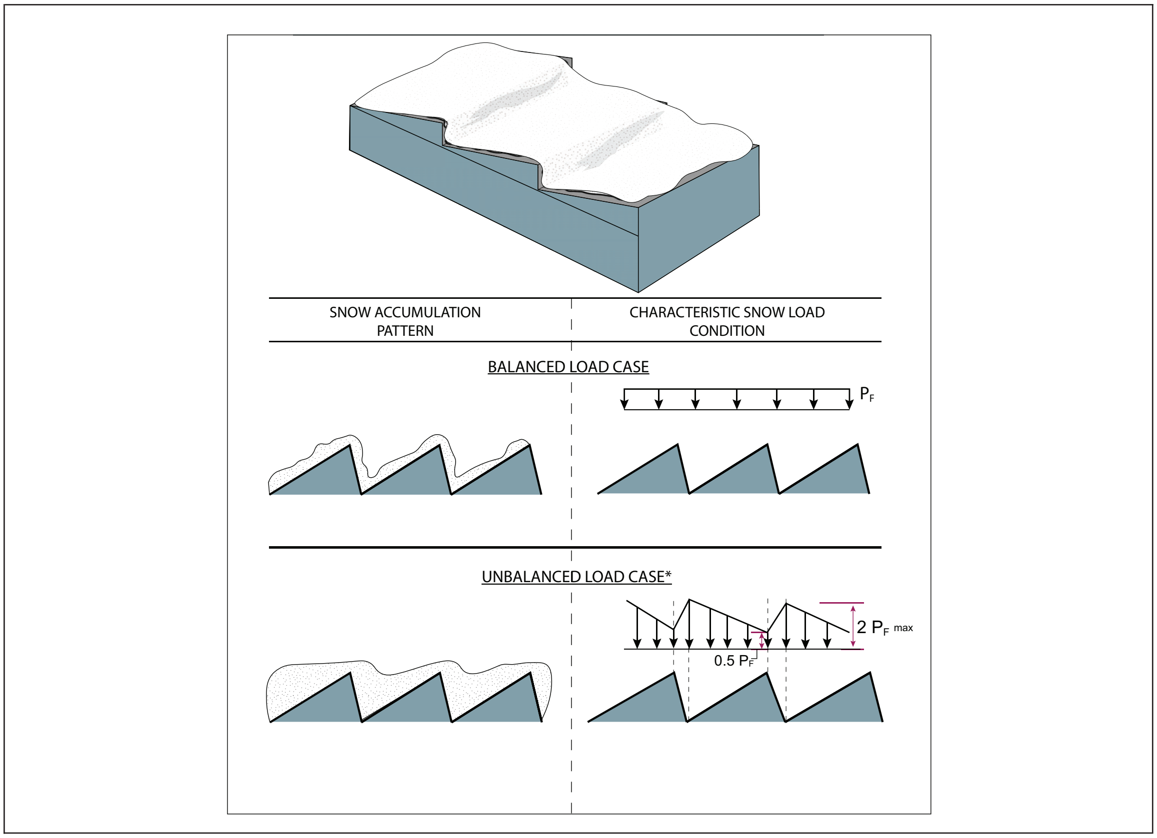


Fig. 2.4.4.5. Snow loads for sawtooth valley roofs

2.4.5 Snow Drifts and Sliding Snow

2.4.5.1 Drifts on Lower Roofs: Snow Loads

In areas where the ground snow load (P_g) is less than 5 psf (0.25 kN/m^2) or the ratio h_c/h_b is less than 0.2, drift loads on lower roofs need not be considered. Otherwise, design lower levels of multilevel roofs to sustain localized loads from snow drifts caused by wind over upper roofs of the same structure, adjacent structures, or terrain features within 20 ft (6 m) (leeward drifting); sliding snow; or snow drifts formed on lower roofs by windblown snow across the lower roof (windward drift).

Examine the following three load cases when determining the maximum demand placed on the supporting structure of the lower roof:

- Balanced snow + leeward drift
- Balanced snow + windward drift
- Balanced snow + sliding snow

Note that drift load need not be combined with sliding snow load.

Also note that more than one load case may govern the structural design. For example, for a low roof joist spanning perpendicular to the line of the roof step (i.e., parallel to the worst-case wind direction for drifting), load case (A) may produce maximum shear, but load case (C) may produce maximum bending.

A. Low Roof Leeward Drift Load

1. Take the drift load on lower roofs as a triangular surcharge loading superimposed on the balanced roof snow load (P_f), as shown in Figure 2.4.5.1-1. Note that the upper roof may be flat or sloped. For upper roof

slopes less than 30°, use an upwind fetch distance (W_b) equal to the upper roof width parallel to the wind direction (e.g., eave-to-eave distance for a sloped roof). For upper roof slopes of 30° or greater, use an upwind fetch distance (W_b) equal to 85% of the upper roof width.

2. Where intersecting snow drifts of lower roofs are possible due to perpendicular wind directions, at the theoretical drift intersection the larger snow drift governs; the two drift loads need not be superimposed to create a combined (additive) drift load. See Figure 2.4.5.1-2.

3. Note that parapet walls on high roofs will not substantially reduce leeward drifting on adjacent low roofs; therefore, do not credit high roof parapets as a method of reducing low roof leeward drifting.

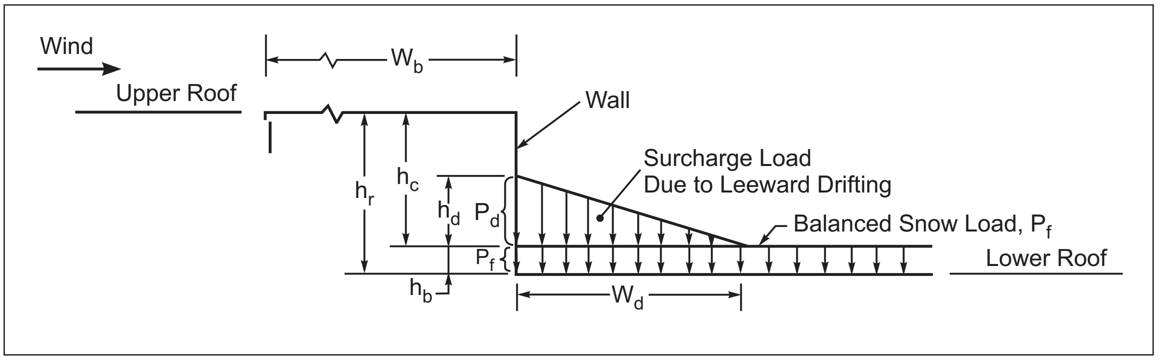


Fig. 2.4.5.1-1. (To be used with Table 2.4.5.1) Leeward snow loads for lower roofs

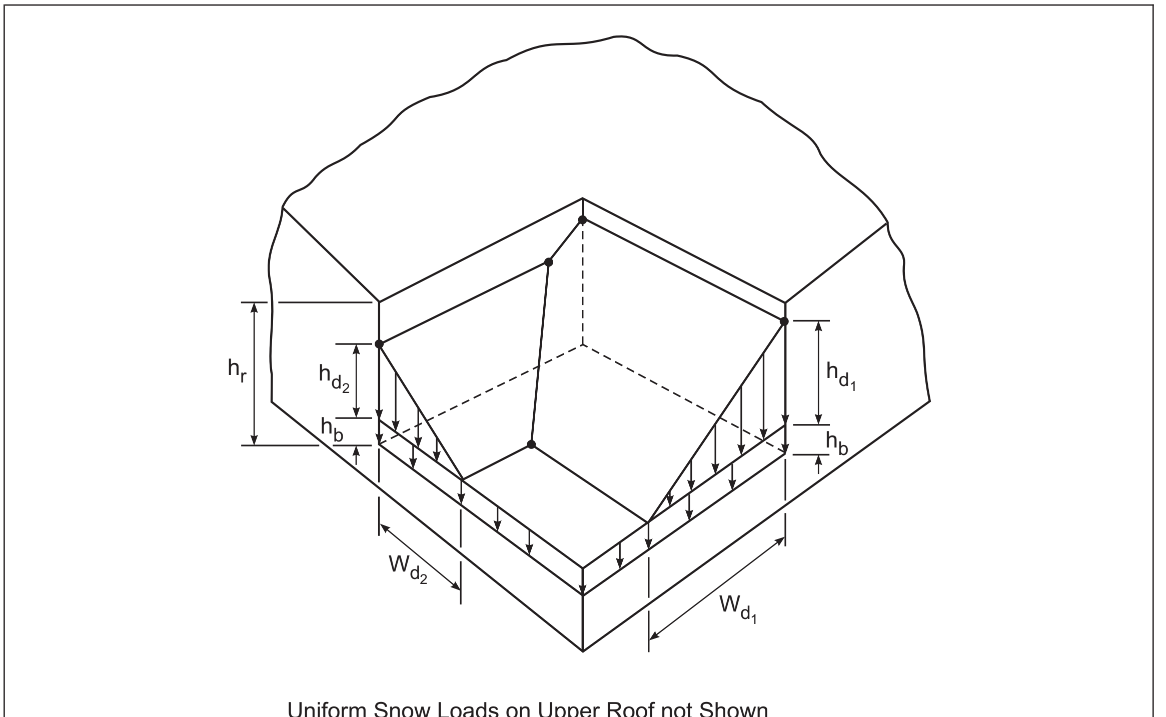


Fig. 2.4.5.1-2. Snow drift intersection at lower roofs

4. Determine maximum drift height (h_d) in ft (m) from Table 2.4.5.1 or the following formulas:

English Units:

$$h_d\ (\text{ft}) = 0.43\ \sqrt[3]{W_b}\ \sqrt[4]{P_g + 10} - 1.5 \le h_c$$

where P_g in psf; W_b and h_c in ft

Metric Units:

h_d (m) = $0.42 \sqrt[3]{W_b} \sqrt[4]{P_g + 0.48} - 0.457 \le h_c$

where P_g in kN/m^2; W_b and h_c in meters

5. Determine the drift surcharge load (P_d) as follows:

Drift surcharge load (maximum intensity), $P_d = (h_d \times D) \le (h_c \times D)$

6. Determine the total snow load as follows:

Maximum snow load (at wall) = $(P_d + P_f) \le (h_r \times D)$

The drift surcharge load (P_d) and the maximum snow load at the wall (see Fig. 2.4.5.1-1) may also be determined by Table 2.4.5.1, provided the product of the density (D) and hc or hr does not govern.

Drift width (W_d) is equal to 4 h_d except for rare cases when the calculated hd exceeds h_c. For these cases, the minimum W_d is established so that the cross-sectional area of the drift (0.5 W_d x h_c) is equal to the cross-sectional area of the hypothetical drift ($0.5h_d \times 4h_d = 2h_d^2$) that would be computed if h_d were less than h_c; however, W_d cannot be less than 6 h_c and need not be greater than 8 h_c. Thus,

$W_d = 4\ h_d$,
except when $h_d > h_c$, then $W_d = \dfrac{4\ h_d^2}{h_c}$ (but $8h_c \ge W_d \ge 6h_c$)

If W_d exceeds the width of the lower roof (this occurs frequently with small canopy roofs), truncate the drift at the far edge of the roof and do not reduce it to zero.

7. Drift load at roofs with multiple steps

For roofs where there are more than two roof elevations (i.e., more than one roof step), follow the provisions of the preceding sections (1 through 3), but use an upwind fetch distance ($W_{b)}$ equal to the width of the high roof directly adjacent plus 75% of the higher roof width upwind of the adjacent high roof. If there are more than three adjacent roofs, apply multiples of the 75% factor to the upwind higher roofs. For example, in Figure 2.4.5.1-3, for leeward drifting (wind blowing from left to right) at:

Roof B: $W_b = L_A$
Roof C: $W_b = L_B + 0.75L_A$
Roof D: $W_b = L_C + 0.75L_B + 0.75\ (0.75L_A)$

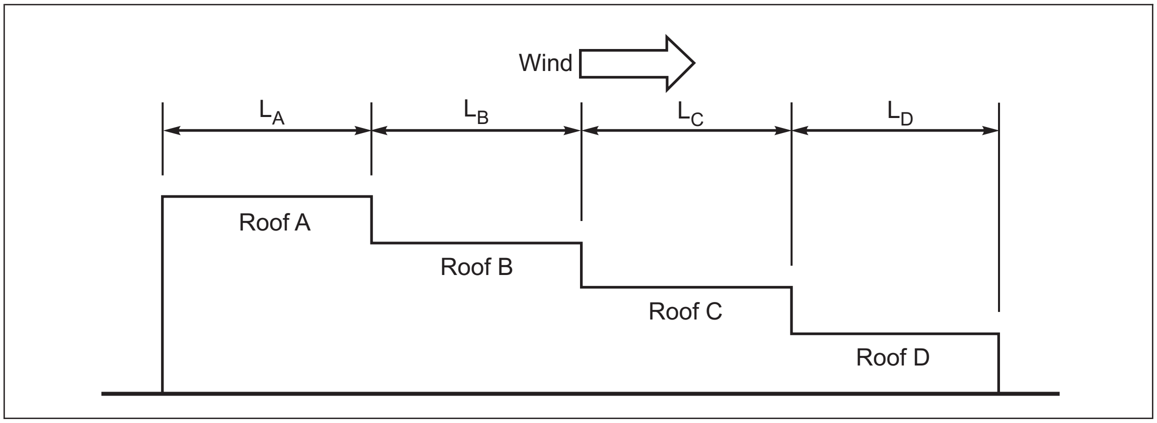


Fig. 2.4.5.1-3. W_b for leeward snow drift at multiple roofs steps

Table 2.4.5.1. (To be used with Figure 2.4.5.1-1) Ground Snow Load (P_g) versus Balanced Snow Load (P_f), Density (D), Balance Snow Load Height (h_b), Drift Height (h_d), Max Drift Load (P_d) and Max Load (P_d+P_f)

English Units:															
Ground Snow Load, P_g (psf) Balanced Snow Load, P_f (psf)															
P_g		5	10	15	20	25	30	35	40	50	60	70	80	90	100
P_f		5	10	15	20	23	27	32	36	40	48	56	64	72	80
Density, D (pcf) Balanced Snow Load Height, h_b (ft)															
D		14.7	15.3	16.0	16.6	17.3	17.9	18.6	19.2	20.5	21.8	23.1	24.4	25.7	27.0
h_b		0.3	0.7	0.9	1.2	1.3	1.5	1.7	1.9	2.0	2.2	2.4	2.7	2.8	3.0
Upwind Distance W_b (ft)		**Drift Height, h_d (ft)[a] Max. Drift Load, P_d (psf)[a] Max. Load at Wall, P_d + P_f (psf)[a]**													
25	h_d	0.97	1.16	1.31	1.44	1.56	1.66	1.76	1.84	2.00	2.14	2.26	2.37	2.47	2.57
	P_d	14	18	21	24	27	30	33	35	41	47	52	58	63	64
	P_d+P_f	19	28	36	44	50	57	65	71	81	95	108	122	135	144
50	h_d	1.61	1.85	2.04	2.21	2.35	2.48	2.60	2.71	2.91	3.08	3.24	3.38	3.51	3.62
	P_d	24	28	33	37	41	44	48	52	60	67	75	82	90	98
	P_d+P_f	29	38	48	57	64	71	80	88	100	115	131	146	162	178
100	h_d	2.42	2.72	2.96	3.17	3.35	3.52	3.67	3.81	4.05	4.27	4.47	4.65	4.81	4.96
	P_d	36	42	47	53	58	63	68	73	83	93	103	113	124	134
	P_d+P_f	41	52	62	73	81	90	100	109	123	141	159	177	196	214
200	h_d	3.44	3.82	4.12	4.39	4.62	4.83	5.01	5.19	5.50	5.78	6.02	6.25	6.45	6.64
	P_d	51	58	66	73	80	86	93	100	113	126	139	153	166	179
	P_d+P_f	56	68	81	93	103	113	125	136	153	174	195	217	238	259
300	h_d	4.15	4.59	4.94	5.24	5.50	5.74	5.96	6.16	6.51	6.83	7.11	7.37	7.60	7.82
	P_d	61	70	79	87	95	103	111	118	133	149	164	180	195	211
	P_d+P_f	66	80	94	107	118	130	143	154	173	197	220	244	267	291
400	h_d	4.72	5.20	5.58	5.91	6.20	6.46	6.71	6.92	7.32	7.67	7.97	8.26	8.52	8.76
	P_d	69	80	89	98	107	116	125	133	150	167	184	202	219	237
	P_d+P_f	74	90	104	118	131	143	157	169	190	215	240	266	291	317
500	h_d	5.20	5.72	6.13	6.48	6.80	7.08	7.34	7.58	8.00	8.37	8.70	9.01	9.29	9.55
	P_d	76	88	98	108	118	127	137	146	164	182	201	220	239	258
	P_d+P_f	81	98	113	128	141	154	169	182	204	230	257	284	311	338
600	h_d	5.62	6.17	6.61	6.99	7.32	7.62	7.89	8.14	8.59	8.99	9.34	9.67	9.97	10.3
	P_d	83	94	106	116	127	136	147	156	176	196	216	236	256	278
	P_d+P_f	88	104	121	136	150	163	179	192	216	244	272	300	328	358
800	h_d	6.34	6.94	7.43	7.84	8.21	8.54	8.84	9.11	9.61	10.0	10.4	10.8	11.1	11.4
	P_d	93	106	119	130	142	153	164	175	197	219	241	264	286	308
	P_d+P_f	98	116	134	150	165	180	196	211	237	267	297	328	358	388
1000	h_d	6.94	7.59	8.11	8.56	8.98	9.31	9.64	9.93	10.5	10.9	11.4	11.7	12.1	12.4
	P_d	102	116	130	142	155	167	179	191	215	238	262	286	311	335
	P_d+P_f	107	126	145	162	178	194	211	227	255	286	318	350	383	415

Note: Linear interpolation is appropriate.
[a] The drift height (h_d), maximum drift load (P_d), and maximum load at wall (P_d + P_f) are limited to h_c, ($h_c \times$ D), and ($h_r \times$ D) respectively.

Table 2.4.5.1. (To be used with Figure 2.4.5.1-1) Ground Snow Load (P_g) versus Balanced Snow Load (P_f), Density (D), Balance Snow Load Height (h_b), Drift Height (h_d), Max Drift Load (P_d) and Max Load (P_d+P_f) (continued)

Metric Units:												
Ground Snow Load, P_g (kN/m²) Balanced Snow Load, P_f (kN/m²)												
		0.25	0.5	0.6	0.9	1.0	1.4	1.9	2.0	3.0	4.0	5.0
		0.25	0.5	0.6	0.9	1.0	1.3	1.7	1.7	2.4	3.2	4.0
Density, D (kN/ cu m) **Balanced Snow Load Height, h_b (m)**												
		2.3	2.4	2.5	2.6	2.6	2.8	3.0	3.1	3.5	3.9	4.4
		0.1	0.2	0.2	0.3	0.4	0.4	0.6	0.6	0.7	0.8	0.9
Upwind Distance W_b (m)		**Drift Height, h_d (m)[a]** **Max. Drift Load, P_d (kN/m²)[a]** **Max. Load at Wall, P_d + P_f (kN/m²)[a]**										
10	h_d	.37	.43	.46	.51	.53	.59	.66	.67	.77	.85	.91
	P_d	.85	1.04	1.14	1.34	1.38	1.66	1.97	2.07	2.68	3.30	4.02
	P_d+P_f	1.10	1.54	1.74	2.24	2.38	2.92	3.67	3.77	5.08	6.50	8.02
15	h_d	.49	.56	.59	.65	.67	.74	.82	.83	.91	1.03	1.11
	P_d	1.13	1.35	1.47	1.70	1.75	2.08	2.45	2.53	3.18	4.03	4.89
	P_d+P_f	1.38	1.85	2.07	2.60	2.75	3.34	4.15	4.23	5.58	7.23	8.89
30	h_d	.74	.83	.86	.94	.97	1.06	1.15	1.16	1.31	1.42	1.52
	P_d	1.69	1.99	2.15	2.45	2.52	2.96	3.44	3.61	4.58	5.55	6.69
	P_d+P_f	1.94	2.49	2.75	3.35	3.52	4.22	5.14	5.31	6.98	8.75	10.69
50	h_d	.96	1.07	1.10	1.2	1.23	1.34	1.44	1.46	1.63	1.77	1.89
	P_d	2.20	2.56	2.76	3.13	3.20	3.74	4.33	4.54	5.72	6.91	8.30
	P_d+P_f	2.45	3.06	3.36	4.03	4.20	5.00	6.03	6.24	8.12	10.11	12.30
100	h_d	1.32	1.46	1.51	1.63	1.67	1.8	1.94	1.96	2.18	2.35	2.49
	P_d	3.05	3.51	3.77	4.25	4.34	5.04	5.81	6.08	7.62	9.16	10.97
	P_d+P_f	3.30	4.01	4.37	5.15	5.34	6.30	7.51	7.78	10.02	12.36	14.97
120	h_d	1.44	1.58	1.63	1.76	1.80	1.94	2.09	2.11	2.34	2.52	2.68
	P_d	3.30	3.80	4.08	4.59	4.69	5.44	6.26	6.55	8.17	9.84	11.78
	P_d+P_f	3.55	4.30	4.68	5.49	5.69	6.70	7.96	8.25	10.57	13.04	15.78
150	h_d	1.58	1.74	1.79	1.94	1.98	2.13	2.29	2.31	2.56	2.76	2.92
	P_d	3.64	4.18	4.48	5.03	5.14	5.96	6.86	7.17	8.96	10.75	12.85
	P_d+P_f	3.89	4.68	5.08	5.93	6.14	7.22	8.56	8.87	11.36	13.95	16.85
180	h_d	1.71	1.88	1.93	2.09	2.13	2.29	2.46	2.49	2.75	2.96	3.13
	P_d	3.93	4.51	4.83	5.42	5.54	6.41	7.37	7.71	9.62	11.53	13.78
	P_d+P_f	4.18	5.01	5.43	6.32	6.54	7.67	9.07	9.41	12.02	14.73	17.78
200	h_d	1.79	1.96	2.02	2.18	2.22	2.39	2.56	2.59	2.86	3.08	3.26
	P_d	4.11	4.70	5.05	5.66	5.78	6.68	7.58	8.03	10.01	12.00	14.34
	P_d+P_f	4.36	5.20	5.65	6.56	6.78	7.94	9.38	9.73	12.41	15.20	18.34
300	h_d	2.11	2.31	2.38	2.56	2.61	2.80	3.00	3.03	3.34	3.59	3.8
	P_d	4.86	5.54	5.94	6.65	6.79	7.84	8.99	9.40	11.70	14.00	16.71
	P_d+P_f	5.11	6.04	6.54	7.55	7.79	9.10	10.69	11.10	14.10	17.20	20.71

Note: Linear interpolation is appropriate.
[a] The drift height (h_d), maximum drift load (P_d), and maximum load at wall (P_d + P_f) are limited to h_c, ($h_c \times$ D), and ($h_r \times$ D) respectively.

B. Adjacent Structures and Terrain Features

Apply a drift load to lower roofs or structures sited within 20 ft (6 m) of a higher structure or terrain feature (e.g., tanks, hills) as shown in Figure 2.4.5.1-4. Determine the drift load using the methodology of Section 2.4.5.1(A); apply the factor 1-(S/20) with S in ft, or (1-[S/6] with S in meters), to the maximum intensity of the drift P_d to account for the horizontal separation between the structures S, expressed in ft (m). Drift loads need not be considered for separations greater than 20 ft (6 m).

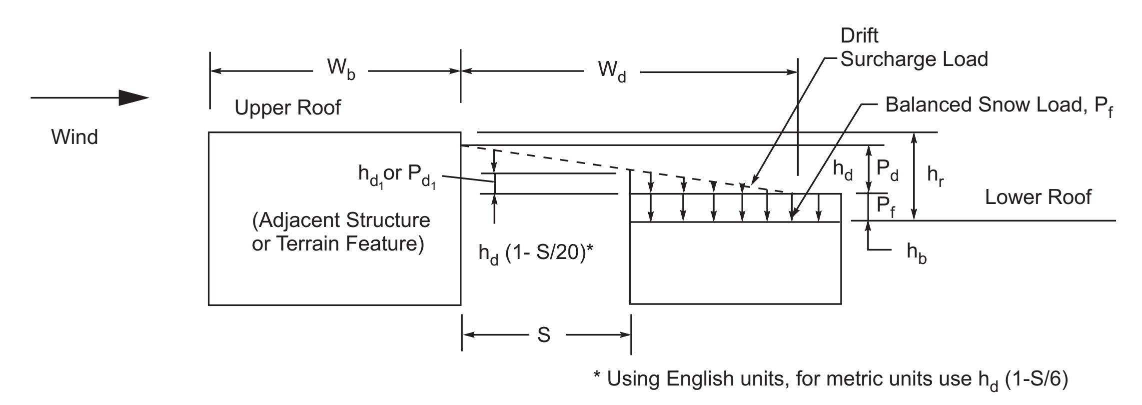


Fig. 2.4.5.1-4. Snow loads for lower roof of adjacent structures

C. Roof Projections and Parapets

1. Snow drift generated from snow blowing across the roof

Projections above lower roofs, such as high bays or higher roofs of the same building, parapet walls, or penthouses and mechanical equipment, can produce drifting on the lower roof as depicted in Figure 2.4.5.1-5. Calculate such drift loads on all sides of projections using the methodology described in this section, even though the surcharge loading shape may be quadrilateral rather than triangular. To compensate for a probable lower drift load, 75% of the drift height (h_d) is used, based on a value of W_b taken as the greater distance upwind from the projection to the edge of the roof.

For example, in Figure 2.4.5.1-5, W_b on the left side of the roof projection is larger than W_b on the right side, therefore the left side W_b is used to calculate the drift load on both sides of the roof projection.

Compute drift loads at roof projections and parapets as follows:

Drift surcharge load (maximum), $P_d = (0.75h_d \times D) \leq (h_c \times D)$

Drift width $W_d = 4(0.75h_d) = 3h_d$

2. Snow drift generated from the top of the roof projection (or from the high roof)

Determine the leeward drift load in accordance with Section 2.4.5.1.(A) for windblown snow transported from the top of the rooftop projection to the roof surface on the leeward side of the roof projection, but only where the width of the roof projection (W_p) is 10 ft (3.0 m) or greater. However, if the length of the projection (perpendicular to W_p) is less than 1/3 of h_c, leeward drift need not be considered. Leeward drift load is superimposed on balanced snow load; it need not to be added to the windward drift load.

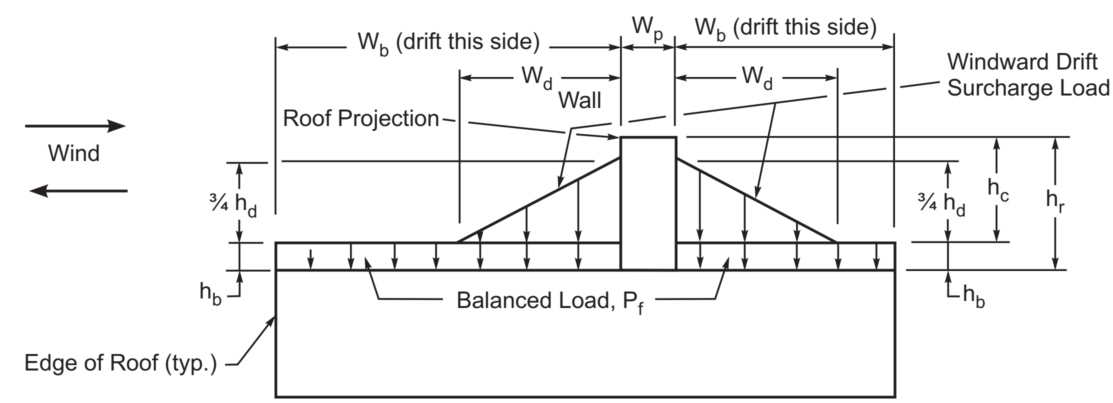


Fig. 2.4.5.1-5. Snow load at roof projections

3. Exceptions

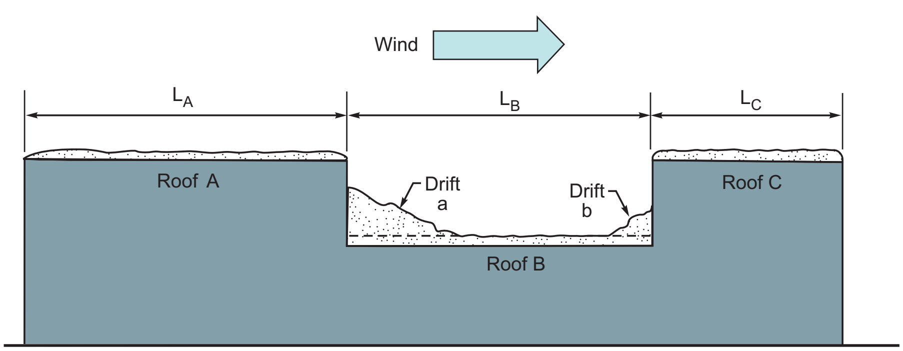
Drifting snow need not be considered for the following:

a. Where the clear height from the balanced snow surface (based on h_b) to the bottom of the roof projection is 2.0 ft (0.6 m) or greater.

b. On the side(s) of the roof projection where the horizontal dimension is less than 15 ft (4.6 m).

D. Drifting at a Roof Pocket

Where a roof pocket is formed by two roof steps (high/low/high roof), as shown in Figure 2.4.5.1-6, both leeward drifting and windward drifting will occur due to a single wind direction. Evaluate both wind directions (right to left as shown in Figure 2.4.5.1-6, and the opposite wind direction) and use the greater total snow load (including drift load) as the design load.



NOTE: For the wind direction depicted, the drift height and drift width of Drift a is dependent on L_A, whereas Drift b is dependent on both L_A and L_B. Where Drift a appears larger in the figure, this assumes L_A is long relative to L_B, which is short by comparison.

Fig. 2.4.5.1-6. Windward and leeward drifing at a roof pocket

1. For the leeward drift, follow the provisions of the Section 2.4.5.1.(A), and use an upwind fetch distance (W_b) equal to the width of the high roof (i.e., for drift “a” in Figure 2.4.5.1-6, $W_b = L_A$).

2. For the windward drift, use an upwind fetch distance (W_b) equal to the width of the low roof on which the drift forms plus 75% of the higher roof width upwind of the adjacent high roof (i.e., for drift “b” in Figure 2.4.5.1-6, $W_b = L_B + 0.75L_A$).

2.5.4.2 Sliding Snow

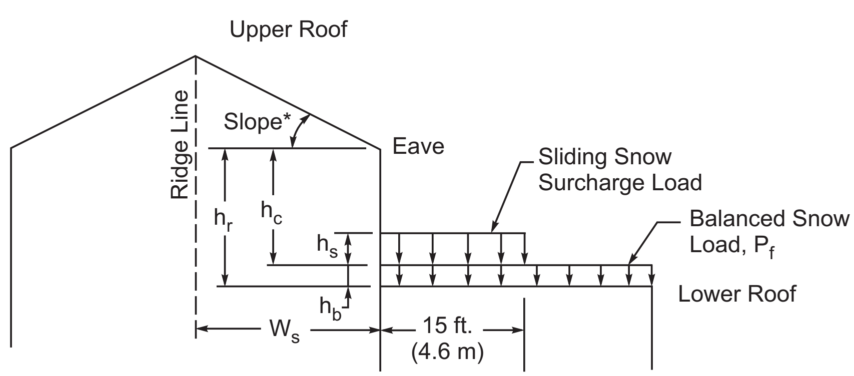
A. For lower roofs located below slippery roofs having a slope greater than 1.2° (1/4 in 12), or below other (non-slippery) roofs having a slope greater than 9.5° (2 in 12), consider a sliding snow surcharge load (psf) of $0.4P_fW_s/15$ where P_f is psf, and W_s is feet (sliding surcharge load [kN/m^2] of $0.4P_fW_s/4.6$ where P_f is kN/m^2, and W_s is meters); except that hs needs to exceed h_c. Determine hs by dividing the snow surcharge load by the appropriate snow density (D). Note that W_s is the horizontal distance from the ridge to the eave of the upper roof. See Figure 2.4.5.2.

B. Apply sliding snow surcharge load to the balanced snow load (P_f) of the lower roof.

C. For consideration of the sliding snow surcharge, "slippery" roof surfaces are defined as metal (aluminum, copper, galvanized or enameled steel panels such as are used on all-metal buildings); rubber or plastic membranes; bituminous or asphalt without granular surfacing; or slate, concrete, clay tile, composite, or similar shingles without granular surfacing. Other ("non-slippery") roof surfaces are defined as all surfaces not defined here as slippery.

D. Sliding snow need not be considered if the lower roof is separated a distance S greater than h_r, or 20 ft (6 tm), whichever is less.

E. Do not locate rooftop equipment (including solar panels) or electrical or piping systems within the 15 ft (4.6 m) area of the roof exposed to sliding snow (see Fig. 2.4.5.2).



* Consider sliding snow surcharge loads only when upper roof slope is greater than 1.2º (1/4 on 12) for slippery upper roofs or when upper roof slope is greater than 9.5º (2 on 12) for other (non-slippery) upper roofs.

Sliding snow surcharge load (psf) = $0.4\ P_f\ W_s\ /15$ with P_f in psf and W_s in feet.
Sliding snow surcharge load (kN/m^2) = $0.4\ P_f\ W_s\ /4.6$ with P_f in kN/m^2 and W_s in meters.

Fig. 2.4.5.2. Sliding snow for lower roofs (upper roof snow load not shown)

F. Do not use snow guards (or other systems designed to prevent sliding) to reduce or omit sliding surcharge snow load on low roofs. However, where a snow guard system is used, this constitutes an obstruction; therefore, for the purpose of determining the sloped roof snow load on the roof with the snow guards, do not use an unobstructed slippery surface.

2.4.6 Building Additions

Where new construction will increase snow loading on an existing adjoining or adjacent roof, do one of the following:

A. Evaluate the existing roof for potential overload and collapse and reinforce the existing roof structure as needed; or

B. Incorporate into the new construction a "snow bay" to ensure the new construction will not impose snow loads on the existing roof that exceed its original design load.

The increase in snow loading can be produced by a new high roof causing sliding and/or drifting snow load to form on the existing low roof. If a new snow bay is used, the snow bay construction should be designed to accommodate the width of the drifting snow or sliding snow surcharge and the associated loading. For the snow drifting case, this is illustrated in Figure 2.4.6.

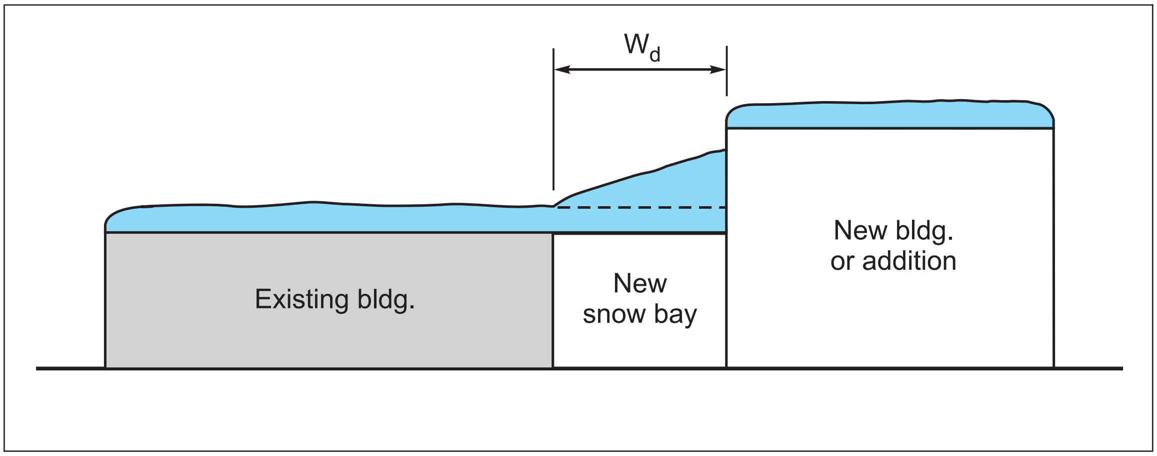


Fig. 2.4.6. New snow bay to prevent drift loading on an existing roof

2.4.7 Ice Accretion

Avoid locating rooftop equipment or electrical and piping systems in roof areas exposed to unusually high levels of ice accretion, such as from industrial processes where steam or moist air is vented to the roof and accumulates and freezes to rooftop equipment or piping. If this cannot be avoided, establish a maintenance plan to inspect the area during the winter months to evaluate and remove ice buildup as needed and keep the area roof drains and scuppers free of ice.

2.4.8 Snow and Ice Melting Devices

Use only FM Approved snow/ice melting systems, but do not reduce the design snow load on roofs.

2.5 Rain Loads and Roof Drainage

2.5.1 General

Determine design rain loads in accordance with the recommendations in this section; however, ensure the governing design roof loads are not less than the minimum live loads or snow loads designated by the applicable building code, nor less than the minimum roof live loads and snow loads covered in Sections 2.3 and 2.4 of this data sheet. Rain loads cannot be determined until the roof drainage systems have been designed.

2.5.2 Basis for Design Rain Loads

2.5.2.1 Design Rain Loads

Design rain loads: Design each section of the roof structure to sustain the load from the maximum depth of water that could accumulate if the primary drainage system is blocked, including the depth of water ABOVE the inlet of the secondary drainage system at its design flow.

Determine this design rain load (load due to the depth of water [total head]) by the relative levels of the roof surface (design roof line) and overflow relief provisions, such as flow over roof edges or through overflow drains or scuppers. If the secondary drainage system contains drain lines, ensure they are independent of any primary drain lines. (See Figures 2.5.2.1-1 and 2.5.2.1-2.)

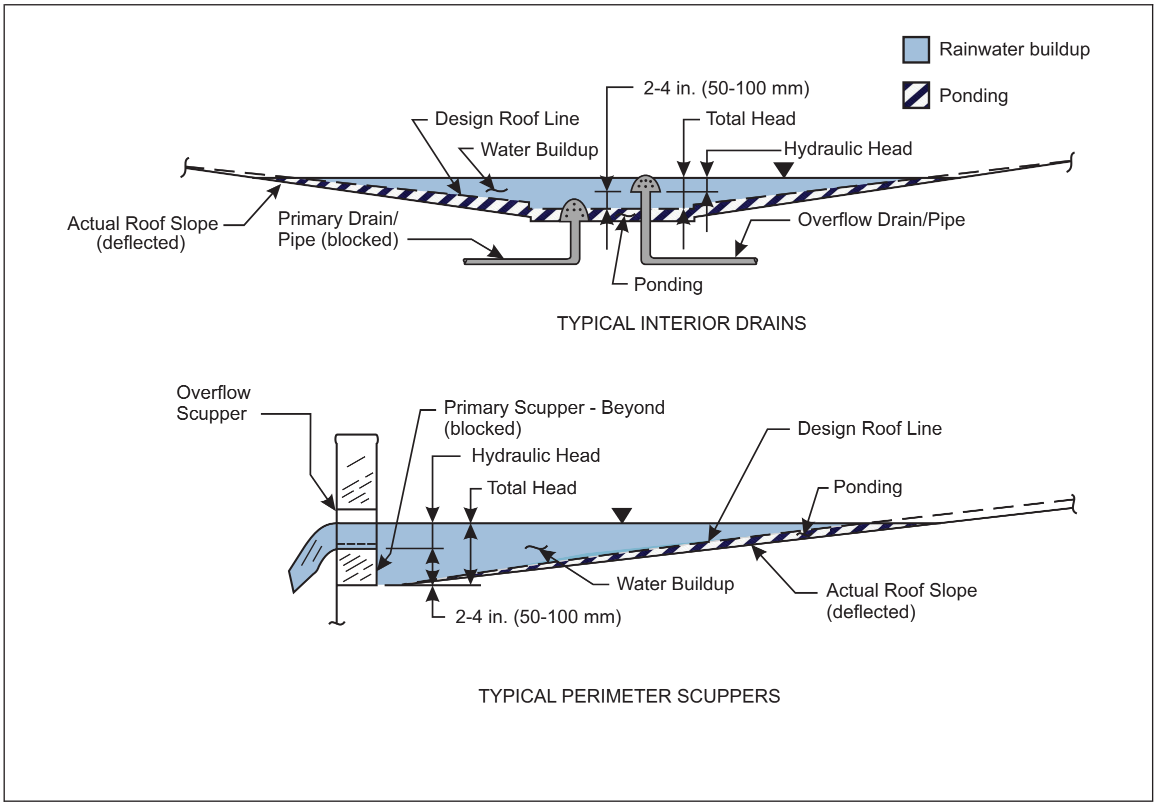


Fig. 2.5.2.1-1. Typical primary and overflow systems for pitched roofs

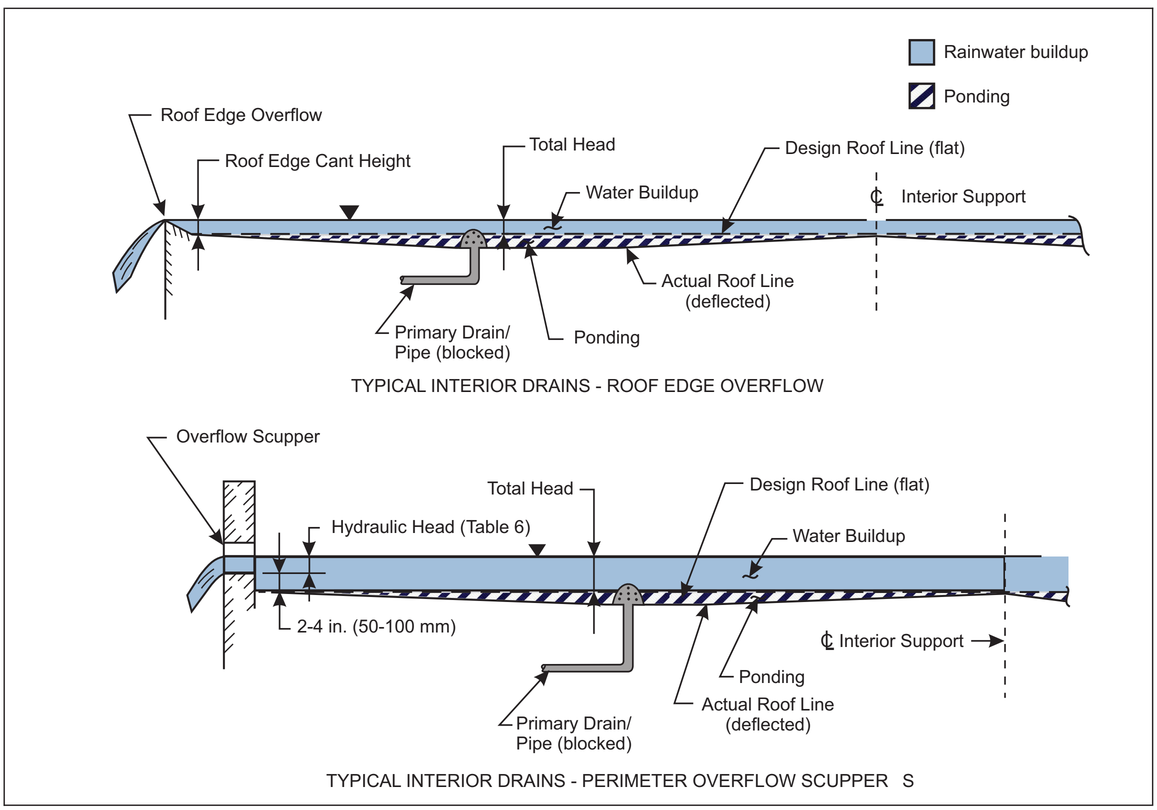


Fig. 2.5.2.1-2. Typical primary and overflow drainage systems for flat roofs

2.5.2.2 Rain Load Calculations

The design rain load for roof-supporting members is the total head times the weight density of the water. Total head is measured from the design roof line to the maximum water level (overflow discharge), as illustrated in Figures 2.5.2.1-1 and 2.5.2.1-2. The total head includes the depth of water from the design roof line to the overflow provision plus the hydraulic head corresponding to either an overflow drain or scupper. In addition, have the roof framing designer prepare calculations substantiating that the roof design precludes roof instability due to ponding.

Total head = maximum water depth from design roof line to overflow discharge level, including any hydraulic head.

2.5.2.3 Minimum Design Rain Loads

Design the roof structure to support at least 6 in. (150 mm) depth of water on the roof deck at the low point of drains and scuppers, which is equivalent to a rain load of approximately 32 psf (1.5 kN/m^2), but not less than the total head based on hydraulic analysis.

2.5.2.4 Ponding instability

Design roofs with a slope less than 1/4 in 12 (1.2°) to preclude instability from ponding with the primary drainage system blocked. Use the larger of the rain or snow loads.

2.5.2.5 Controlled Drainage

A. Where controlled drainage hardware is used to limit or delay rainwater outflow from primary roof drainage, do the following:

1. Provide roofs that use controlled flow drains with an overflow drainage system at a higher elevation.

2. Design the roof to support the load of the maximum possible water depth (e.g., to the elevation of the overflow drainage system) plus any load due to the water depth (hydraulic head) needed to cause flow from the overflow drainage system.

3. Design the controlled drainage system to meet the same maximum head restriction for conventional roof drainage (see Section 2.5.2.6).

4. Consider roof instability due to ponding in this situation. Ensure the overflow drainage system is independent of any primary drain lines.

B. Do not use controlled drainage hardware on secondary roof drainage.

2.5.2.6 Maximum Design Head

Design the primary roof drainage system so the maximum total head (including hydraulic head) will not exceed 6 in. (150 mm) at the design flow rate.

A. Adjusting Hydraulic Head for Different Drain Geometry

1. Weir Flow and Transition Flow

Where the primary drain bowl (sump) diameter, or the secondary (overflow) drain dam or standpipe diameter, differs from what is provided in Tables 2.5.4.1-5 to 2.5.4.1-8 by:

a. 15% or less, the effect on hydraulic head corresponding to a given flow rate is not significant; therefore, use the values in the tables as provided.

b. More than 15%, use the following equation to approximate the effect on the hydraulic head with the flow rate held constant (but see Part i. below):

$$H_2 = [(D_1/D_2)^{0.67}] (H_1)$$

Where:

H_1 = known hydraulic head from the tables.
D_1 = drain bowl diameter for primary drains, or overflow dam or standpipe diameter for secondary (overflow) drains, corresponding to H_1 for a given flow rate.
H_2 = hydraulic head to be determined.

D_2 = drain bowl diameter for primary drains, or overflow dam or standpipe diameter for secondary (overflow) drains, corresponding to H_2 for a given flow rate.

i. Do not use less than 80% of the hydraulic head indicated in Tables 2.5.4.1-5 to 2.5.4.1-8 for the given drain (outlet) size and flow rate unless flow test results from a reputable testing laboratory, witnessed and signed by a licensed professional engineer, are provided to justify the hydraulic head values.

ii. Example:

Determine the total head for an 8 in. secondary drain (8 in. outlet diameter), with a 10 in. diameter x 2 in. high overflow dam outlet, at a flow rate (Q) of 300 GPM.

From Table 2.5.4.1-7:

D_1 = 12.75 in. (dam diameter).
H_1 = 2.0 in. for 300 GPM, 8 in. outlet.

For the 10 in. diameter overflow dam on an 8 in. drain outlet:

D_2 = 10 in. (dam diameter).

Therefore:

$H_2 = [(D_1/D_2)^{0.67}](H_1)$.

H_2 = [(12.75 in./10 in.)$^{0.67}$] (2.0 in.) H_2 = (1.18)(2.0 in.) = 2.4 in. at Q = 300 GPM.

Total head = 2.4 in. hydraulic head + 2 in. dam height = 4.4 in.

For secondary (overflow) drains with standpipes, the standpipe diameter has a larger impact on the hydraulic head than the drain bowl (sump); therefore make any adjustments to hydraulic head (H_2) based on standpipe diameter.

2. Orifice Flow

The total hydraulic head can include the depth of the drain bowl (sump). Therefore, where the depth of the drain bowl is less than that indicated in Tables 2.5.4.1-5 to 2.5.4.1-8, add the difference to the hydraulic head from the tables to determine the design hydraulic head. Where the depth of the drain bowl is <u>greater than</u> that indicated in the tables, use the hydraulic head in the tables as the design hydraulic head.

2.5.2.7 Rain Load for Ballasted Roofs

Determine the combined load associated with rainwater and ballast, with rainwater depth based on the recommended rainfall intensity and the roof drainage conditions. Assume the ballast is saturated and account for the volume of rainwater displaced by the ballast when determining the combined load of the ballast and rainwater.

A. Concrete Pavers

Use the saturated weight of concrete pavers when determining the combined paver and rainwater load. Use the saturated paver weight even if the pavers are elevated above the design rainfall level. Unless a different value is confirmed, assume solid concrete pavers are 15% porous for a given dry weight or density. This will result in an increase of the dry density and weight of roughly 8% when saturated, for most commonly used pavers.

B. Stone Ballast

Use an estimated open volume (void ratio) for the ballast depth based on the stone size and sieve analysis. Unless a different value is confirmed, use a void ratio of 35% (i.e., 65% of the ballast depth is solid stone) for the depth of stone ballast.

2.5.2.8 Rain Load for Green Roofs

Refer to Data Sheet 1-35 to determine rain loads on green (vegetative) roofs.

2.5.3 Designing for Stability Against Ponding

A. Roof instability due to ponding can be minimized or controlled in the initial roof design by any of the following methods:

1. Provide sufficient overflow relief protection to remove the water before it reaches an excessive depth.

2. Slope the roof sufficiently to ensure water will flow off the edges of the roof.

3. Provide a sufficiently stiff and strong roof to limit the amount of deflection and to withstand ponding as well as the total load.

4. Specify camber for roof supporting members (e.g., open web joists, structural shapes, and plate girders of steel).

B. Analyze roof framing systems in accordance with the following recommendations (as applicable) to ensure instability from ponding does not occur based on the total load (dead plus snow and rain loads) supported by the roof framing before consideration of ponding, or by substantiating that a roof slope is sufficient.

1. Sloped roofs to drains or scuppers: Ensure the total load supported is the design rain load distributed locally to the low areas, plus the dead load of the roof. An acceptable analysis method, conservative for sloped roofs, is the AISC method using an appropriate equivalent uniform load based on the design rain load distribution plus dead load for the total load supported. Also, if the design roof slope is less than 1/4 in 12 (2%), ensure it is sufficient according to Section 2.5.4.1.(M.2).

2. Sloped roofs to free drainage over the roof edge: If the design roof slope is less than 1/4 in 12 (2%), ensure it is sufficient according to Section 2.5.4.1.(M.2).

2.5.4 Roof Drainage

2.5.4.1 Conventional (Non-Siphonic) Roof Drainage

A. Positive Drainage

Design all roofs with positive drainage; sloping the roof surface 1/4 in 12 (2%) toward roof drains, scuppers, or points of free drainage (roof edge) should be sufficient for positive drainage. If a slope of less than 1/4 in 12 (2%) is desired for positive drainage, use the analysis methods presented in Section 2.5.4.1.(M).

B. Secondary Drainage

Provide secondary (overflow or emergency) roof drains or scuppers where blockage of the primary drains allows water to accumulate. This includes when roof gutters or other drains are located behind a parapet.

C. Minimum Design Rainfall Intensities

1. Primary roof drainage: Use the 100-year, 60-min rainfall intensity.

2. Secondary roof drainage: Use twice (two-times) the 100-year, 60-min rainfall intensity. Alternatively, the use of the 100-year, 15-minute rainfall intensity is acceptable if it is from a nationally recognized source (e.g., a national weather service).

However, if local code uses rainfall intensities greater than those listed here, use the rainfall intensities based on local code.

Refer to Section 2.5.4.2 for design rainfall intensities for siphonic drainage systems.

Rainfall intensity maps are in Appendix C.

In areas outside those covered by the maps and tabulation, or in local areas of intense rainfall history, obtain the rainfall intensities from local meteorological stations based on a 1-hr duration rainfall and a 100-yr MRI. Reasonable, but not exact, multiplication factors for converting a 1-hr duration rainfall of 30-yr and 50-yr MRI to a 100-yr MRI are 1.2 and 1.10, respectively.

D. Design Drainage Area

Use the roof area along with one-half (1/2) the area of any vertical walls that drain to the roof area in sizing drains and determining roof loads and stability from ponding.

E. Roof Loads

The roof drainage systems must be designed before the roof loads can be determined.

F. Roof Drains and Scuppers

Roof drains may be used for conventional or controlled-flow drainage systems. Roof drains and scuppers may be used separately or in combination for primary or secondary drainage systems. The following sections, when referring to drains, apply to conventional and controlled-flow drainage systems.

1. Quantity

Provide at least two primary roof drains or scuppers, and two secondary roof drains or scuppers, for total roof areas of 10,000 ft^2 (930 m^2) or less.

For larger roof areas, provide a minimum of one primary drain or scupper, and one secondary drain or scupper, for each 10,000 ft^2 (930 m^2) of roof area. The roof area may be increased to 15,000 ft^2 (1400 m^2) with a minimum scupper width of 8 in. (200 mm).

2. Drain and Drain Leader Sizes

Provide roof drains and vertical leaders in sizes of 4 in. to 10 in. (100 to 250 mm) diameter. Areas of less than 2500 ft^2 (230 m^2), such as canopies, may use a 3 in. (75 mm) diameter drain.

While it is acceptable to use 10 in. (250 mm) diameter drains, this may be impractical due to drainage area limitations and drain flow restrictions imposed by drainage piping.

Always use a drain leader (vertical and horizontal piping) with a diameter that is the same size or larger than the drain outlet.

3. Drain Strainers

Provide strainers extending a minimum of 4 in. (102 mm) above the roof surface over all roof drains. Use strainers with an available inlet area that is at least one and one-half times the area of the conductor or leader connected to the drain. Flat-surface strainers with an inlet area at least two times the area of the conductor can be used on decks, including parking decks and sun decks.

4. Placement

The placement of (primary) roof drains or scuppers are influenced by the roof structure's support columns and walls, expansion joints, roof equipment, and other projections.

Locate roof drains at mid-bay low points, or within 20% of the corresponding bay spacing from the low points in each direction. If roof drains or scuppers are located at points of little deflection, such as columns and walls, slope the roof surface toward them at least 1/4 in 12 (1.2°) to compensate for minimum deflections at these locations.

5. Secondary (Overflow) Drainage

a. Provide secondary drainage to prevent rainwater overload. The overflow relief provision establishes the maximum possible water level based on blockage of the primary drainage system. Ensure the provision is in the form of minimal height roof edges, slots in roof edges, overflow scuppers in parapets or overflow drains adjacent to primary drains.

b. Ensure the overflow relief protection provides positive and uniform drainage relief for each roof section.

c. When designing and sizing the secondary drainage system (drains or scuppers), assume the primary drains are 100% blocked and cannot flow water.

d. Ensure the inlet elevation of overflow drains and the invert elevation (see sketches in Table 2.5.4.1-2 and Figure 2.5.4.1-2) of overflow scuppers are not less than 2 in. (50 mm) nor more than 3 in. (75 mm) above the low point of the (adjacent) roof surface unless a safer water depth loading, including the required hydraulic head to maintain flow, has been determined by the roof-framing designer.

e. For secondary (overflow) roof drains, use a dam or standpipe diameter at least 30% larger than the drain outlet diameter.

6. Secondary Drainage Discharge

a. Discharge secondary drainage systems using vertical leaders, conductors, or piping separate from the primary drainage system. Discharge to an above-grade location normally visible to building occupants.

b. Discharge to points of free drainage, such as over-the-roof edges or through relief openings atop conductors, if this is not practical.

G. Scuppers and Gutters

Use three-sided, channel-type roof scuppers whenever possible. For parapet walls, use four-sided, perimeter, closed-type scuppers (see sketch with Table 2.5.4.1-2). Provide scuppers and leaders or conductors with minimum dimensions of 6 in. (150 mm) wide by 4 in. (100 mm) high and 5 in. (125 mm) diameter or equivalent, respectively. Ensure the height of the closed-type scupper is at least 1 in. (25 mm) higher than the estimated water buildup height (hydraulic head) developed behind the scupper (see Table 2.5.4.1-2).

Provide a watertight seal between gutters and the underside of the roof to ensure that rainwater will not enter the building, nor breach the building's weather tight envelope, due to wind-driven rain or gutter overflow.

H. Drain Pipe Protection

Where drain pipe inside the building is exposed to potential impact damage (e.g., industrial occupancies, with vertical pipe exposed to moveable equipment or adjacent to building stock or supplies), provide impact protection to ensure pipe damage will not occur. Impact damage to drain piping could impair proper roof drain operation or allow rainwater to enter the building and wet contents. This is especially important where plastic drain pipe is used, or where the building contents are particularly susceptible to water damage.

I. Downspouts

Provide downspouts that are protected or truncated above the highest expected level of snow banks and potential impacting objects (e.g., truck docks) or are of open-channel design.

J. Inspection

Inspect roofs and their drainage inlets after roof construction, prior to the start of the rainy or tropical cyclone seasons, following storms, and at least every three months. Clear obstructions or accumulations of foreign matter as frequently as necessary.

Inspect gutters to ensure they are properly sealed at the underside of roofing to prevent rainwater from entering the building.

K. Drainage System Sizing

Determine the rainfall intensity for a given location, then calculate the number and sizes of roof drains and/or scuppers for the primary and secondary drainage systems, as well as the sizes of vertical leaders or conductors and horizontal drainage piping as follows:

1. Sizing Conventional Roof Drains/Vertical Leaders and Scuppers

a. Determine the total number of roof drains or scuppers needed:

Equation 1.1, English Units

$n = A/10{,}000$; or $n = A/15{,}000$ for 8 in. wide scuppers per Section 2.5.4.1.(F.1)

Where:

n = number of drains needed (nearest higher whole number > 2).
A = total roof drainage area (ft^2).

Equation 1.2, Metric Units

$n = A/930$; or $n = A/1400$ for 200 mm wide scuppers per Section 2.5.4.1.(G.1)

Where:

n = Number of drains needed (nearest higher whole number > 2).
A = Total roof drainage area (m^2).

b. Determine the flow rate needed per roof drain, leader, or scupper:

Equation 2.1, English Units

Q = 0.0104 x i x A / n (see note below)

Where:

Q = drain, leader or scupper flow needed (gpm).
i = rainfall intensity (in./hr), Section 2.5.4.1.(C.1) = total roof drainage area (ft^2).
n = number of drains needed (Equation 1.1).

Equation 2.2, Metric Units

Q = 0.0167 x i x A / n (see note below)

Where:

Q = drain, leader or scupper flow needed (L/min).
i = rainfall intensity (mm/hr), Section 2.5.4.1.(C).
A = total roof drainage area (m^2).
n = number of drains needed (Equation 1.2).

Note: The above coefficients (0.0104 or 0.0167) times "i" convert the rainfall intensity to an (average) flow rate per unit area (see Table 2.5.4.1-4); however, these coefficients may vary for controlled drainage systems (see "Sizing Controlled Roof Drains/Vertical Leaders" below).

c. Determine the size needed for roof drains, leaders, or scuppers:

i. Drains and Vertical Leaders

Apply the flow, Q, needed per drain or vertical leader to one of Table 2.5.4.1-5 through 2.5.4.1-8 and select a drain or vertical leader diameter that provides adequate flow capacity.

ii. Scuppers

Apply the flow, Q, needed per scupper to Table 2.5.4.1-2 or 2.5.4.1-3 and select a scupper type and size that provides adequate flow capacity.

2. Sizing Controlled Roof Drains/Vertical Leaders

a. Use the methodology in this section for controlled drainage systems by converting the rainfall intensity to the design peak flow rate rather than to the (average) flow rate.

b. The design peak flow rate is usually approximated at twice the average flow rate for a controlled drainage system.

c. The peak flow rate is the limited (controlled) flow rate required to maintain a predetermined depth of water on a roof and drain the roof within a 24-hour or 48-hour period. It varies according to the controlled drainage design criterion, rainfall intensity, and roof slope configuration.

3. Sizing Horizontal Drainage Piping

a. Determine the flow, Q_p, needed per horizontal drainage pipe section:

Q_p = Q times the number of drains serviced by the pipe section.

b. Determine the size of horizontal drainage piping needed:

Apply the flow, Qp, needed per pipe section to Table 2.5.4.1-1 and select the pipe diameter and slope that provide adequate flow capacity.

Table 2.5.4.1-1. Flow Capacity for Roof Drain Piping

English Units			
Diameter of Drain or Pipe (in.)	**Horizontal Drainage Piping, gpm Slopes (in. per ft)**		
	⅛ Slope	**¼ Slope**	**½ Slope**
3	34	48	69
4	78	110	157
5	139	197	278
6	223	315	446
8	479	679	958
10	863	1217	1725
12	1388	1958	2775
15	2479	3500	4958
Metric Units			
Diameter of Drain or Pipe (mm)	**Horizontal Drainage Piping, L/min Slopes (percentages)**		
	1 Slope	**2 Slope**	**4 Slope**
75	130	180	260
100	295	415	595
125	525	745	1050
150	845	1190	1690
200	1815	2570	3625
255	3265	4605	6530
305	5255	7410	10,500
380	9385	13,245	18,770

L. Rain Loads with Drains and/or Scuppers

1. Determine the hydraulic head and the total head (rainwater depth):

a. Roof edges:

i. Where the entire roof edge is at the same elevation and rainwater can flow freely over the edge, the hydraulic head needed to cause flow over the roof edge will be negligible; therefore, assume the total head is equal to the height of the roof edge above the roof surface.

ii. Where only a portion of the roof edge will allow for rainwater to flow freely over the edge, if the lowest elevation roof edge is greater than the following, the hydraulic head will be negligible; therefore, assume the total head is equal to the height of the lowest roof edge above the roof surface:

Roof edge (ft) > A (ft^2) x i (in./hr)/400
Roof edge (m) > A (m^2) x i (mm/hr)/3100

b. Primary roof drains: Use Table 2.5.4.1-5 or 2.5.4.1-6 with the needed flow rate Q, and for the appropriate drain size, to determine the hydraulic head. Where the drain rim is flush with the roof surface (which is typical), the total head is equal to the hydraulic head.

c. Secondary (overflow) roof drains: Use Table 2.5.4.1-7 or 2.5.4.1-8 with the needed flow rate Q, and for the appropriate drain size, to determine the hydraulic head above the rim of the drain dam or standpipe. Add the height of the dam or standpipe (height above the roof surface) to the hydraulic head listed in the table to determine the total head.

d. Overflow roof scuppers: Use Table 2.5.4.1-2 or 2.5.4.1-3 with the needed flow rate, Q (Section 2.5.4.1.K) under an appropriate scupper type and size, and determine the approximate depth of water above the scupper's invert (by interpolation when necessary). Add the height of the scupper invert above the roof surface to the hydraulic head listed in the table to determine the total head.

Refer to Figures 2.5.4.1-1 and 2.5.4.1-2 for details of primary and secondary (overflow) roof drains, respectively, and hydraulic and total head for weir and transition flow regimes.

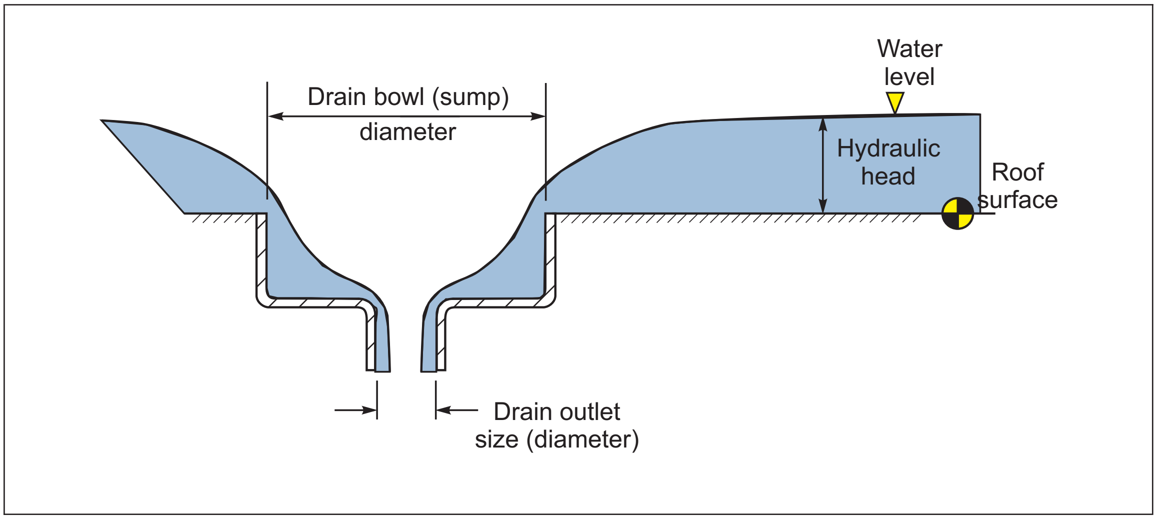


Fig. 2.5.4.1-1. Primary roof drain and hydraulic head (debris guard not shown for clarity)

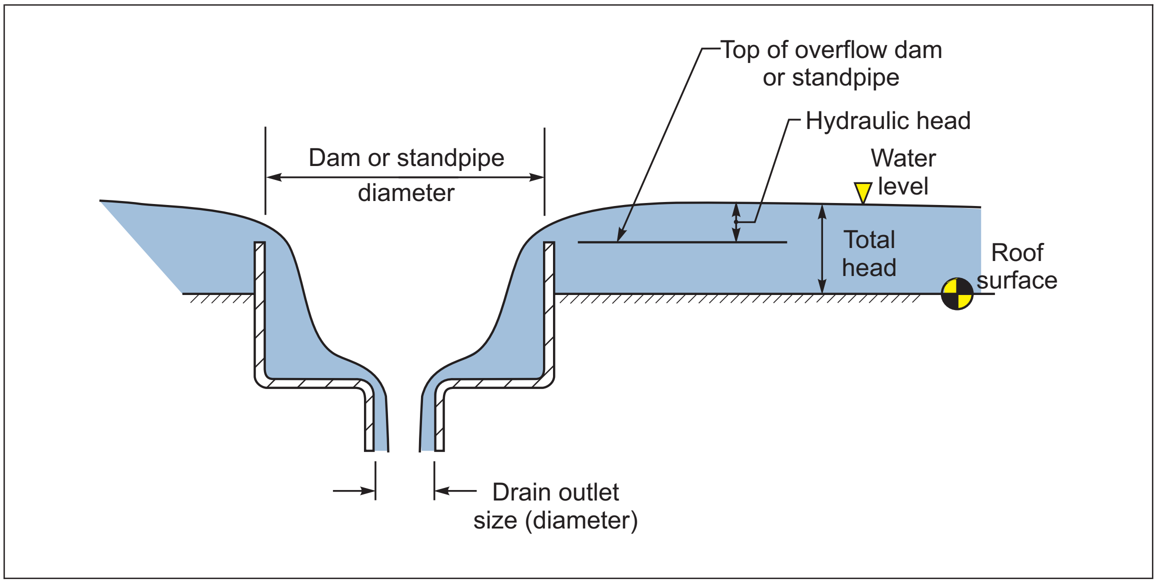


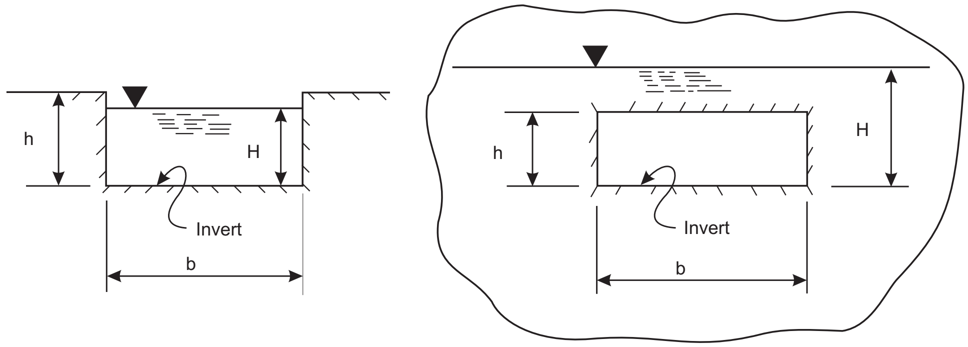
Fig. 2.5.4.1-2. Overflow (secondary) roof drain with hydraulic head and total head (debris guard not shown for clarity)

2. Determine the Rain Load

The design rain load is based on the total head (rainwater depth) as follows:

Rain Load = Total Head (in.) x 5.2 psf per in.
Rain Load = Total Head (mm) x 0.01 kN/m^2 per mm

Table 2.5.4.1-2. Hydraulic Head Versus Flow Capacity for Rectangular Roof Scuppers
(Depth of Water Over Invert Versus Flow of Water Through Scupper)



CHANNEL-TYPE SCUPPER

Flow (gpm) = $(2.9)(b)(H^{1.5})$
when h > H; units: in.

Flow (L/min) = $(0.0034)(b)(H^{1.5})$
when h > H; units: mm

CLOSED -TYPE SCUPPER

Flow (gpm) = $(4.3)(b)(h)(H - h/2)^{0.5}$
when $h \le H$; units: in.

Flow (L/min) = $(0.005)(b)(h)(H - h/2)^{0.5}$
when $h \le H$; units: mm

English Units

Scupper Flows (gpm)

Water Buildup H, in.	**Channel Type h ≥ H Width b, in.**				**Closed Type Height h = 4 in. Width b, in.**				**Closed Type Height h = 6 in. Width b, in.**			
	6	8	12	24	6	8	12	24	6	8	12	24
1	18	24	36	72	(see channel type)				(see channel type)			
2	50	66	100	200								
3	90	120	180	360								
4	140	186	280	560								
5	194	258	388	776	177	236	354	708				
6	255	340	510	1020	206	274	412	824				
7	321	428	642	1284	231	308	462	924	303	404	606	1212
8	393	522	786	1572	253	338	506	1012	343	456	686	1372

Metric Units

Scupper Flows L/min

Water Buildup H, mm	**Channel Type h ≥ H Width b, mm**				**Closed Type Height h = 100 mm Width b, mm**				**Closed Type Height h = 150 mm Width b, mm**			
	150	200	300	500	150	200	300	500	150	200	300	500
25	63	84	126	210	(see channel type)				(see channel type)			
50	178	237	356	595								
75	327	437	656	1093								
100	505	673	1009	1682								
125	705	940	1411	2351	642	856	1284	2141				
150	927	1236	1854	3090	749	998	1497	2495				
175	1168	1558	2337	3894	841	1121	1681	2802	1105	1474	2211	3684
200	1427	1903	2855	4758	923	1230	1846	3076	1249	1665	2498	4163

Notes: Whenever h ≥ H for a closed-type scupper, the scupper flows under channel-type scuppers are appropriate.
Interpolation is appropriate.

Table 2.5.4.1-3. Hydraulic Head and Flow Capacity for Circular Roof Scuppers

Scupper Flow (gpm)							
H (in.)	Scupper Diameter (in.)						
	5	6	8	10	12	14	16
1	6	7	8	8	10	10	10
2	25	25	30	35	40	40	45
3	50	55	65	75	75	90	95
4	80	90	110	130	140	155	160
5	115	135	165	190	220	240	260
6	155	185	230	270	300	325	360
7	190	230	300	350	410	440	480
8	220	280	375	445	510	570	610
Scupper Flow (L/min)							
H (mm)	Scupper Diameter (mm)						
	123	150	200	250	300	350	400
25	22	26	30	32	37	38	38
50	95	95	114	132	151	151	170
75	189	208	246	284	284	341	360
100	303	341	416	492	530	587	606
125	435	511	625	719	833	908	984
150	587	700	871	1022	1136	1230	1363
175	719	871	1136	1325	1552	1666	1817
200	833	1060	1420	1685	1931	2158	2309

Notes:
1) H = static head above scupper invert (design water level above base of scupper opening).
2) Linear interpolation is acceptable.
3) Extrapolation is not appropriate.

Table 2.5.4.1-4. Conversion of Rainfall Intensity to Flow Rate and Rain Load per Unit Area

English Units		
Rainfall Intensity (in./hr)	**Flow Rate (gpm/ft^2)**	**Rain Load/hr (psf)**
1.0	.0104	5.2
1.5	.0156	7.8
2.0	.0208	10.4
2.5	.0260	13.0
3.0	.0312	15.6
3.5	.0364	18.2
4.0	.0416	20.8
4.5	.0468	23.4
5.0	.0520	26.0
5.5	.0572	28.6
6.0	.0624	31.2
7.0	.0728	36.4
8.0	.0832	41.6
9.0	.0936	46.8
10.0	.1040	52.0
Metric Units		
Rainfall Intensity (mm/hr)	**Flow Rated (L/min per m^2)**	**Rain Load/hr (kilonewtons [kN] per m^2)**
25	0.42	.25
30	0.5	.29
35	0.58	.34
40	0.67	.39
45	0.75	.44
50	0.83	.49
55	0.92	.54
60	1.0	.59
70	1.2	.69
80	1.3	.79
90	1.5	.88
100	1.7	.98
200	3.3	1.96
300	5.0	2.94

Note: Interpolation is appropriate.

Table 2.5.4.1-5. Hydraulic Head and Corresponding Drain Flow for Primary Roof Drains (US units)

Flow Rate (GPM)	*Hydraulic Head (in.)*						*Flow Rate (GPM)*
	Drain Outlet Size (in.)						
	3	4	5	6	8	10	
	Diameter Bowl (Sump) Diameter (in.)						
	10.5	10.5	10.5	10.5	11.75	15.25	
	Drain Bowl (Sump) Depth (in.)						
	2	2	2	2	3.25	4.25	
50	1.5	1.5	1.5	1.0	1.0	-	50
75	1.5	1.5	1.5	1.5	-	-	50
100	2.5	2.0	2.0	2.0	2.0	2.0	100
125	4 .0	2.5	-	-	-	-	125
150	5.0	3.0	2.5	2.5	-	-	150
175	5.5	4.0	-	-	-	-	175
200	-	4.5	3.0	3.0	3.0	2.5	200
225	-	5.5	-	-	-	-	225
250	-	6.0	3.5	3.5	-	-	250
275	-	-	-	-	-	-	275
300	-	-	4.5	4.0	4.0	3.0	300
325	-	-	-	-	-	-	325
350	-	-	5.5	4.5	-	-	350
375	-	-	-	-	-	-	375
400	-	-	6.0	4.5	4.5	3.5	400
450	-	-	-	4.5	-	-	450
500	-	-	-	5.0	4.5	3.5	500
550	-	-	-	6.0	-	-	550
600	-	-	-	-	4.5	4.0	600
650	-	-	-	-	-	-	650
700	-	-	-	-	5.0	4.0	700
800	-	-	-	-	5.5	4.5	800
900	-	-	-	-	6.0	4.5	900
1000	-	-	-	-	-	5.0	1000
1100	-	-	-	-	-	5.5	1100
1200	-	-	-	-	-	6.0	1200

Notes:
1) Hydraulic head in this table is the height of water above the drain rim. Where the drain rim is at the same elevation as the surrounding roof surface, the total head is the same as the hydraulic head.
2) Assume that the flow regime is either weir flow or transition flow, except where the hydraulic head values are in blue cells below the heavy line that designates orifice flow.
3) Refer to Section 2.5.2.6 for recommendations for differing drain geometry.
4) Linear interpolation is acceptable.
5) Extrapolation is not appropriate.

Table 2.5.4.1-6. Hydraulic Head and Corresponding Drain Flow for Primary Roof Drains (SI units)

Flow Rate (L/min)	*Hydraulic Head (mm)*						*Flow Rate (L/min)*
	Drain Outlet Size (mm)						
	75	100	125	150	200	250	
	Diameter Bowl (Sump) Diameter (mm)						
	270	270	270	270	300	390	
	Drain Bowl (Sump) Depth (mm)						
	50	50	50	50	85	110	
190	38	38	38	25	25	-	190
285	38	38	38	38	-	-	285
380	64	51	51	51	51	51	380
475	102	64	-	-	-	-	475
570	127	76	64	64	-	-	570
660	140	102	-	-	-	-	660
755	-	114	76	76	76	64	755
850	-	140	-	-	-	-	850
945	-	152	89	89	-	-	945
1040	-	-	-	-	-	-	1040
1135	-	-	114	102	102	76	1135
1230	-	-	-	-	-	-	1230
1325	-	-	140	114	-	-	1325
1420	-	-	-	-	-	-	1420
1515	-	-	152	114	114	89	1515
1705	-	-	-	114	-	-	1705
1895	-	-	-	127	114	89	1895
2080	-	-	-	152	-	-	2080
2270	-	-	-	-	114	102	2270
24600	-	-	-	-	-	-	2460
2650	-	-	-	-	127	102	2650
3030	-	-	-	-	140	114	3030
3405	-	-	-	-	152	114	3405
3785	-	-	-	-	-	127	3785
4165	-	-	-	-	-	140	4165
4540	-	-	-	-	-	152	4540

Notes:
1) Hydraulic head in this table is the height of water above the drain rim. Where the drain rim is at the same elevation as the surrounding roof surface, the total head is the same as the hydraulic head.
2) Assume that the flow regime is either weir flow or transition flow, except where the hydraulic head values are in blue cells below the heavy line that designates orifice flow.
3) Refer to Section 2.5.2.6 for recommendations for differing drain geometry.
4) Linear interpolation is acceptable.
5) Extrapolation is not appropriate.

Table 2.5.4.1-7. Hydraulic Head (above dam) and Corresponding Drain Flow for Secondary (Overflow) Roof Drains (US units)

Flow Rate (GPM)	*Hydraulic Head (in.)*							*Flow Rate (GPM)*
	Overflow Dam 8 in. Diameter			Overflow Dam 12.75 in. Diameter		Overflow Dam 17 in. Diameter	Overflow Standpipe 6 in. Diameter	
	Drain Outlet Size (in.)			Drain Outlet Size (in.)		Drain Outlet Size (in.)	Drain Outlet Size (in.)	
	3	4	6	6	8	10	4	
50	0.5	0.5	0.5	0.5	0.5	-	1.0	50
75	1.0	-	-	-	-	-	-	75
100	1.5	1.0	1.0	1.0	0.5	1.0	1.5	100
125	2.0	-	-	-	-	-	-	125
150	2.0	1.5	1.5	1.0	-	-	2.5	150
175	3.0	-	-	-	-	-	-	175
200	-	2.0	2.0	1.5	1.5	1.5	2.5	200
225	-	-	-	-	-	-	-	225
250	-	2.5	2.5	1.5	-	-	2.5	250
300	-	3.0	3.0	2.0	2.0	1.5	3.0	300
350	-	3.5	3.5	2.5	-	-	3.5	350
400	-	5.5	3.5	3.0	2.5	2.0	-	400
450	-	-	4.0	3.0	-	-	-	450
500	-	-	5.0	3.5	3.0	2.5	-	500
550	-	-	5.5	4.0	-	-	-	550
600	-	-	6.0	5.0	3.5	2.5	-	600
650	-	-	-	-	-	-	-	650
700	-	-	-	-	3.5	3.0	-	700
800	-	-	-	-	4.5	3.0	-	800
900	-	-	-	-	5.0	3.5	-	900
1000	-	-	-	-	5.5	3.5	-	1000
1100	-	-	-	-	-	4.0	-	1100
1200	-	-	-	-	-	4.5	-	1200

Notes:
1) To determine total head, add the height of the dam or standpipe (height above the roof surface) to the hydraulic head listed in this table.
2) The drain bowl (sump) diameter is the same as for the primary drains of the same drain outlet size (see Table 8a).
3) Assume that the flow regime is either weir flow or transition flow, except where the Hydraulic Head values are in blue cells below the heavy line that designates orifice flow.
4) Refer to Section 2.5.2.6 for recommendations for differing drain geometry.
5) Linear interpolation is acceptable.
6) Extrapolation is not appropriate.

Table 2.5.4.1-8. Hydraulic Head (above dam) and Corresponding Drain Flow for Secondary (Overflow) Roof Drains (SI units)

Flow Rate (L/min)	Hydraulic Head (mm) above Dam or Standpipe: Overflow Dam 200 mm Diameter, Drain Outlet Size (mm) 75	Overflow Dam 200 mm Diameter, Drain Outlet Size (mm) 100	Overflow Dam 200 mm Diameter, Drain Outlet Size (mm) 150	Overflow Dam 325 mm Diameter, Drain Outlet Size (mm) 150	Overflow Dam 325 mm Diameter, Drain Outlet Size (mm) 200	Overflow Dam 430 mm Diameter, Drain Outlet Size (mm) 250	Overflow Standpipe 150 mm Diameter, Drain Outlet Size (mm) 100	Flow Rate (L/min)
190	13	13	13	13	13	-	25	190
285	25	-	-	-	-	-	-	285
380	38	25	25	25	13	25	38	380
475	51	-	-	-	-	-	-	475
570	51	38	38	25	-	-	64	570
660	76	-	-	-	-	-	-	660
755	-	51	51	38	38	38	64	755
850	-	-	-	-	-	-	-	850
945	-	64	64	38	-	-	64	945
1135	-	76	76	51	51	38	76	1135
1325	-	89	89	64	-	-	89	1325
1515	-	140	89	76	64	51	-	1515
1705	-	-	102	76	-	-	-	1705
1895	-	-	127	89	76	64	-	1895
2080	-	-	140	102	-	-	-	2080
2270	-	-	152	127	89	64	-	2270
2460	-	-	-	-	-	-	-	2460
2650	-	-	-	-	89	76	-	2650
3030	-	-	-	-	114	76	-	3030
3405	-	-	-	-	127	89	-	3405
3785	-	-	-	-	140	89	-	3785
4165	-	-	-	-	-	102	-	4165
4540	-	-	-	-	-	114	-	4540

Notes:
1) To determine total head, add the height of the dam or standpipe (height above the roof surface) to the hydraulic head listed in this table.
2) The drain bowl (sump) diameter is the same as for the primary drains of the same drain outlet size (see Table 8b).
3) Assume that the flow regime is either weir flow or transition flow, except where the hydraulic head values are in blue cells below the heavy line that designates orifice flow.
4) Refer to Section 2.5.2.6 for recommendations for differing drain geometry.
5) Linear interpolation is acceptable.
6) Extrapolation is not appropriate.

M. Roof Slope

1. Roofs with interior drains: Ensure the points of maximum sag are no lower than the roof surface between these points, and the drains of roofs with interior drainage provide a positive drainage slope of at least 1/4 in 12 (2%). In Figure 2.5.4.1-3 this is illustrated in the sloped roof detail where ponding occurs locally at the origin, whereas in the flat roof detail ponding occurs in every bay.

If water must flow across one bay into another, relatively complicated two-way deflection analysis is involved. The recommendations in Section 2.5.4.1.(M.2) for roof slope with edge drainage are appropriate. Have the roof framing designer prepare calculations according to these recommendations, or other appropriate method, to substantiate that the design slope is sufficient to prevent roof instability due to ponding.

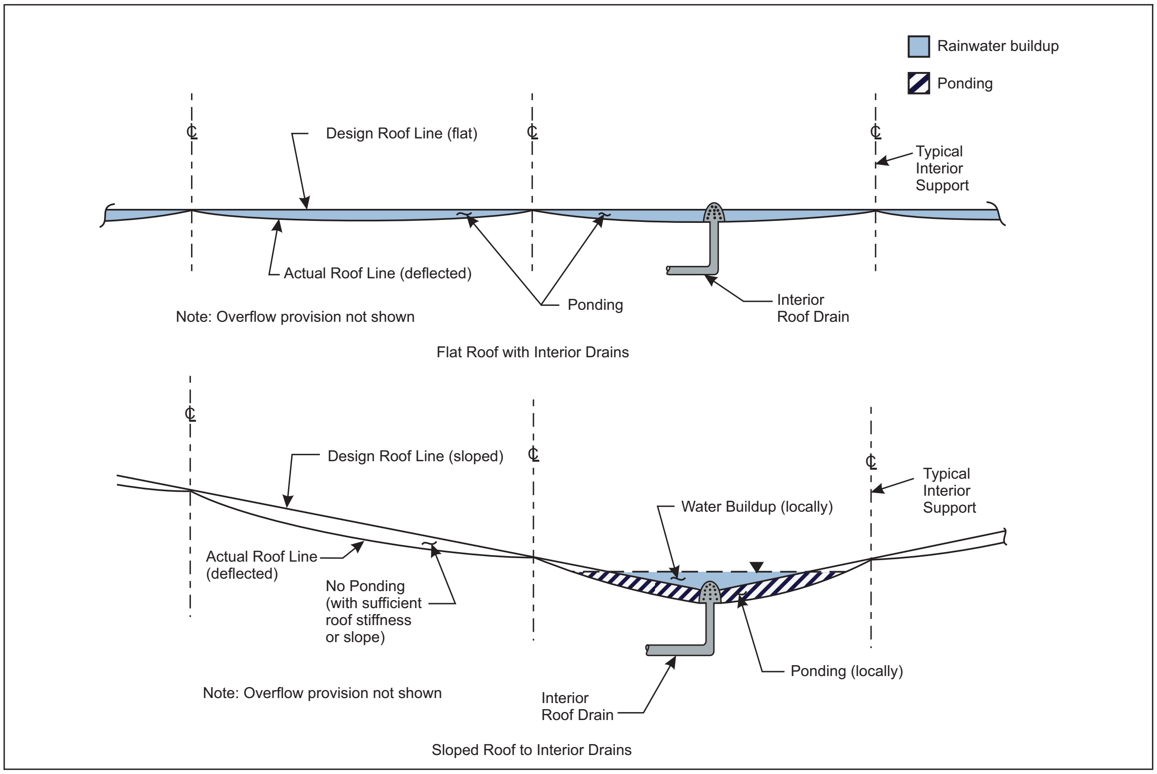


Fig. 2.5.4.1-3. Flat and sloped roofs with interior roof drains

2. Roofs with edge drainage: If interior drains are not provided and drainage is accomplished by causing the water to flow off the perimeter of the roof, sufficient roof slope of at least 1/4 in 12 (2%) is vital. Sufficient slope is needed to overcome the deflections caused by the dead load of the roof plus the weight of the 1-hour design storm less the effect of any specified camber. This is achieved when the actual downward pitch of the roof surface exceeds the upward slope for all deflected roof framing at or near their downward support column (or wall) (see Fig. 2.5.4.1-4).

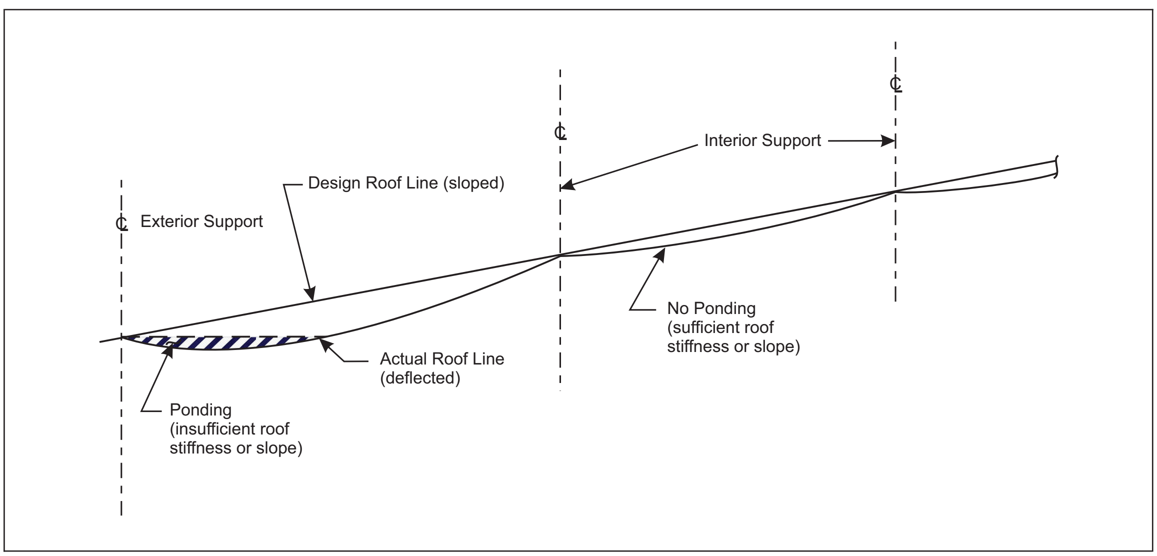


Fig. 2.5.4.1-4. Sloped roof with roof edge drainage

If a design roof slope (S_d) less than 1/4 in 12 (2%) is desired, have the roof framing designer prepare calculations according to the following recommendations, or other appropriate method, to substantiate that the design slope is sufficient to prevent roof instability due to ponding:

a. Ensure the actual slope (S_A) under the dead load of the roof less the upward camber (when specified) is at least 1/8 in 12 (1%).

b. Ensure the actual slope (S_A) from the perimeter of the roof, under the dead load of the roof, plus the rain load, less the upward camber (when specified) is greater than zero (i.e., upward positive slope, not flat).

c. Ensure all primary and secondary members perpendicular to the roof edge, for the entire roof slope, have actual slopes (SA) calculated by the roof designer that meet the slope criteria of (a) and (b) above as follows:

English Units:

$$S_a\ (\%) = S_d\ (\%) + \frac{240 \times (\text{Camber})}{L} - \frac{(\text{D.L.})\ L^3}{1.44 \times 24 \times E \times I} \geq 1\%$$

$$S_a\ (\%) = S_d\ (\%) + \frac{240 \times (\text{Camber})}{L} - \frac{(\text{D.L.} + 5.2 \times i)\ L^3}{1.44 \times 24 \times E \times I} \geq 0\%$$

Where: S_a and S_d = the actual and design roof slopes in percent, respectively.
D.L. = the roof's dead load in psf
Camber = upward camber in inches when it is specified (not optional) by fabrication specifications (see Part e).
I = rainfall intensity in in./hr
L = span length of member in inches
E = modulus of elasticity of members material, psi
I = effective moment of inertia of member, $(\text{in.})^4$ per inch of (tributary loaded) roof width

To convert roof slope (percent) to in./ft multiply percent by 0.12

Metric Units:

$$S_a\ (\%) = S_d\ (\%) + \frac{0.24 \times (\text{Camber})}{L} - \frac{(\text{D.L.})\ L^3}{24 \times E \times I} \geq 1\%$$

$$S_a\ (\%) = S_d\ (\%) + \frac{0.24 \times (\text{Camber})}{L} - \frac{(\text{D.L.} + 0.01 \times i)\ L^3}{24 \times E \times I} > 0\%$$

Where: S_a and S_d = the actual and design roof slopes in percent, respectively.
D.L. = Roof's dead load in kN/m^2
Camber = upward camber in mm when it is specified not optional by fabrication specifications (see Part e).
I = rainfall intensity, in mm/hr
L = span length of member in meters
E = modulus of elasticity of members material, in kN/m^2
I = effective moment of inertia of member, in $(m)^4$ per meter of (tributary loaded) roof width

d. If secondary members are parallel to relatively stiff perimeter walls (e.g., masonry or metal panel walls), increase the actual roof slope to compensate for maximum deflection (adjusted for any specified camber) of the secondary member closest to the wall. Adjust the actual slope computed in the equations of Part c above by a decrease as follows:

$$S_a\ \text{Decrease}\ (\%) = -\frac{(\text{Max. Deflection of secondary member})\ 100}{(\text{Distance secondary member from wall})}$$

Where: deflection and distance are in the same units (e.g., in. or mm)

e. The following are cambers specified in the Standard Specifications of the Steel Joist Institute (SJI) for LH-Series (Longspan) and DLH-Series (Deep Longspan) Joists and Joist Girders:

Table 2.5.4.1-9 LH-Series and DL-Series Joist Camber

Top Chord Length ft (m)	Approximate Camber in. (mm)
20 (6)	¼ (6)
30 (9)	⅜ (10)
40 (12)	⅝ (16)
50 (15)	1 (25)
60 (18)	1½ (38)
>60 (>18)	See SJI Specifications

Do not assume the above cambers for K-Series (Open Web) Joists because they are optional with the manufacturer.

N. Replacement and Retrofit Roof Drains

1. When replacing existing roof drains, use drains with the same drain bowl and outlet size and geometry (i.e., in-kind replacement) to ensure the replacement drains will have the same hydraulic performance as the existing drains.

2. If replacement of drains is not in-kind, then have a hydraulic analysis of the roof drainage performed by a licensed plumbing engineer, or provide drain test results, to verify the rain load with the replacement drains will not exceed the rain load with the existing drains, based on the needed volumetric flow rate for the drains.

3. Avoid using retrofit roof drains that are installed over and/or into existing roof drains. These typically have a very shallow drain bowl (or no drain bowl) and are less hydraulically efficient than the original drains; they can result in substantially more total rain load on the roof.

4. For drains with anti-vortex devices, do not credit any reduction in hydraulic head or rain load unless the devices have been proven to perform adequately based on drain test results.

2.5.4.2 Siphonic Roof Drainage

A. Restrictions

1. For roofs with internal drains distributed throughout the roof, do not use siphonic roof drainage in hurricane-prone, tropical cyclone-prone, or typhoon-prone regions as defined in FM Global Data Sheet 1-28. This recommendation does not apply to roofs with siphonic drains located only in eave (perimeter) gutters or valley gutters.

2. Do not use siphonic roof drainage for roofs that will be prone to debris accumulation, such as roofs with nearby or overhanging vegetation where leaves, pine needles, or other vegetation is prone to substantially restrict roof drains flows or clog the siphonic piping system. Keep vegetation at least 50 ft (15 m) offset horizontally from the roof perimeter and no higher than the elevation of the lowest roof parapet. Ensure that a program is in place to control vegetation.

3. Do not use siphonic roof drainage for gravel covered, stone ballasted, or for vegetative (green) roofs.

B. Design Rainfall Intensity, Duration, and Frequency

Rainfall intensity (i) is the rate that rainfall accumulates over time, is frequently expressed in inches or millimeters per hour (in/hr or mm/hr), and is a function of both duration (minutes or hours) and frequency (MRI or return period, in years) for a given location and climate.

1. Determine the flow rate (Q [gpm or L/min]) needed per roof drain, leader, or scupper in the same manner as for gravity roof drainage, but with any adjustments as noted to the rainfall intensity (i).

C. Acceptable Drainage Designs and Design Assumptions

1. Acceptable Design Options

Note that the recommendations in Section 2.5.4.2.(C.2), General Design Assumptions and Requirements, apply to all acceptable design options.

a. Option 1

i. Primary siphonic drainage designed for the 2-year, 5-min rainfall intensity.

ii. Secondary conventional (non-siphonic) drainage designed for twice (2 times) the 100-year, 60-minute rainfall intensity, with primary drainage completely blocked.

b. Option 2

i. Primary siphonic drainage designed for the 2-year, 5-min rainfall intensity.

ii. Secondary siphonic drainage designed for the 100-year, 5-min rainfall intensity, with primary drainage completely blocked.

2. General Design Assumptions and Requirements

a. The design life of the drainage systems should not be less than the design life of the building, nor less than 50 years.

b. Ensure that primary and secondary drainage are completely independent systems.

c. For secondary gravity drainage and scupper details (minimum sizes, inlet elevations), follow the recommendations in Section 2.5.4.1 (the conventional drainage section).

d. The siphonic drainage system must be designed to operate properly at all flow rates and rainfall intensities, up the maximum design flow rate and rainfall intensity. Ensure the water depths on the roof or in the roof gutters will not exceed depths occurring at the maximum design flow rate and rainfall intensity.

e. Secondary siphonic drainage systems should be designed to operate properly at the design rainfall intensity based on the following assumptions:

i. All secondary siphonic roof drains are operating as designed (no clogging or blinding).

ii. At least one secondary siphonic drain per roof, but not less than 5% of the total secondary drains on a roof, are completely clogged or blinded, with the blocked or blinded secondary drains arranged to place the most demand on the roof drainage and roof structure.

f. Do not credit any temporary storage of water on roofs or in gutters for the siphonic drainage design.

3. Roof Load

Arrange the secondary drain high enough above the primary drain so water will reach a sufficient depth to ensure the primary drainage system operates properly, but not so high that water reaches a depth that will overload the roof structure.

D. Roof Slope, Positive Drainage, and Stability against Ponding

Follow the recommendations for gravity drainage in Section 2.5.4.1 except as noted in Section 2.5.4.2.(A), Restrictions.

E. Roof Drains

1. Quantity (minimum number of drains per roof area): Follow the recommendations for gravity drainage in Section 2.5.4.1.

2. Drain strainers (debris guards): Provide domed drain strainers extending at least 4-inches (100 mm) above the roof surface for all siphonic roof drains, including those placed in roof gutters. Ensure that the open area of the strainer is at least three-times (3x) the cross-sectional area of the drain outlet or tailpipe, whichever is larger. Ensure that the hydraulic performance properties for the roof drain account for the presence of the drain strainers.

3. Drain baffle (anti-vortex plate): All siphonic drains must have a baffle to prevent air entrainment into the siphonic system and allow for full-bore siphonic flow. Ensure that the baffle is clearly and permanently marked with a warning not to remove the baffle.

4. Sump bowl or drainage basin for secondary drainage systems: Roof drains on low-sloped roof (2% slope or less) should have a sump bowl or drainage basin to allow for siphonic flow while minimizing water depth on the roof.

5. Provide roof drains with the manufacturer name and model number, drain outlet size (in2 [mm2]), and hydraulic resistance coefficient (e.g., “K” value), clearly and permanently marked on the drain body where it will be legible in its installed condition to an observer on the roof.

F. Design Validation

1. Siphonic design and analysis must be performed by a plumbing engineer licensed to practice in the project location. The design calculations, including computerized calculations and results, must be signed and stamped by the licensed plumbing engineer.

2. The hydraulic properties and performance of manufactured roof drains used in the siphonic system must be based on physical test results from a testing program established in a nationally-recognized standard (such as ASME A112.6.9) and tested by a laboratory that has been verified to be qualified to perform the testing. Using roof drains with hydraulic performance based on calculation alone - or based on calculated hydraulic performance taken from test results of a different, albeit similar, roof drain - is not acceptable.

G. Disposable (Available) Head

1. Use the design disposable dead (Hd), also known as the design available head, as the vertical distance in ft (m) from the inlet (rim) of the roof drain to the highest elevation (i.e., least vertical distance) of the following:

- Grade elevation at discharge inspection chamber(s) or manhole(s)
- Flood elevation
- Elevation of siphonic break (for discharge above grade)

Refer to Figure 2.5.4.2-2, Elevation view of siphonic system and disposable (available) head.

2. Use the theoretical disposable head (H_t) as the vertical distance in ft (m) from the water level directly upstream of the roof drain to the centerline of siphonic discharge pipe at or below grade.

3. Ensure that either H_t or H_d, whichever provides for the more demanding condition, has been used when determining the properties or performance of the siphonic drainage system. For example, use H_d when determining if the system has adequate capacity to drain the roof based on the design rainfall intensity (i), or to determine the maximum depth of water buildup on the roof based on the design rainfall intensity. However, use H_t when determining the minimum pressure or maximum velocity to compare to allowable values.

H. Pipe Joints and Fitting

Use pipe joints and fitting that are rated to prevent leakage and air infiltration when subjected to maximum and minimum operating pressures. Use a negative (gauge) pressure rating of no greater than -12.3 psig (-85.0 kPa) for 1-hour.

I. Pipe Flow Velocity

Ensure that, at the design flow rate, the velocity in horizontal collector pipes and downpipes is adequate for efficient priming, to maintain siphonic flow, and to flush sediment from the system.

J. Siphonic Discharge

1. Discharge the siphonic drainage system to the open atmosphere - either to a below-grade inspection chamber (manhole), or to an above-grade trench or swale - to break the siphonic action.

2. Below-grade inspection chamber (manhole): Provide a vented cover for the chamber (manhole) that is at least 50% open area, or where the total open area of the vented cover is not less than three times (3x) the cross-sectional area of the siphonic discharge pipe, whichever is greater.

3. Keep the manhole cover clear or snow, ice, and debris. Provide bollards or similar protective devices to keep materials, vehicles, etc. from blocking the manhole cover.

4. Avoid the use of vermin guards on discharge pipes because they could collect debris and block proper siphonic flow. The preferred alternative is to conduct frequent visual inspections to ensure discharge pipes remain free of debris. See Section 2.5.4.2.(O), Inspection and Maintenance, for additional details.

K. Pipe Strength, Details, and Materials

1. Piping and Fittings: General

a. Use metal pipe, such as cast iron, galvanized steel, stainless steel, or copper, rather than plastic pipe for better long-term durability and performance. Ensure pipe and associated joints, fittings, couplings, etc. meet or exceed applicable, nationally recognized plumbing materials standards such as those by ASTM, CSA, BS, or DIN.

b. If plastic pipe cannot be avoided, use Schedule 40 pipe or better (or an SI equivalent based on the minimum ratio of pipe wall thickness to mean pipe diameter, see Table D.10-1) for all piping components of the siphonic drain system. Ensure plastic pipe (such as ABS, HDPE, or PVC) meets or exceeds applicable, nationally recognized plumbing materials standards such as those by ASTM, CSA, BS, or DIN.

c. If plastic pipe is used, take care to address the issues associated with thermal expansion, expansion joints, and pipe supports and restraints, and to provide the necessary detailing to prevent damage.

2. Expansion Joints

Avoid the use of expansion joints in siphonic systems wherever possible because proper connection detailing and adequate long-term performance can be difficult to achieve. If the use of expansion joints cannot be avoided, ensure the joint detail is designed to account for thermal expansion or contraction, the expansion joints are rated for critical buckling strength no less than that required of the adjacent siphonic piping.

3. Horizontal Collector Pipe

Ensure all reducers or increasers are eccentric (not concentric) with the crown (top) of the pipe set flush and the offset at the pipe invert.

4. Downpipe (Stack)

Ensure the downpipe diameter is no greater than the diameter of the horizontal collector pipe.

5. Minimum Pipe Size

Use pipe with an inside diameter of at least 1.6 in. (40 mm).

L. Pipe Supports and Bracing

Provide pipe supports and bracing as needed based on engineering analysis when accounting for all applicable conditions. This includes but is not limited to: gravity loads, deflections, and material creep, siphonic pipe pressures, operational vibrations and fatigue, thermal expansion/contraction, and seismic bracing when located in a 50-year to 500-year earthquake zone. Reference FM Global Data Sheet 1-2, *Earthquakes*.

M. Icing, Freeze, and Impact and Environmental Damage

1. Keep roof drains free of ice and snow.

2. Use FM Approved heat tracing on siphonic drain bodies and outlets exposed to freezing temperatures.

3. Where siphonic drainage piping is used in an unheated building or is installed at the exterior of a building (e.g., downpipe attached to the building facade), and is exposed to freezing temperature, install FM Approved heat tracing at all the exposed piping.

4. Use only noncombustible metallic materials for drain components that are to be heat traced.

5. Position above-grade secondary discharge pipes above the maximum expected snow level (including drift) and take special precautions to protect them from crushing or impact when exposed to car parks or storage areas (e.g., bollards).

6. Protect exposed siphonic drainage piping from ultraviolet radiation and other environmental sources of degradation.

N. Testing and Handover

1. Verify the siphonic system is clean and free of debris. Since it is very difficult to perform an in-situ operational test of the siphonic system, video verification or other means can ensure the system is not clogged and will operate as designed.

2. Verify all roof drains have baffles (anti-vortex plates) and securely attached debris guards.

3. Pressure test the siphonic system to 50% greater than the maximum pressure at design conditions, but not less than 13 psig (89.9 kPa) or 30 ft (9.0 m) water column. Ensure the system holds the test pressure for at least 1 hour.

O. Inspection and Maintenance

Ensure facilities personnel visually inspect the roof drains and discharge pipes at least once every 3 months and keep a written log of the inspections. Inspect each roof drain to ensure the debris guard and baffle plate are intact and there is no debris clogging the opening around the baffle plate. Inspect each discharge pipe to ensure the pipe is free of debris. Have facilities personnel remove any scattered debris on the roof that could clog or otherwise degrade the performance of the roof drains.

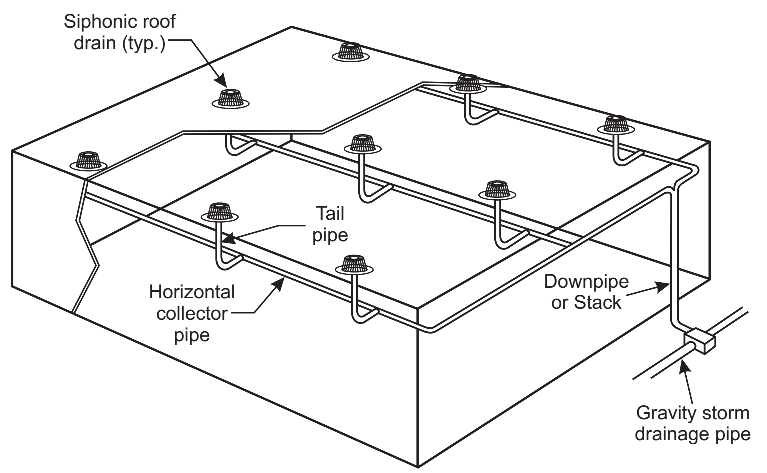


Fig. 2.5.4.2-1. Diagram of siphonic roof drain system

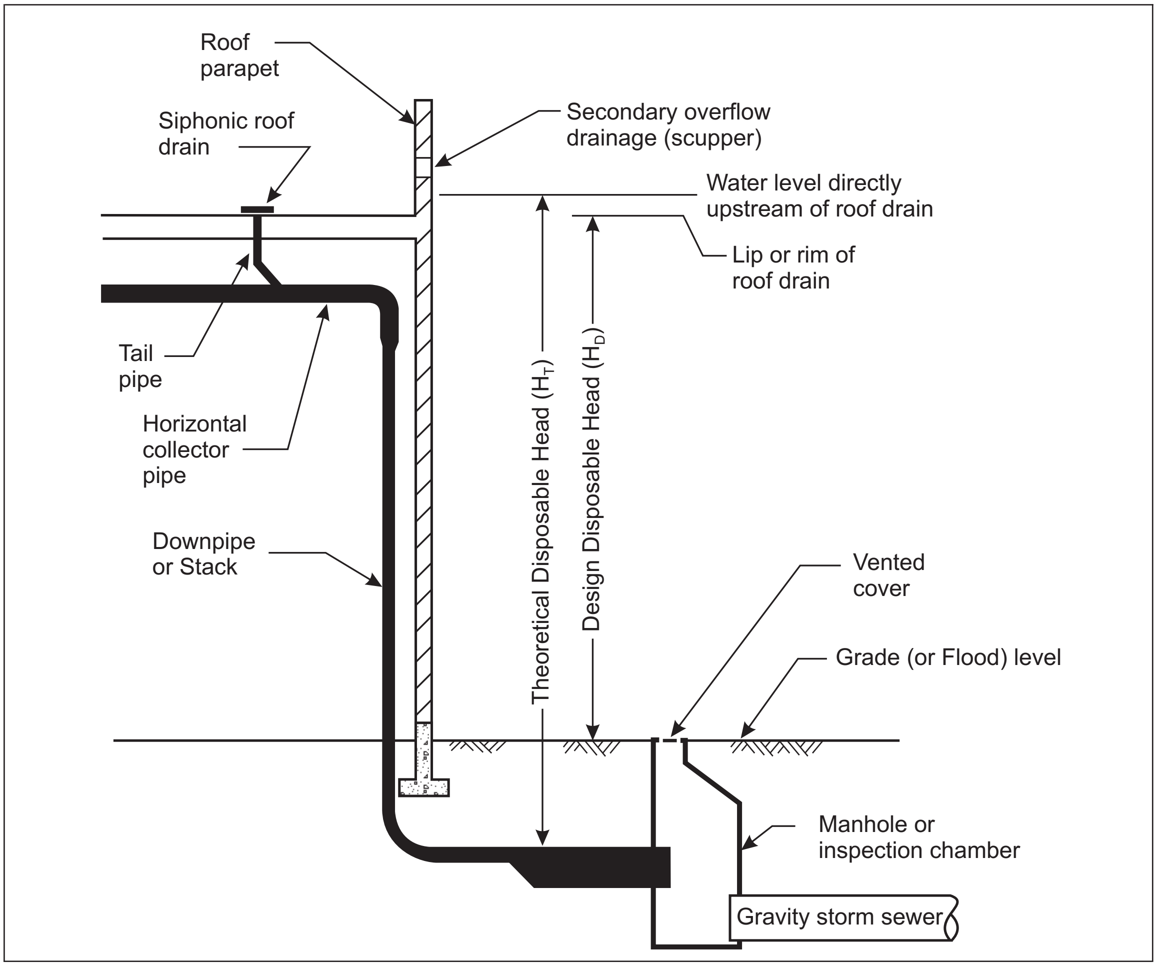


Fig. 2.5.4.2-2. Elevation view of siphonic system and disposable (available) head

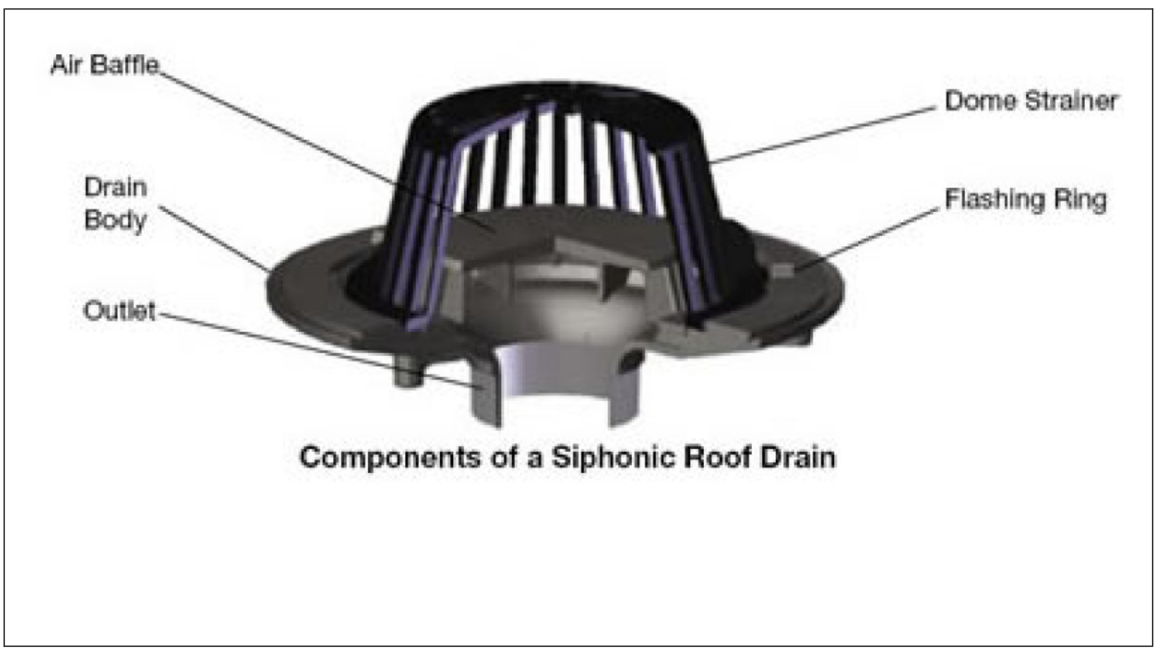


Fig. 2.5.4.2-3. Siphonic roof drain (photo courtesy of Jay R. Smith Mfg. Co.)

Fig. 2.5.4.2-4. Siphonic roof drain for gutters (without dome strainer or debris guard) (photo courtesy of Jay R. Smith Mfg. Co.)

Table 2.5.4.2. Rainfall Intensity Conversion Rates

Rainfall Intensity (i)		
in./hr	mm/min	L/sec-m^2
1.4	0.6	0.01
2.1	0.9	0.015
2.8	1.2	0.02
3.5	1.5	0.025
4.3	1.8	0.03
5.0	2.1	0.035
5.7	2.4	0.04
6.4	2.7	0.045
7.1	3.0	0.05
7.8	3.3	0.055
8.5	3.6	0.06
9.2	3.9	0.065
9.9	4.2	0.07
10.6	4.5	0.075
11.3	4.8	0.08

Note: (L/sec-m^2) x 141.7 = in./hr
(mm/min) x 2.362 = in./hr

where L = liter

2.6 Other Roof Loads

2.6.1 Collateral Loads and Roof Mounted Equipment

A. Determine the adequacy of the roof structure to support additional loading from added or modified roof-mounted or roof-suspended equipment/structures. Include the supporting roof framing, columns, and bearing walls in the analysis. Retain a qualified structural engineer to perform the analysis and design of any needed reinforcing.

The addition or modification of roof-mounted or roof-suspended equipment and structures can lead to overloading. These fixed loads become critical if coupled with other loadings such as rain and snow.

B. Design suspended or otherwise supported ceilings that allow access for maintenance workers for appropriate concentrated and uniform live loads based on the anticipated maintenance work.

2.6.2 Solar (Photovoltaic) Panels

This section applies to roof-mounted rigid solar (photovoltaic) panels used to generate electrical power, and is limited to the effects of snow load, rain load and drainage, and roof live load.

2.6.2.1 General

A. Consider the loads due to the weight of solar panels, like other fixed rooftop equipment, to be dead load, and use for the following three design load combinations for gravity loads:

1. Roof dead load (including solar panel load) + roof live load
2. Roof dead load (including solar panel load) + snow load
3. Roof dead load (including solar panel load) + rain load

Use the most severe or demanding load combination as the governing design load combination for the roof structure.

B. For solar panels with ballasted support systems (i.e., not mechanically anchored to the roof), it is feasible that the position of the solar panel arrays may change in relation to the roof framing. Therefore, when determining the design roof loads, assume the solar panel arrays will be positioned in such a way as to place the most severe or demanding design load on the roof structure.

C. For roofs intended to support solar panels, use the following general design conditions:

1. With the solar panels in place as designed
2. Without the solar panels in place

Use the condition that is the more severe or demanding as the governing design condition for the roof structure.

D. For new solar panel installations on existing roofs, a qualified engineer should evaluate the roof for adequate structural capacity for all recommended load conditions.

2.6.2.2 Roof live load

Use the roof live load recommendations in Section 2.3.

2.6.2.3 Snow Load

Use the snow loads recommendations in Section 2.4 with the following additions or changes:

A. Wind Directions

1. As is the case when determining drifting snow load on roofs without solar panels, for roofs with solar panels assume wind directions that cause the most severe or demanding load condition when determining drifting snow loads for design.

2. Snow drifting at tilted solar panel arrays need not be evaluated for wind directions parallel to the length of the panel rows.

For example, for tilted solar panels facing south, with the rows running east-west (e.g., common in the northern hemisphere), assume east or west winds will not cause inter-row drifting at the tiled solar panel arrays, and assume the tilted solar panel arrays will not affect leeward drifting at low roofs or windward drifting at parapets, roof projections, and walls due to east-west winds.

B. Load Combinations

There are two general categories of snow load effects for roof with solar panels:

1. Roof Snow Loads

Use the following load combinations:

a. Unbalanced snow
b. Balanced snow + leeward drift
c. Balanced snow + windward drift
d. Balanced snow + sliding

2. Inter-Row (Localized) Roof Snow Loads at Solar Panel Arrays

Use the following load combinations:

a. Balanced snow + inter-row drift
b. Balanced snow + inter-row sliding

Evaluate each load category above (1 and 2), and the load combinations within those categories, separately; these six load combinations do not occur or act concurrently. The only exception to this is in Section 2.6.2.3.(K.1) where surplus inter-row drifting is combined with traditional windward drift load snow loading (e.g., at parapet walls) in some cases.

For the design loads on the solar panels themselves, consider all six load combinations and use the most severe or demanding as the design load condition.

C. Solar Panel and Snow Load Parameters

Use the following notations:

h_b = height of the balanced (uniform) snow.
h_c = height of the solar panel above the roof balanced (uniform) snow.
h_d = height of the snow drift (from Section 2.4).
h_r = height of the solar panel above the roof surface.
W_A = width of the solar panel aisle (space).
W_b = upwind fetch distance.
W_d = width of the snow drift.
W_r = width of the solar panel row.
D = snow density (from Section 2.4).

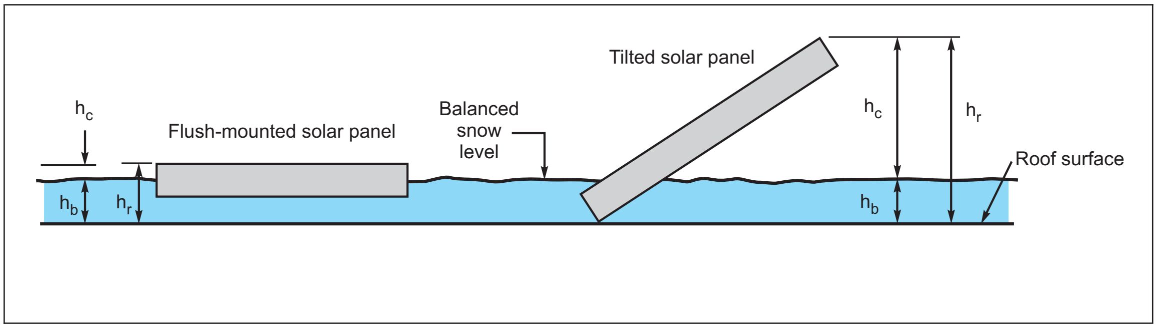


Fig. 2.6.2.3-1. Flush-mounted and tilted solar panels, schematic elevation view

1. Define solar panel height (h_r) as “significant height” are follows:

If h_r is not “significant” the sliding or drifting load effect is not significant and can be disregarded.

a. Sliding Snow Loads

Flush-mounted solar panels: Significant height is where $h_r > h_b$Tilted solar panels: Significant height is where hr > 1.2h_b

b. Drifting:

Significant height where hr > 1.2h_b

2. Elevated Solar Panels

Where the clear height from the balanced snow surface (based on h_b) to the bottom of the solar panel is 2.0 ft (0.6 m) or greater, drifting snow load at the solar panels will not be significant and need not be considered.

3. Length of Solar Panel Rows

Where solar panel rows are less than 15 ft (4.6 m) in length, drifting snow load at the solar panels will not be significant and need not be considered.

4. Spacing of Tilted Solar Panel

Where WA ≤ 8h_c, the rows are considered “closely spaced″

Where WA > 8h_c, the rows are considered “widely spaced”

D. Ground Snow Load Thresholds

Omit drift loads where Pg < 5 psf (0.25 kN/m^2).

This applies to leeward drifting on low roofs, windward drifting at roof projections and walls; and inter-row drifting at solar panel arrays. Neglect inter-row sliding snow load at solar panel arrays where Pg < 5 psf (0.25 kN/m^2).

E. Slope Threshold

Assume inter-row sliding snow load at solar panel arrays will not occur when solar panel slope ≤ 1.2° (1/4 in 12).

F. Sloped Roof Snow Loads

1. For sloped roofs with solar panels, use a sloped roof factor (C_s) based on a cold obstructed roof in accordance with Section 2.4.4.1.

2. Assume the cold obstructed condition extends from the lowest (most downslope) position of the solar panel array upslope at a 45-degree angle to the roof ridge (as shown in Figure 2.6.2.3-2 below). For roof bays where the area of the roof bay covered by the cold obstructed condition (with the solar panels in place) is at least 25% of the roof bay, assume the cold obstructed condition for those entire roof bays.text

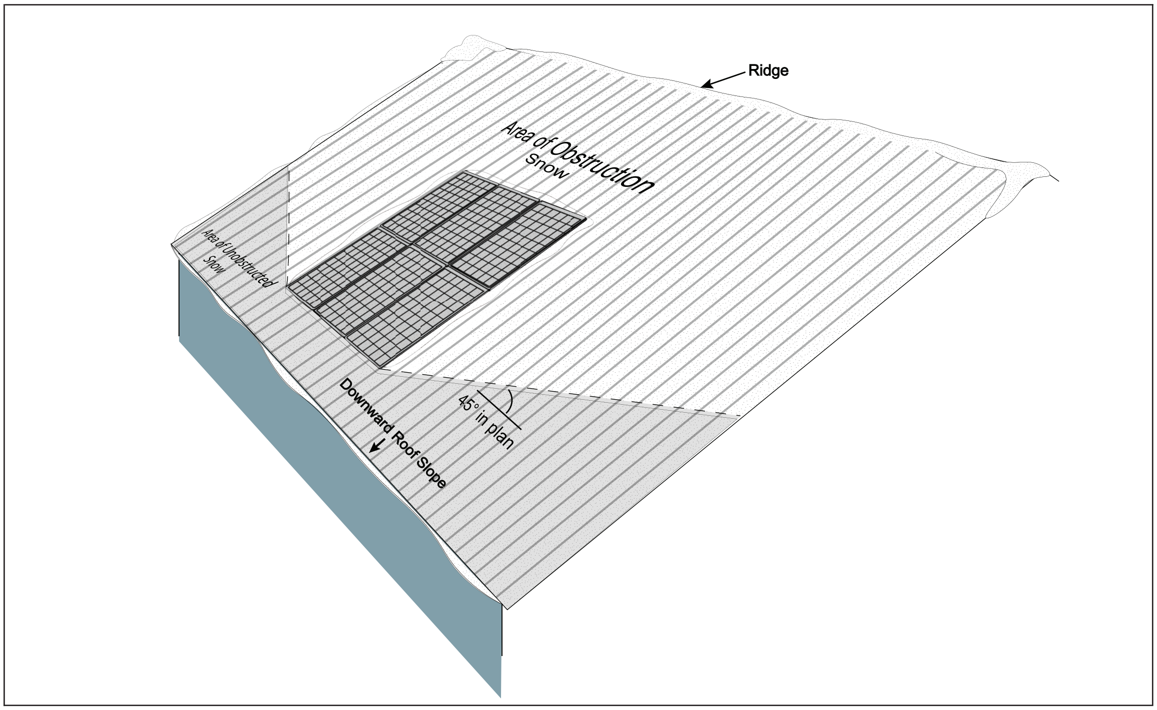


Fig. 2.6.2.3-2. Obstructed portions of sloped roofs

G. Balanced Snow Loads

Determine the balanced snow loads on roofs with solar panels as shown in Figure 2.6.2.3-3. For the tilted solar panels in Figure 2.6.2.3-4, assume the snow load is same for both open and closed back panels (closed back is shown).

Base the load (uniform snow load of P_f or P_s) on the roof slope (not the solar panel slope) and assume a cold obstructed roof in accordance with Section 2.4.3.1 or Section 2.4.4.1.

For the balanced snow load case, assume the solar panels do not alter the uniform nature of the snow loads.

H. Unbalanced Snow Loads

1. Hip or Gable Roofs

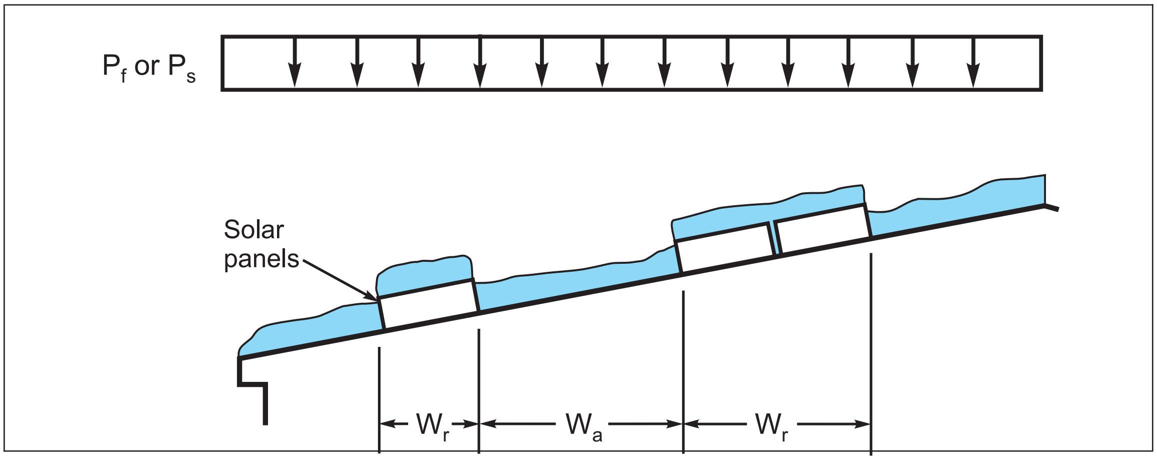


Fig. 2.6.2.3-3. Balanced snow loads on roofs with flush-mounted solar panels

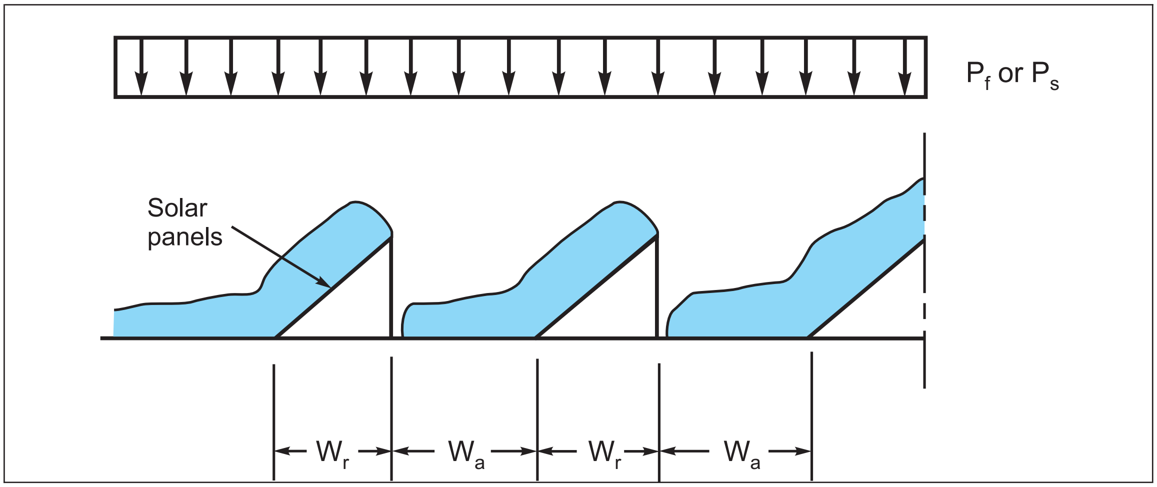


Fig. 2.6.2.3-4. Balanced snow loads on roofs with tilted solar panels

Determine the unbalanced snow loads (uniform snow load of $0.3P_s$ or $1.5P_s$) on a hip or gable roof with solar panels as indicated in Section 2.4.4.3 and Figure 2.4.4.3, assuming the solar panels have no effect on the snow loading. Base the load (P_s) on the roof slope (not the solar panel slope), and assume a cold obstructed roof.

2. Valley (Sawtooth) Roofs

Determine the unbalanced snow loads (uniform snow load of $0.5P_s$ or $2P_s$) on valley or sawtooth roofs with solar panels as indicated in Section 2.4.4.5 and Figure 2.4.4.5, assuming the solar panels have no effect on the snow loading. Base the load (P_s) on the roof slope (not the solar panel slope), and assume a cold obstructed roof.

I. Leeward Snow Drifts on Lower Roofs

1. For determining leeward drifts on low roofs, where solar panels are installed on the adjacent high roof, assume the solar panels on a high roof have no effect on leeward drifting on an adjacent low roof (i.e., use W_b equal to the upwind dimension of the high roof), and determine the leeward drift load on the low roof in accordance with Section 2.4.5.1 (see Figure 2.6.2.3-5 below).

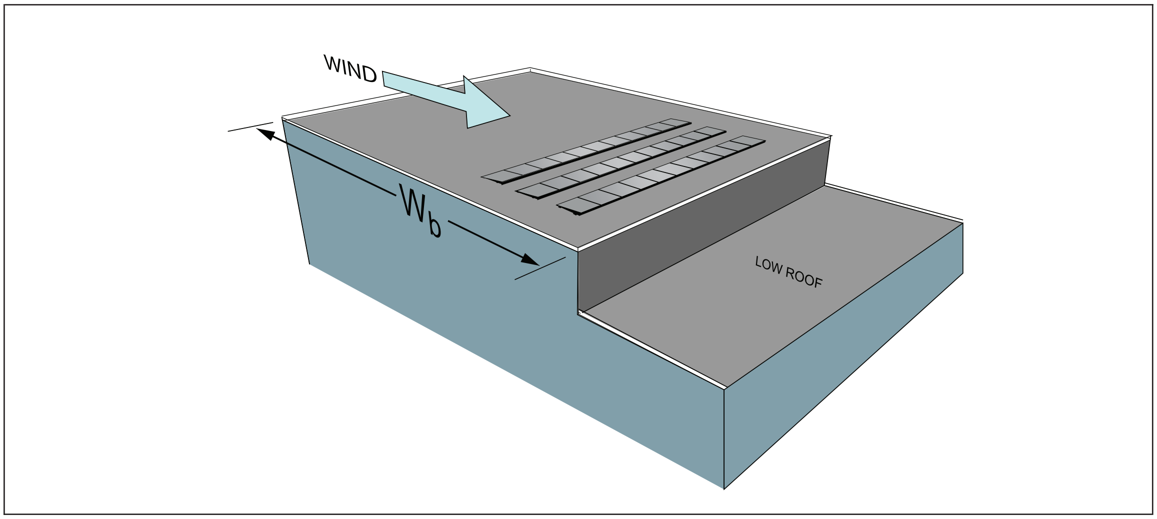


Fig. 2.6.2.3-5. Upwind fetch distance (W_b) for leeward snow drift at low roof with solar panels on high roof

2. Do not locate solar panels on a lower roof where they are exposed to leeward drifting from an adjacent high roof (i.e., within W_d from the high roof); however, if the solar panels are so located, and exposed to leeward drifting, use the combined balanced snow load and drift load as the design snow load for the roof and solar panels, assuming the solar panels have no effect on the balanced and drifting snow load (regardless of the slope of the solar panels) as shown in Figure 2.4.5.1-1. There is no need to consider sliding or inter-row (localized) drifting at the solar panels for this load condition.

J. Drifting at Flush-Mounted Solar Panel Array Perimeter

1. For flush-mounted solar panels where the width of the panel array (perpendicular to the wind direction) is less than 15 ft (4.6 m), regardless of the panel height, drifting need not be considered.

2. For flush-mounted solar panels with significant height ($hr > 1.2h_b$), determine drifting at the leeward and windward perimeter of the panel array based on a drift width of $8h_c$ and a drift height to the top of the panel ($h_d = h_c$) as shown in Figure 2.6.2.3-6.

3. As shown in Figure 2.6.2.3-7, for the two perpendicular wind directions, there will be four snow drifts (at each edge of each solar panel array) that are in place at the same time and therefore constitute the drifting snow load design condition. If the aisle width (W_a) is less than $16h_c$ the drift will intersect within the aisle; if this is the case, use both drift loads concurrently (superimposed) but with the combined drift load not exceeding the maximum single drift load (P_d).

K. Drifting at Roof Projections (other than solar panels) and Walls

1. For closely-spaced tilted solar panels, if all of the following apply, the inter-row drifting at the panel array will affect the snow drifting at parapets, roof projections (other than solar panels) and walls:

a. There are 2 or more rows of panels.
b. The length of the panel rows are 15 ft (4.6 m) or more.
c. The panels have “significant height” as defined in Section 2.6.2.3 (C.1).
d. The “clear height” for the panels is less than 2 ft (0.6 m), as defined in Section 2.6.2.3.(C.2).

Refer to Section 2.6.2.3.(L.3) to determine inter-row drifting at closely spaced solar panels.

If the total “drift supply,” as noted in Section 2.6.2.3.(L.3.c), is not consumed by inter-row drifting at the panel array, use the remaining inter-row drift area surplus to generate a windward drift load at the wall of a high roof or parapet wall based on the traditional wedge shaped drift (drift width = 4 x drift height). Additionally, if the wall at a high roof or parapet wall is exposed to windward drift due to an open roof area windward of the solar panel array (i.e., between the solar panel array and the wall), calculate the windward drift based on Section 2.4.5.1.(D), but add the inter-row drift area surplus (if any) to the windward drift to create the design windward drift load. Refer to Example problem 7 in Appendix E.

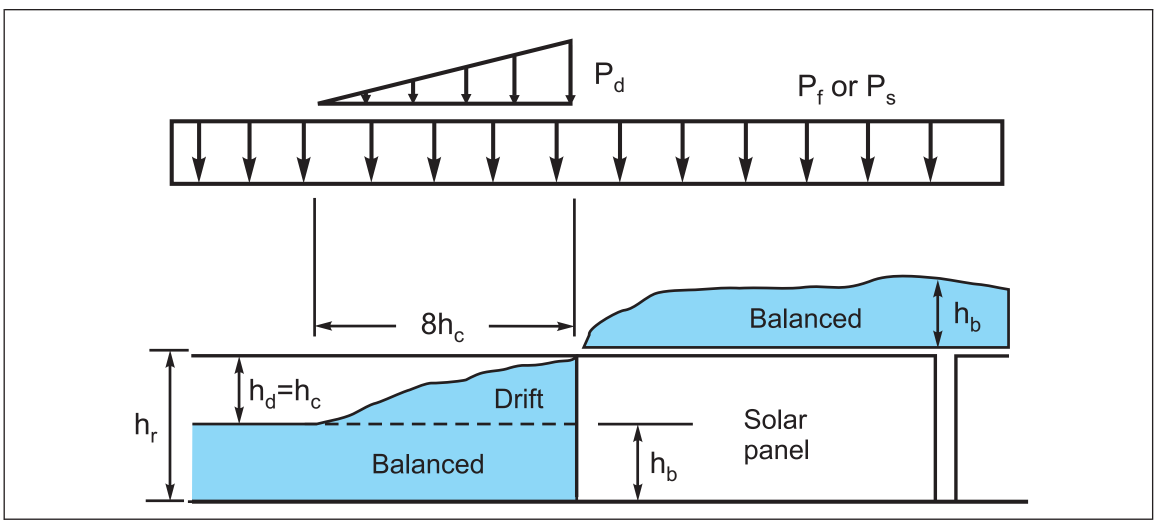


Fig. 2.6.2.3-6. Balanced and drifting snow load at flush-mounted solar panel array

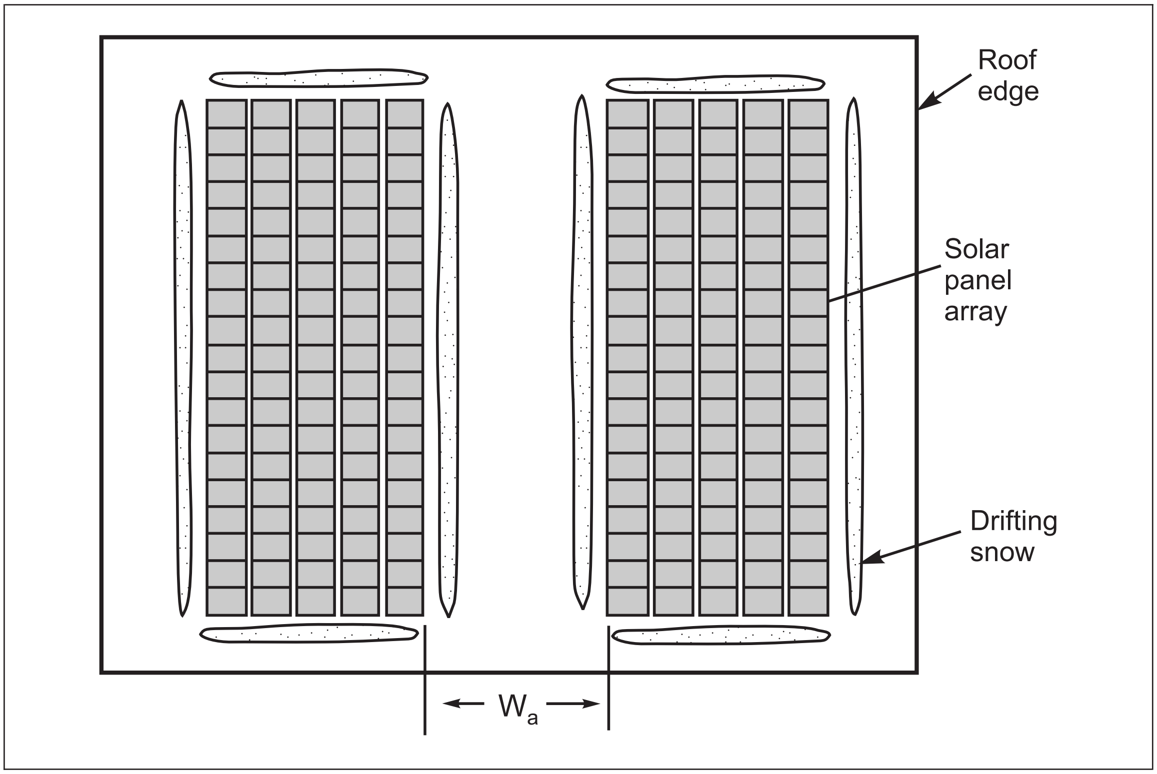


Fig. 2.6.2.3-7. Drifting snow load at flush-mounted solar panel arrays

2. For situations where Section 2.6.2.3.(K.1) is not applicable, snow drifting at the solar panel arrays (e.g., inter-row drifting) will not be significant and will not affect windward drifting at roof parapets, roof projections (other than solar panels) and walls. Therefore, determine windward drifts in accordance with Section 2.4.5.1.(D) assuming the solar panels have no effect on the drifting, and use W_b equal to the roof width, as shown in Figure 2.6.2.3-8 (cases 1 and 2).

See Section E.3 for an example.

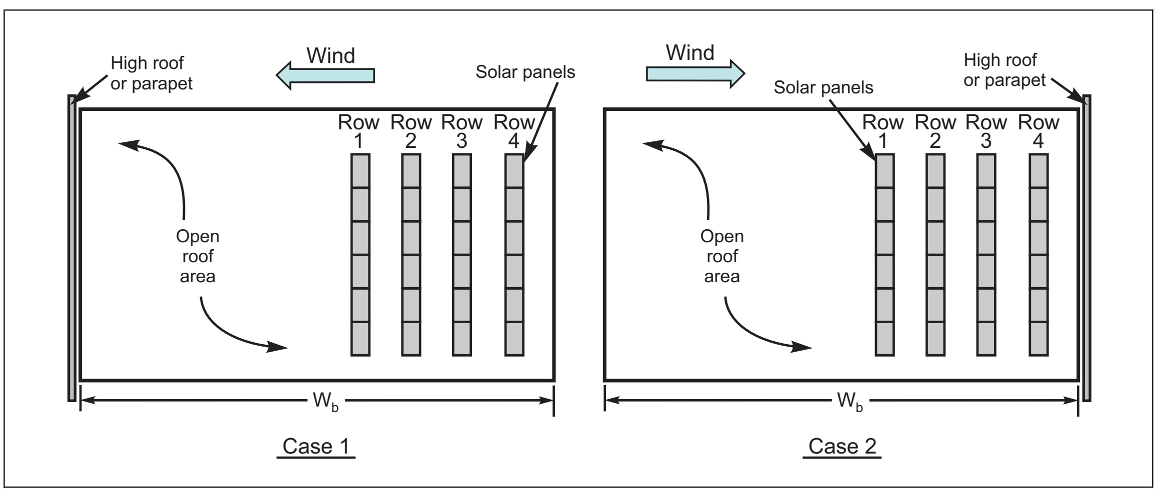


Fig. 2.6.2.3-8. W_b for snow drift at parapets, roof projections, or high roof walls for flush-mounted solar panels, widely-spaced titled solar panels, and tilted solar panels with less than significant height

L. Inter-Row (Localized) Drifting Snow Load at Tilted Solar Panels

1. Single Row

Determine snow drift loads at a single row of solar panels as shown in Figure 2.6.2.3-9 based on an upwind fetch (W_b) equal to the distance from the solar panel row to farther roof edge.

Recall that: h_d = leeward drift height (see Section 2.4)

a. Drift load at back of tilted solar panel

The drift loading at the back of the solar panels (P_{d1}) in Figure 2.6.2.3-9 is for closed black panels. For open back solar panels, assume the open space under the tilted panels is filled with drifted snow and account for this snow load.

P_{d1}= drift load at back of tilted solar panel
h_{d1} = drift height at back of tilted solar panel
$h_{d1} = 0.75h_d \leq h_c$

Where the drift height is restricted ($h_{d1} \geq h_c$), use:
$h_{d1} = h_c$
$W_{d1} = 4\ (h_{d1})^2/h_c \leq 8h_c$
$P_{d1} = (h_c)\ (D)$

Where the drift height is not restricted ($h_{d1} < h_c$), use:
h_{d1}
$W_{d1} = 4h_{d1}$
$P_{d1} = (h_{d1})\ (D)$

b. Drift load at front face of tilted solar panel

P_{d2} = drift load at front face of tilted solar panel
h_{d2} = drift height at front face of tilted solar panel
$h_{d2} = 0.5h_d \leq h_c$
$W_{d2} = 4h_{d2}$
$P_{d2} = (h_{d2})\ (D) \leq (h_c)\ (D)$

2. Widely Spaced Rows

Where $W_a > 8h_c$, the rows are considered “widely spaced”.

a. For drift loads at solar panels in widely spaced rows, use the same procedure to determine the drift loads as for single row solar panels; that is, treat each row as a single row when determining the drift load, except as noted:

i. The drift loading at the back of the solar panels (P_{d1}) in Figure 2.6.2.3-9 is for closed black panels. For open back solar panels, assume the open space under the tilted panels at each row is filled with drifted snow and account for this snow load.

b. Use an upwind fetch (W_b) equal to the distance from each panel row to the farthest roof edge, as shown in Figure 2.6.2.3-10: For example, the drift load (as shown in Figure 2.6.2.3-9) at Row 1 is based on W_{b1} while the drift load at Row 2 is based on W_{b2}.

3. Closely Spaced Rows

Where $W_a \leq 8h_c$, the rows are considered “closely spaced.”

The snow drift condition for Part a (Wind Direction toward Panel Face [Panel Face is Windward]) and Part b (Wind Direction toward Panel Back [Panel Back is Windward]) below do not occur concurrently; therefore, evaluate each conditions to determine the more severe or demanding condition, but do not combine the drift loads from Parts a and b.

Recall that: h_d = leeward drift height (see Section 2.4).

Refer to Section E.3 for an example problem.

a. Wind Direction toward Panel Face (Panel Face is Windward)

For drift loads at solar panels in closely spaced rows, refer to the loading in Figure 2.6.2.3-11 to determine the drift loads, where Row 1 is the most windward (upwind) row.

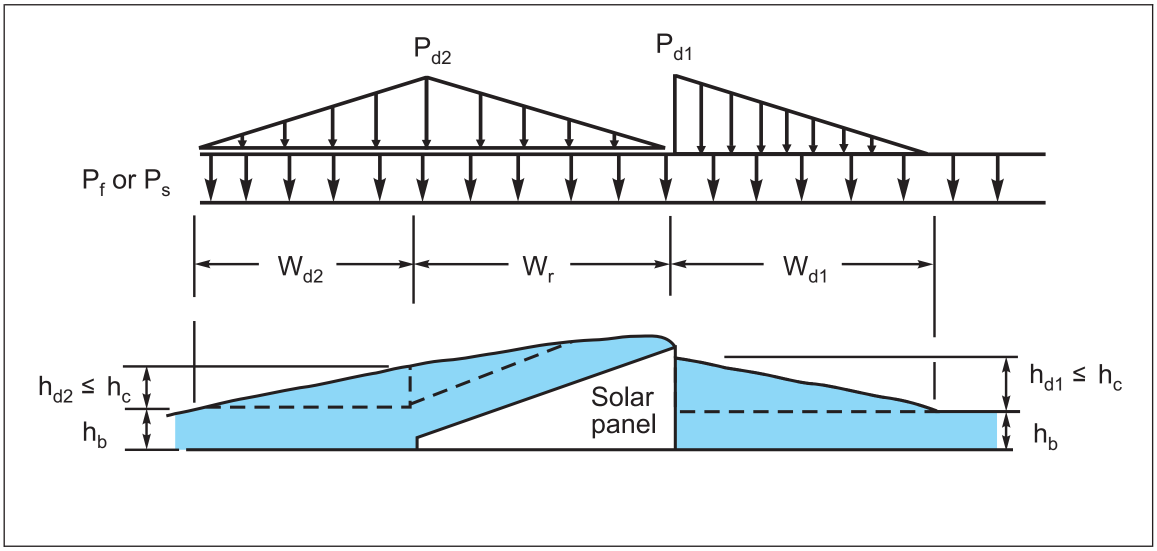


Fig. 2.6.2.3-9. Snow drift loads at tilted closed-back solar panel widely spaced rows (or a single row)

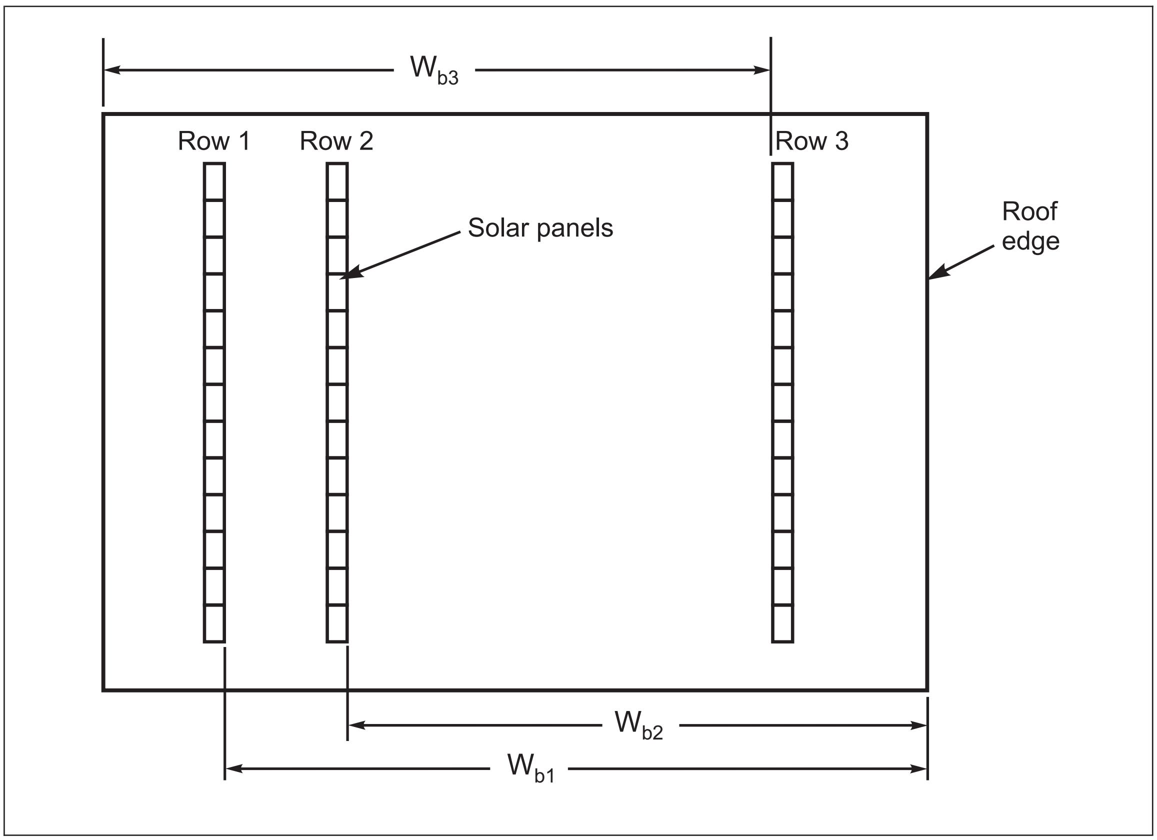


Fig. 2.6.2.3-10. Upwind fetch (W_b) for drift load at widely spaced, or single row, solar panels (drifting is not shown)

Use an upwind fetch (W_b) equal to the distance from the most upwind panel row (Row 1) to the roof edge, as shown in Figure 2.6.2.3-12.

i. Windward Drift

The windward drift (P_{d1}) only occurs at the most windward row (Row 1) and not at the other rows.

P_{d1} = drift load at front face of tilted solar panel
h_{d1} = drift height at front face of tilted solar panel
$h_{d1} = 0.5h_d \leq h_c$
$W_{d1} = 4h_{d1}$
$P_{d1} = (h_{d1})\ (D) \leq (h_c)\ (D)$

Cross-sectional area of the windward drift (A_{d1}): $A_{d1} = ½\ (h_{d1})\ (W_{d1} + W_r)$

ii. Leeward Drift

The leeward drift (P_{d2}) occurs at all rows until the “drift supply” is exhausted. See Part c below.

P_{d2} = leeward drift load at back of tilted solar panel
$W_{d2} = W_a$ (leeward drift width)
h_{d2} = drift height at back of tilted solar panel
$h_{d2} = (2)\ (h_d)\ ^2/W_a \leq h_c$
$P_{d2} = (h_{d1})\ (D) \leq (h_c)\ (D)$

Cross-sectional area of the leeward drift (A_{d2}): $A_{d2} = (h_{d2})\ (W_a)$

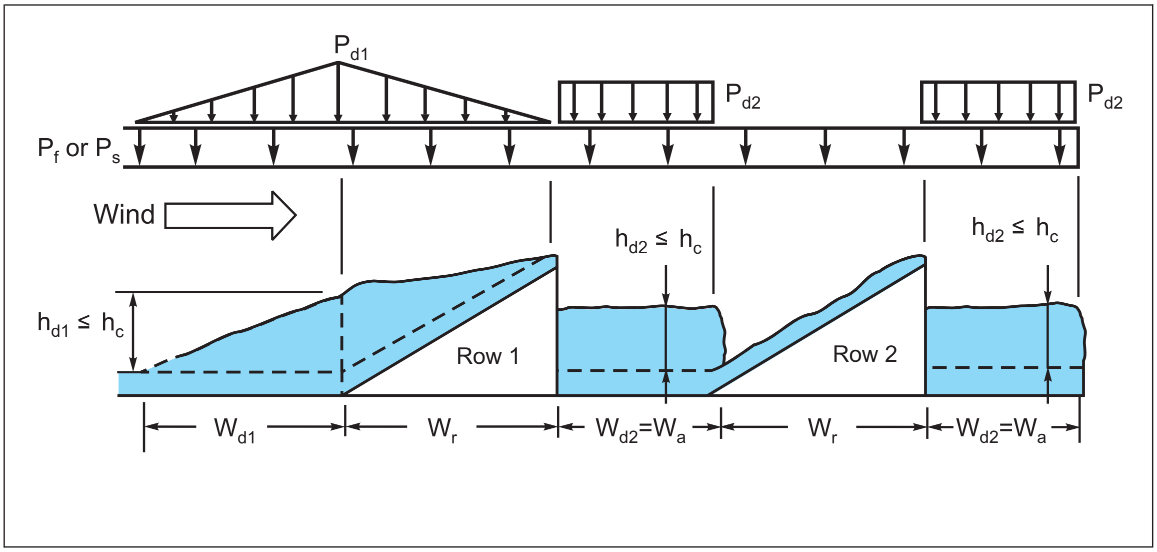


Fig. 2.6.2.3-11. Snow drift loads at tilted solar panels for closely spaced rows with panels facing windward

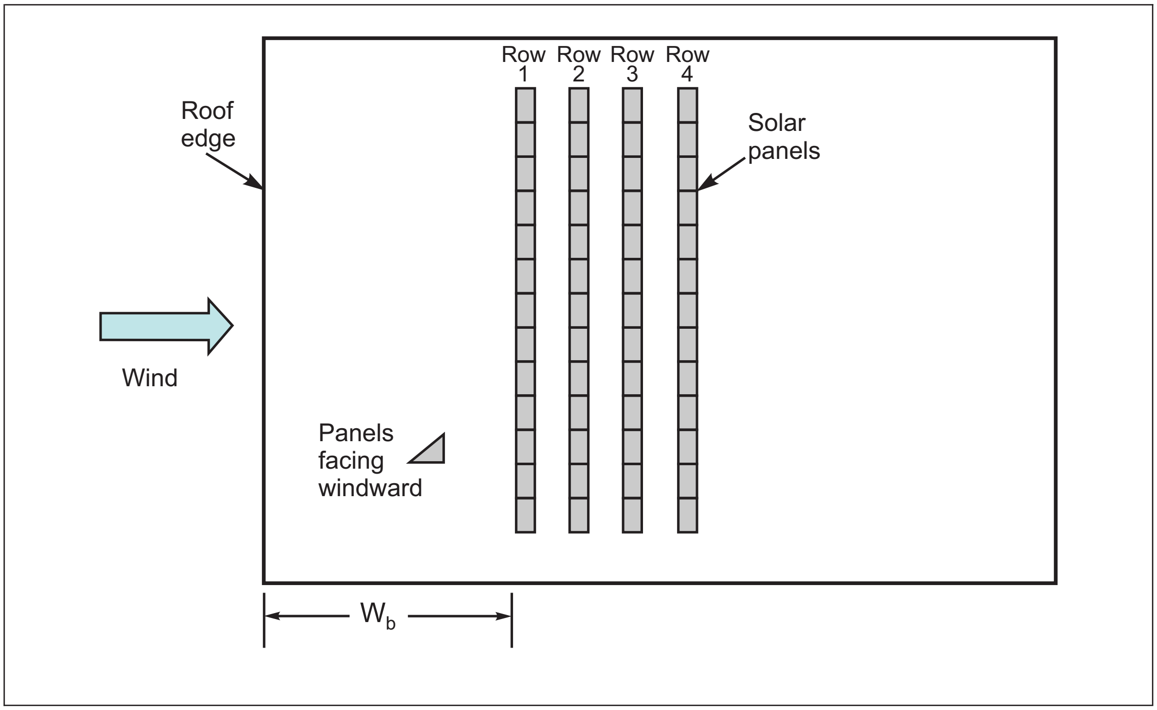


Fig. 2.6.2.3-12. Upwind fetch distance (W_b) for snow drift at multiple rows of closely spaced tilted solar panels with panels facing windward

b. Wind Direction toward Panel Back (Panel Back is Windward)

For drift loads at solar panels in closely spaced rows, refer to the loading in Figure 2.6.2.3-13 to determine the drift loads, where Row 4 is the most windward (upwind) row.

Use an upwind fetch (W_b) equal to the distance from the most windward panel row (Row 4) to the roof edge, as shown in Figure 2.6.2.3-14.

i. Windward Drift

The windward drift loading (P_{d1}) only occurs at the most windward row (Row 4) and not at the other rows, as shown in Figure 2.6.2.3-13, and is based on a closed back solar panels. For open back solar panels at the most windward row, assume the space under the tilted panel is filled with drifted snow and account for this snow load.

P_{d1} = drift load at back of tilted solar panel
h_{d1} = drift height at back of tilted solar panel

Where the drift height is restricted ($h_{d1} \geq h_c$), use:
$h_{d1} = h_c$
$W_{d1} = 4\ (h_{d1})\ ^2/h_c \leq 8h_c$
$P_{d1} = (h_c)\ (D)$

Where the drift height is not restricted ($h_{d1} < h_c$), use:
$h_{d1} = 0.75h_d$
$W_{d1} = 4h_{d1}$
$P_{d1} = (h_{d1)}\ (D)$

Cross-sectional area of the windward drift (A_{d1}): $A_{d1} = ½\ (h_{d1})\ (W_{d1})$

ii. Leeward Drift

The leeward drift loading (P_{d2}) as shown in Figure 2.6.2.3-13 occurs between rows or solar panels, and on the leeward side of the most leeward row (Row 1 in Figure 2.6.2.3-14). The leeward drift load is the same whether or not the panel back is closed or open.

The leeward drift (P_{d2}) occurs at all rows only until the “drift supply” is exhausted. See Part c below.

P_{d2} = leeward drift load at back of tilted solar panel, tapering across the face of the panel to zero at the top of the panel.

$W_{d2} = W_a$ (uniform leeward drift width)
W_r = tapered width of leeward drift
h_{d2} = drift height at back of tilted solar panel
$h_{d2} = (2)\,(h_d)^2/W_a \le h_c$
$P_{d2} = (h_{d1})(D) \le (h_c)(D)$

Cross-sectional area of the leeward drift (A_{d2}):
$A_{d2} = (h_{d2})\,(W_a) + ½\,(h_{d2})\,(W_r)$

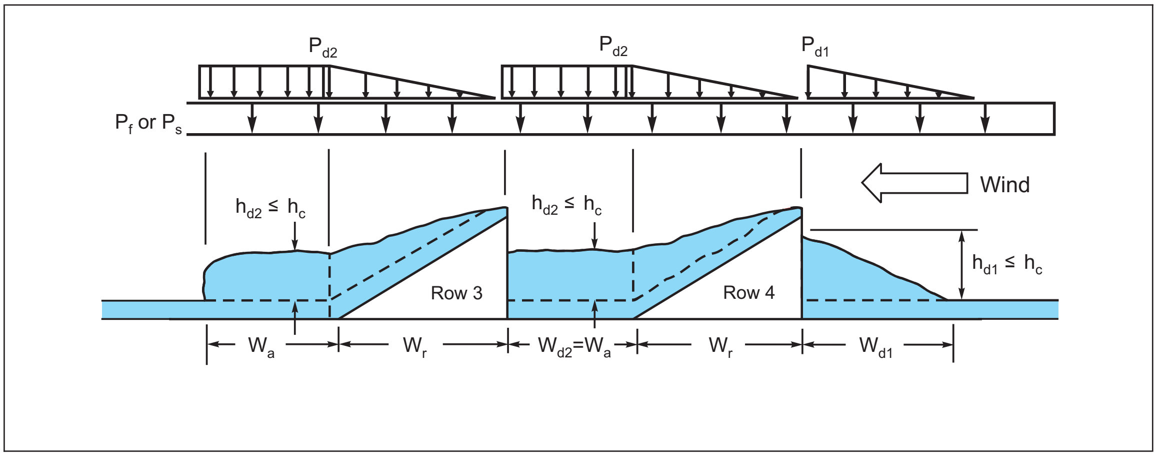


Fig. 2.6.2.3-13. Snow drift loads at tilted solar panel for closely spaced rows with panels facing leeward

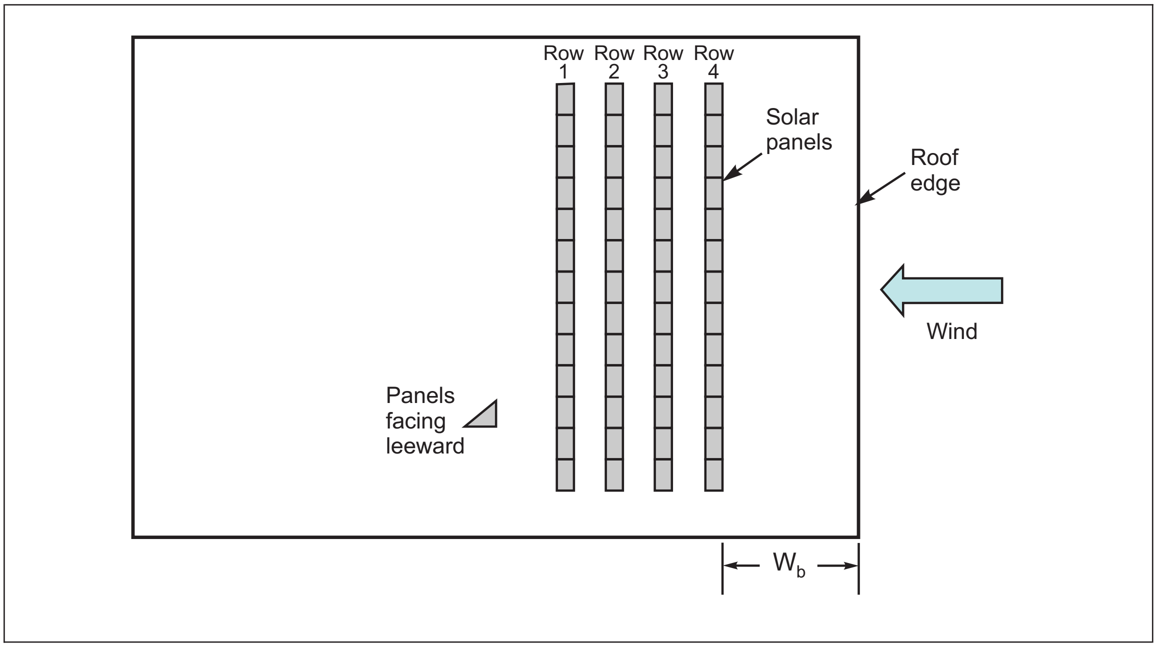


Fig. 2.6.2.3-14. Upwind fetch distance (W_b) for snow drift at multiple rows of closely spaced tilted solar panels with panels facing leeward

c. Drift Supply and Number of Inter-Row Drifts

To determine how many closely spaced solar panel rows will have inter-row snow drifting:

i. Calculate the total drift supply area (A_{dt}) for the roof area: (A_{dt}) = 6 $(h_d)^2$

where h_d is based on the upwind fetch distance (W_b) for closely spaced tilted panels.

ii. Calculate the cross sectional area of the most windward drift (A_{d1}). For example, if the drift windward of Row 4 in Figure 2.6.2.3-13 has a height (h_{d1}) of 10 in. (250 mm) and a width (W_{d1}) of 40 in. (1015 mm), the cross sectional area is 200 in.^{2} (0.13 m^2).

iii. Calculate the cross sectional area (in.^{2} or mm^2) of the inter-row drift (A_{d2}). For example, if the drift between Row 3 and Row 4 in Figure 2.6.2.3-13 has a total cross-sectional area of 500 in.^{2} (0.32 m^2), then A_{d2} = 500 in.^{2} (0.32 m^2).

iv. Determine the number of rows (N) with inter-row drifting:

$N = [(A_{dt} - A_{d1}) / A_{d2}]$ and round up to the next whole number

v. If the entire A_{dt} is not consumed by inter-row drifting (e.g., if there are a small number of rows), use the remaining inter-row drift area surplus ($A_{dt} - A_{d1} - NA_{d2}$) to create a windward drift load at the wall of a high roof or parapet wall (if one exists). If there is an open roof area between the high roof wall or parapet wall and the solar panel array, then add the remaining inter-row drift area surplus to the windward drift area (from Section 2.6.2.3. [K.1]). Refer to Example Problem 7 in Appendix E.

M. Skewed Solar Panel Rows

Where the alignment of solar panel rows is skewed relative to the roof edge, use an upwind fetch distance (W_b) based on the distance from the roof corner to the solar panel row, measured perpendicular to the row. See Figure 2.6.2.3-15.

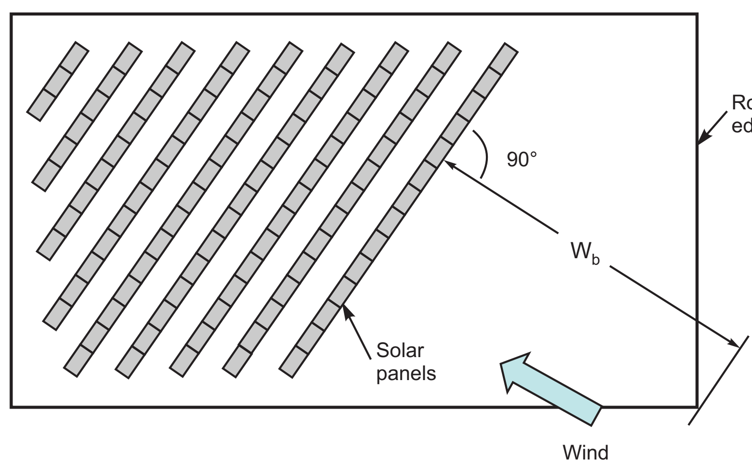


Fig. 2.6.2.3-15. Upwind fetch distance ($W_{b)}$ for snow drift at closely spaced skewed rows of solar panels

N. Sliding Snow Load at Lower Roof

This section applies to sliding snow surcharge load from the upper roof to lower roof, but does not address localized (inter-row) sliding snow load between the rows of solar panels.

Refer to Section 2.4.5.2, Sliding Snow.

1. It is advisable to not locate solar panels on a lower roof where they are exposed to sliding snow surcharge from an adjacent high roof; however, if the solar are exposed, use the combined balanced snow load and sliding snow surcharge load as the design load for the roof and solar panels, regardless of the slope of the solar panels, as shown in Figure 2.4.5.2. There is no need to consider drifting or additional (localized) sliding for this load condition.

2. If the upper roofing surface is slippery, assume solar panels located on the upper roof are not in place when determining sliding snow surcharge load on the lower roof.

3. If the upper roofing surface is not slippery, and if flush mounted solar panels are located on the upper roof, assume the presence of the solar panels makes the upper roof slippery when determining the sliding snow surcharge load on a low roof.

4. If the upper roofing surface is not slippery, and if sloped solar panels are located on the upper roof, assume the solar panels located on the upper roof are not in place when determining sliding snow surcharge load on the lower roof.

O. Inter-Row Sliding Snow Load

1. Flush-Mounted Solar Panels

Where the solar panels are of significant height (h_r > and roof slop > 2.1% (1.2°, or 1/4 in 12):

a. Determine the snow load where the balanced roof snow load is combined with localized sliding snow load (snow sliding off the solar panels).

b. Base the sliding snow load (P_f or P_s) on the roof slope in accordance with Section 2.4.

c. Assume a cold obstructed condition when determining P_f or P_s for both the snow on the roof surface and the snow sliding off the solar panels.

d. Where the width of the upslope solar panel does not exceed the width of the space between the panels, use the load case as shown in Figure 2.6.2.3-16(a); otherwise use the load case as shown in Figure 2.6.2.3-16(b). In both cases the maximum snow load (balance + sliding) is twice the flat or sloped roof snow load ($2P_f$ or $2P_s$).

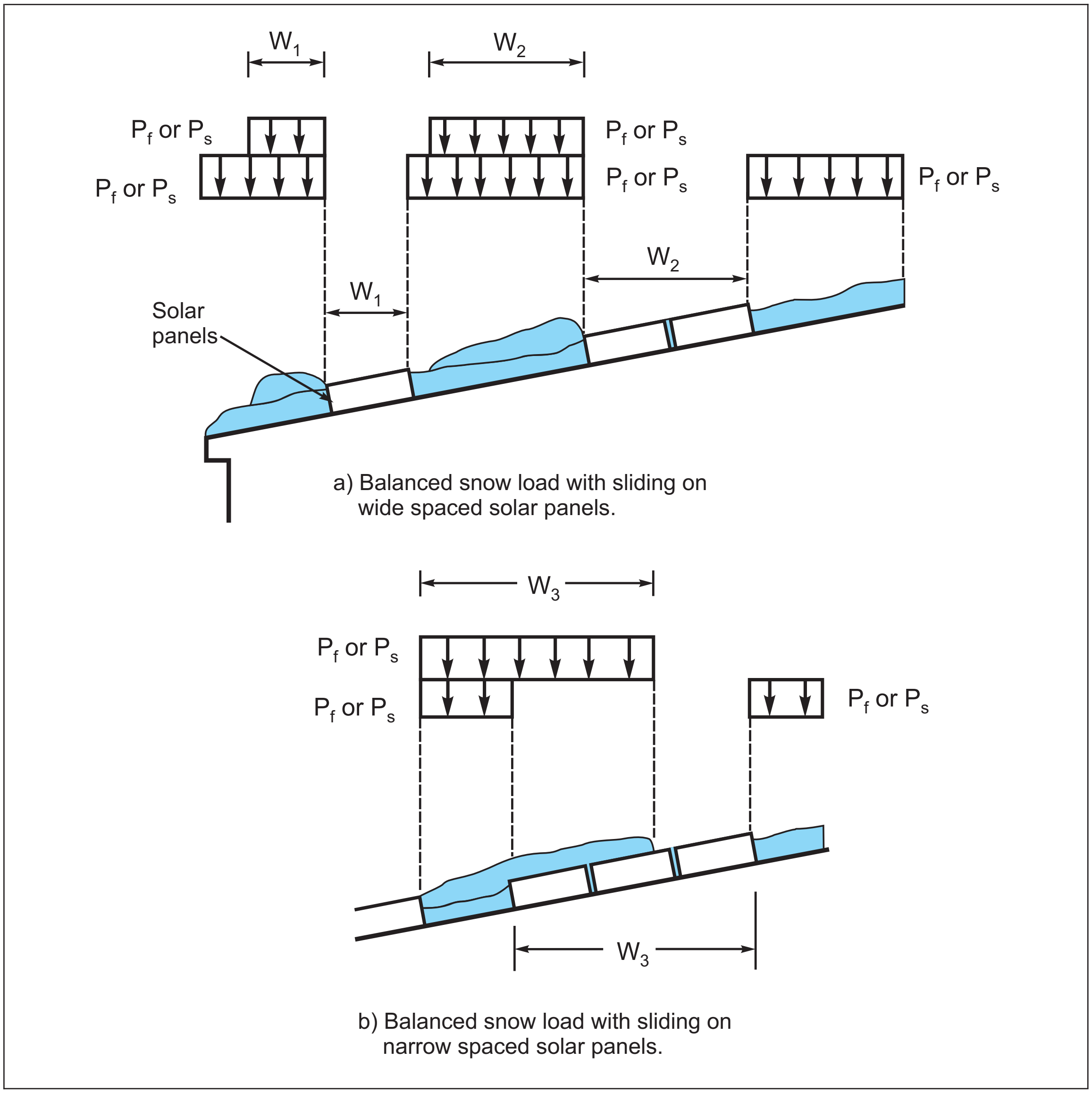


Fig. 2.6.2.3-16. Balanced snow plus sliding snow load with flush-mounted solar panels

2. Tilted Solar Panels

The snow loads shown in Figure 2.6.2.3-17 apply for solar panels with both open and closed backs.

Only where all three of the following criteria are met:

- Solar panel height is significant (hr > $1.2h_b$)
- Projected panel width above h_b: W > 6 in. [0.15 m]
- Solar panel slope > 2.1% (1.2°, or 1/4 in 12)

i. Determine the snow load where the balanced roof snow load is combined with localized sliding snow load (snow sliding off the solar panels) as shown in Figure 2.6.2.3-17.

ii. Assume the snow load sliding off the panel to be the same as the balanced snow load on the roof (P_f or P_s). The maximum snow load is twice the flat roof or sloped roof snow load ($2P_f$ or $2P_s$).

iii. Assume a cold obstructed condition when determining P_s for both the roof surface and the solar panel surface.

iv. If the sliding snow is obstructed (e.g., by the back deflector of the adjacent row), reduce the width (W) of the sliding snow such that the sliding snow does not go beyond the obstruction.

Sliding snow load due to sliding snow off the back deflector of the solar panel need not be considered.

Refer to Section E.3 for an example problem.

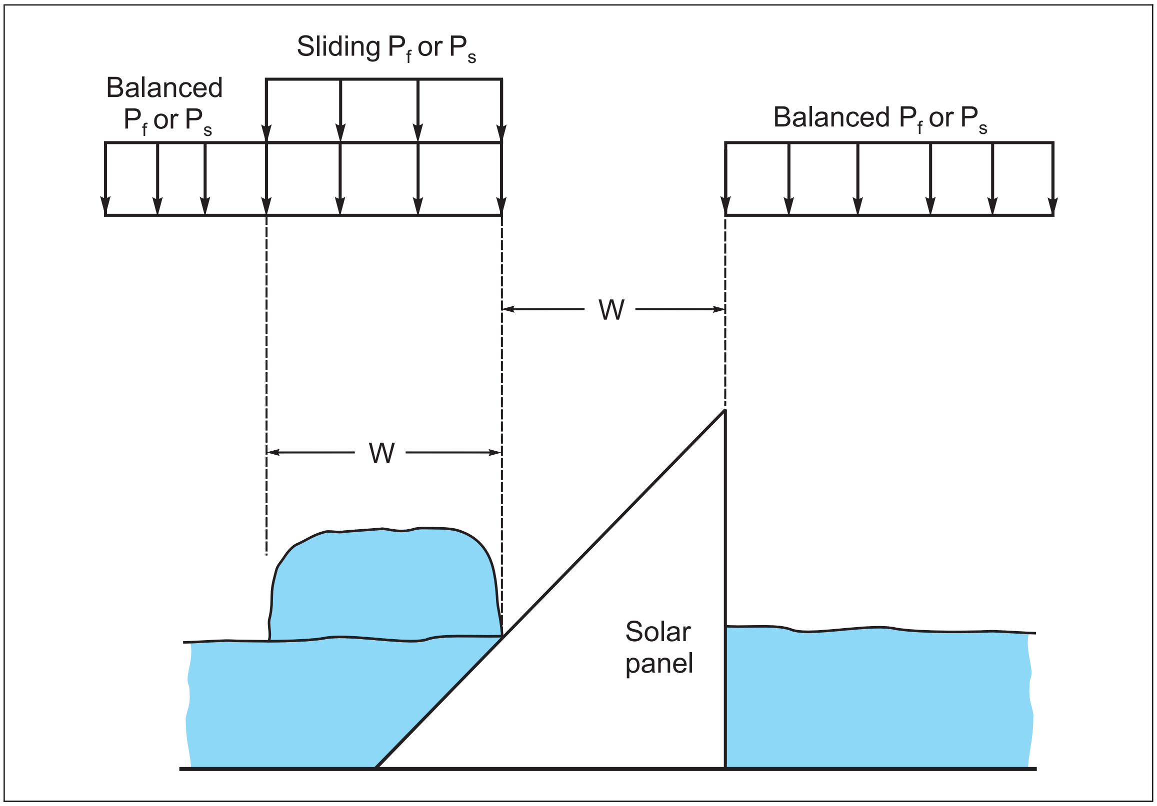


Fig. 2.6.2.3-17. Sliding snow load at tilted solar panels

2.6.2.4 Rain Load and Drainage

Adhere to the following recommendations to ensure solar panel installations do not impair or otherwise negatively affect roof drainage.

A. Provide at least 3 ft (0.9 m) of horizontal clear space between roof drains (or scuppers) and solar panels, solar panel supports, and associated rooftop equipment.

B. Keep solar panels elevated above the rainwater level on the roof based on the recommended rainfall intensity and roof drainage in Section 2.5.

C. Install solar panels such that the panels or supports will not impede or divert the flow of rainwater across the roof surface to the roof drains or scuppers. Retain a qualified engineer to verify that roof drain operations and design rain load will not be adversely affected or increased.

D. For solar panels with ballasted support systems (i.e., not mechanically anchored to the roof), refer to Section 2.5.2.7 to determine the combined weight of the rainwater and the ballast when determining design loads for load combinations that include rain load and the dead load of the solar panels.

2.7 Additional Considerations

2.7.1 Install proper weather-tight detailing and seals at joints, penetrations, scuppers and gutters to ensure water will not seep into the roofing assembly due to wind-driven rain, design rainwater head, or snow melt. Water seepage can saturate large areas of the roofing assembly and this saturation load can contribute to roof overload and collapse.

2.7.2 Indirect roof overloading: The overloading and collapse of the primary vertical support elements of the roof structure, such as columns and bearing walls, is another cause of roof collapse.

Columns adjacent to traffic aisles for fork-lifts and other trucks should be protected from impact. Ensure the base plates of these columns are anchored to their foundations with a minimum of four (4) 1 in. (25mm) diameter anchor bolts, and protected with concrete curbing, steel guard rails, or concrete-filled pipe bollards to resist and/or prevent impact from vehicles.

Ensure walls, particularly masonry walls, are not laterally loaded as a result of having bulk materials (e.g., sand, salt, grain) or rolled products (e.g., carpets or paper) placed against them, unless the wall and roof structure are designed to resist the resulting lateral loads. Likewise, ensure rack storage structures or vertical stays for confining rolled products in storage are not secured to the roof-framing system unless the framing and bracing systems are designed to resist the resulting laterally-induced loads.

2.8 Use of Other Codes and Standards

2.8.1 Use of ASCE 7

A. Roof Live Load

Use the provisions for live load reduction contained in this data sheet.

B. Snow and Ice Loads

The provisions in Chapter 7 of ASCE 7-10 or ASCE 7-16 (ASCE/SEI 7-10, or 7-16, *Minimum Design Loads for Buildings and Other Structures*) may be used for the determination of snow loads provided the following recommendations are adhered to:

1. Factors

Importance factor (I) not less than 1.1

Exposure Factor (C_e) not less than 1.0

Thermal Factor (C_t) not less than 1.3 for structures intentionally kept below freezing (e.g., frozen food storage); 1.2 for unheated or open structures; and not less than 1.1 for other buildings.

2. Hip and Gable Roofs

For unbalanced snow load on hip and gable roofs, use the provisions of this data sheet (see Section 2.4.4.3).

2.8.2 Use of Eurocode

For use by European Committee for Standardization (CEN) member nations that have adopted, and comply with, the Eurocode as the national standard.

A. Roof Live Load

1. Minimum Roof Live Load

a. Where the dead load (characteristic value of a Permanent Action) of the roof is greater than or equal to 1.5 kN/m^2 (31 psf), use a minimum roof live load (characteristic value of a Variable Action) of not less than 0.6 kN/m^2 (12 psf) applied uniformly over the entire roof; however, where the National Annex recommends a minimum roof live load larger than 0.6 kN/m^2 (12 psf), use the larger value. Do not reduce the roof live load to less than 0.6 kN/m^2 (12 psf) for any reason, regardless of tributary area or number of building stories.

b. Where the dead load (characteristic value of a Permanent Action) of the roof is less than 1.5 kN/m^2 (31 psf), use the roof live load provisions of this data sheet (see Section 2.3).

Note that for purposes of foundation design only (e.g., footings, grade beams, piles, and caissons), the use of roof live (imposed) loads and live reduction techniques as recommended in the Eurocode are acceptable without revision or exception; that is, the recommendations in Section 2.3 of this data sheet may be waived for the purposes of foundation design.

2. Load Classification

Consider roof live loads (imposed loads) to be Variable Actions for use in Persistent/Transient design situations.

B. Snow and Ice Loads

Eurocode 1 (Actions on Structures, Part 1-3: General Actions - Snow Loads [EN 1991-1-3: 2003]) may be used in CEN (European Committee for Standardization) member nations for snow load determination where it has been approved as the national standard, provided the following recommendations are adhered to.

1. Snow Density

a. For locations where the 50-year ground snow load is greater than 1.8 kN/m^2 (38 psf):

i. In Equation 5.8, Section 5.3.6, Roof Abutting and Close to Taller Construction Works (leeward drifts on lower roofs) of Eurocode 1, use an upper limit bulk weight snow density of no less than 3 kN/m^3 (18.9 lb/ft^3).

ii. In Equation 6.1, Section 6.2, Drifting at Projections and Obstructions (windward drift at projection or parapet) of Eurocode 1, use an upper limit bulk weight snow density of no less than 3 kN/m^3 (18.9 lb/ft^3).

b. For locations where the 50-year ground snow load is less than or equal to 1.8 kN/m^2 (38 psf), use an upper limit bulk weight snow density of not less than 2 kN/m^3 (12.6 lb/ft^3) for windward and leeward snow drifts as recommended in Eurocode 1 (see Sections 5.3.6 and 6.2 of Eurocode 1).

2. Hip and Gable (Pitched) Roofs

For hip or gable sloped roofs (pitched roofs) of lightweight construction (metal roof, insulated steel deck, boards-on-joists, plywood diaphragm, and similar constructions) with slopes greater than or equal to 5° or slopes less than 60° ($5 \leq \theta < 60$); apply a factor of 1.25 to the pitched roof shape coefficient (1.25 µ 1) to determine the uniform snow drift on the leeward (downwind) roof slope; Note that the shape coefficient for the windward (upwind) roof slope remains as recommended in Eurocode 1 without change (0.5 µ 1) for all roof slopes.

3. Ground Snow Load Maps

Use the ground snow load maps in the appropriate National Annex to Eurocode 1, provided the maps are based on 50-year mean recurrence interval (50-year MRI) ground snow load (P_g) and account for regional conditions.

4. Load Classification

Consider roof snow and snow drift loads based on 50-year ground snow loads to be characteristic values of Variable Actions for use in Persistent/Transient design situations. A partial net load safety factor of no less than 1.5 should be applied for variably loads.

5. Coefficients

As recommended in Eurocode 1, use an exposure coefficient (C_e), and thermal coefficient (C_t), of not less than 1.0.

C. Eurocode for Rain Loads

This section applies only to conventional (non-siphonic) roof drainage. For siphonic roof drainage recommendations, refer to Section 2.5.4.2, Siphonic Roof Drainage. European Standards EN 12056-1, *Gravity Drainage Systems Inside Building - Part 1: General and Performance Requirements*, and EN 12056-3, *Gravity Drainage Systems Inside Buildings - Part 3: Roof Drainage, Layout, and Calculation*, may be used in CEN (European Committee for Standardization) member nations for rain load and roof drainage, with the following exceptions and changes:

1. Use design rainfall intensity based on adequate statistical data from a nationally recognized source or agency, where the rainfall intensity is based on frequency (return period or recurrence interval, in years) and duration (in minutes). If there is any doubt regarding the adequacy or validity of the rainfall data, then apply the risk factors from Table 2 of Section 4.2 of EN 12056-3 with the following restrictions:

a. For eave gutters, use a risk factor of at least 1.5.
b. For all other cases, use a risk factor of at least 3.0.

2. Effective Rainfall Intensity

a. Ensure the primary drainage system is adequate for the 100-year, 60-min rainfall intensity.
b. Ensure the secondary drainage system is adequate for twice (2 times) the 100-year, 60-min rainfall intensity assuming that the primary drainage system is completely blocked.

3. Follow the recommendations in Sections 2.5.2 through Section 2.5.4.1.(M), which include, but are not limited to, independence of primary and secondary drainage systems, minimum design rain depths, ponding instability requirements, roof slope requirements, minimum roof drain quantities (maximum roof drainage area per drain), drain placement, minimum drain sizes, drain strainers (debris guards), inlet elevations of secondary drains or scuppers relative to primary drain inlet elevations, and downspout recommendations (height above snow level, impact protection, freeze-up protection).

4. Design Rainfall Intensities for Various Nations

Germany: Use DIN EN 12056 and DIN 1986-100, including their rain intensity maps and tables, to determine the rainwater runoff for the primary and secondary drainage systems. These require independent secondary drainage systems for all flat roofs and roofs with internal drains with discharge to a free unobstructed location.

United Kingdom: Use BS EN 12056-3:2000, including their rainfall intensity maps, to determine rainwater runoff for the primary and secondary drainage systems.

France, Netherlands, and Switzerland: Use EN 12056-3:2000 with applicable rainfall intensity maps subject to the following minimum rainwater intensities noted in EN 12056-3:2000, Annex B, to determine the rainwater runoff for the primary and secondary drainage systems. Minimum intensities: France - 0.05 L/s/m^2; Netherlands and Switzerland - 0.03 L/s/m^2.

D. Different Partial Safety Factors for CEN Member Nations

Use partial safety factors for loads (load factors), partial safety factors for materials (material factors), and design load combinations as prescribed in the Eurocode for all CEN member nations. Alternatively, different partial safety factors may be used if the Total Factored Demand for design can be verified to be no less than that which would result from using Eurocode partial safety factors for all failure modes. This comparison will only be practical when all loads are uniform (e.g., for uniform snow load or roof live load, but not for drifting snow loads).

Total Factored Demand = (Factored Loads) x (Partial Safety for Materials)

Example:

Let:
Characteristic (Unfactored) Dead Load = 0.5 kN/m^2
Characteristic (Unfactored) Uniform Snow Load = 2.0 kN/m^2

From Eurocode: Dead load factor = 1.35
Snow load factor = 1.5
Material factor = 1.1 (steel beam)

Total Factored Demand = (1.35 (Dead Load) + 1.5 [Snow Load]) (1.1) = (1.35 (0.5 kN/m^2) + 1.5 [2.0 kN/m^2])(1.1) = 4.0 kN/m^2

From a CEN National Annex, let:
Dead load factor = 1.2
Snow load factor = 1.6
Material factor = 1.1

Total Factored Demand = (1.2 (Dead Load) + 1.6 [Snow Load]) (1.1) = (1.2 (0.5 kN/m^2) + 1.6 [2.0 kN/m^2]) (1.1) = 4.2 kN/m^2

Since 4.2 kN/m^2 $\geq$ 4.0 kN/m^2, the use of the National Annex load factors and material factors is acceptable.

2.9 Human Factor

2.9.1 Snow Monitoring and Response Plans

For locations subject to snow ground snow load ≥ 5 psf (0.24 kN/m^2), establish a formal snow monitoring and response plan. The plan should be part of the facility's emergency response plan. Review and update it annually for physical and personnel changes. Refer to Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*, for detailed information.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Design Loads and Methods

There are two general methods used for structural design, they are: (1) ultimate limit state design, also known as load and resistance factor design (LRFD); and (2) allowable stress design (ASD). The LRFD method uses the recommended characteristic loads but applies load factors to these loads to determine the design loads. The load factor accounts for most, but not all, of the total structural safety factor. The ASD design method uses the recommended characteristic loads as the design loads without applying a load factor, but imposes lower allowable stress (resistance) levels than LRFD. The two design methods generally result in similar total safety factors for most commonly used structural materials and roof configurations.

In this data sheet, the design load simply refers to the load used in the design of the roof structure.

Refer to Appendix A for more details on loads and load factors.

3.2 Combinations of Loads

Roof structures are designed to support several types of loads in various combinations. The roof structure, or portions of the roof structure, are designed for the most severe or demanding design load combination, known as the governing design load combination. The governing design load combination may not necessarily be the same for the entire roof structure. For example, the governing design load combination for the low roof framing at a roof step might be dead load plus snow load, including snow drift load. In a different area where the roof framing is not subjected to drifting or sliding snow, the governing load combination might be dead load plus rain load, or dead load plus roof live load.

It is not the intent of this data sheet to make specific recommendations on load factors, allowable stress levels and material resistance, or design techniques; it only makes recommendations for design loads on roofs.

Structural loads applicable to this data sheet include dead, snow and ice, rain, and roof live loads (gravity loads). Wind and seismic loads are not applicable to this data sheet. Snow, ice, rain, wind, and seismic loads, are sometimes known collectively as environmental loads.

Dead load includes the weight of the roof construction itself, the weight of affixed mechanical, electrical, and plumbing (MEP) systems (e.g., mechanical equipment and ductwork, electrical conduit, and process water piping), and the weight of any fixed rooftop equipment (e.g., HVAC equipment or solar panels) and equipment suspended from the roof structure. The roof structure is designed to resist the most demanding or severe effects of the following design load combinations:

- Roof dead load + roof live load
- Roof dead load + snow load
- Roof dead load + rain load

3.3 Roof Live Load

The base minimum uniformly distributed roof live load value of 20 psf (1.0 kN/m^2) given in Sections 2.3.1A and 2.3.2 is a typical code-required value for non-occupiable roofs. For occupiable roofs, the applicable code should be used in combination with the recommendations in Section 2.3.1B.

3.4 Snow and Ice Loads

A. Adjustment for Geometry

The roof snow load calculation in Section 2.4.3 is a function of ground snow and a basic ground-to-roof adjustment factor. The recommendations in Section 2.4 further refine roof snow loads based on the specific roof geometry.

B. Snow Drifts and Sliding Snow

1. Drifts on Lower Roofs: Snow Loads

There are two general types of drifting snow loads: those from leeward drifts and those from windward drifts.

Leeward snow drifting occurs on roof surfaces that are shielded from wind, for example at a roof elevation difference.

Windward snow drifting occurs on roof surfaces upwind of a vertical roof projection that traps wind-blown snow. Windward drift areas are generally less effective at capturing or trapping wind-blown snow, and therefore the loading will be less than the leeward drift loading when the upwind fetch (W_b) and ground snow load (P_g) are the same.

In Figure 3.4, the windward drift on Roof A is caused by windblown snow transported from left to right across Roof A. The leeward drift at Roof C is caused by the windblown snow transported across Roof B and deposited on Roof C.

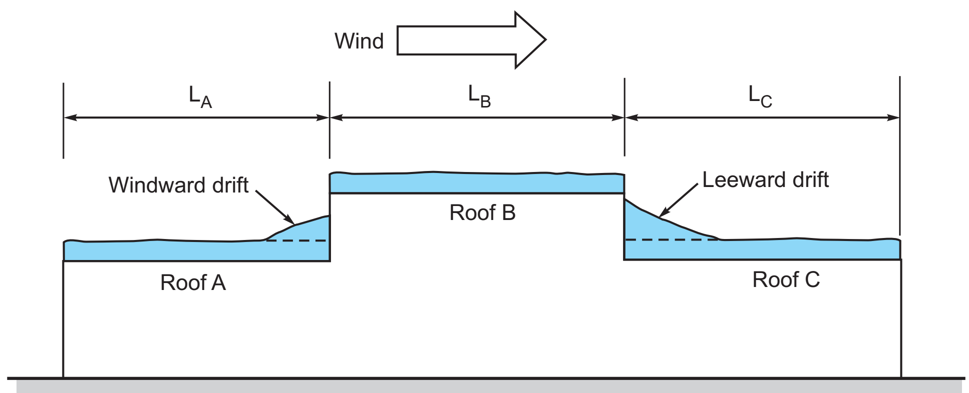


Fig. 3.4. Typical windward and leeward snow drifting

2. Sliding Snow

Snow guards often do not adequately prevent snow from sliding off a sloped roof onto a lower roof. In addition, snow guards may be damaged or impaired due to heavy snow and ice load accumulation, manual snow removal, or re-roofing; or may be removed due to water ingress damage from ice dams, or due to roof maintenance. Therefore, FM Global recommends design conditions for snow loading where:

It is assumed that (1) any proposed snow guards are in place and constitute an obstruction when determining the sloped roof snow load; and (2) any proposed snow guards are impaired, ineffective, or have been removed, and will not prevent or reduce sliding snow, when determining the sliding snow surcharge load on exposed low roofs.

3.5 Rain Loads and Roof Drainage

A. Designing for Stability Against Ponding

Design standards, such as the American Institute of Steel Construction ANSI/AISC 360, *Specifications for Structural Steel Buildings*, require that roof systems be investigated by structural analysis to ensure adequate strength under ponding conditions, unless the roof surface is provided with sufficient slope toward points of free drainage or other means to prevent the accumulation of water.

B. Roof Drainage

Rainfall Intensity, Duration, and Frequency

Intensity (i)

Intensity (i) is the rainfall rate, typically recorded as in./hr, mm/hr, or L/sec-m^2. See Table 2.5.4.2 for conversion rates.

Duration

Duration is the time over which the peak rainfall intensity is averaged. Duration for roof drainage is typically recorded in 2-min, 5-min, 15-min, or 60-min time intervals. Durations as much as 24 hours to 96 hours can be used for site/civil drainage analysis associated with flood events. The shorter the duration, the higher the rainfall intensity for a given frequency.

Frequency

Frequency is the same as the return period or MRI (mean recurrence interval) of the event. For example, the “100-year event” is equivalent to an annual exceedance probability of 1%, while the “5-year event” is equivalent to an annual exceedance probability of 20%.

Siphonic Drainage versus Conventional Drainage

Conventional roof drainage systems use the hydraulic head above the roof drain, which is typically no more that several inches, to create flow through the roof drain, and sloped horizontal piping to maintain flow to the vertical leaders or downpipes. A siphonic drainage system uses the head of the entire drainage system as the energy to drive drainage flow. In theory, this is the head from the elevation of the water directly upstream of the roof drain, to the discharge point at or below the grade elevation, and it can be many ft (m). A siphonic system’s horizontal runs of piping are generally not sloped.

A conventional drainage system operating at capacity could have roughly 20% to 30% of the cross-sectional area of the piping filled with water; however, a siphonic drainage system operating at capacity will be close to 100% full (full-bore flow).

Since siphonic systems use the energy associated with the head of the entire drainage system, design velocities are achieved without pitching or sloping the horizontal pipe runs. Siphonic systems operate with full-bore flow velocities of roughly 10 ft/sec to 20 ft/sec (3 m/s to 6 m/s), while conventional systems operate with effective velocities of roughly 2 ft/sec to 5 ft/sec (0.6 m/s to 1.5 m/s).

Conventional drainage systems operate at or near atmospheric pressure (gauge pressure near zero). However, siphonic systems experience pressures less than atmospheric pressure - so that the operating negative gauge pressure can be substantial. These negative operating pressures present a much more challenging task to the design engineer and installation contractor, as compared to a gravity drainage system, due to the concerns with air infiltration, pipe buckling and crushing, and overall performance and design sensitivity.

The Design Disposable Head (H_d) is based on the reasonable assumption the manhole or inspection chamber will experience surcharge from surface flow or site/storm drainage quite often over the life of the building.

Minimum operating pressures are intended to prevent cavitation, air infiltration at pipe fittings and joints, and pipe overload (buckling or collapsing).

The small size and configuration of siphonic drains and piping (as compared to gravity drainage piping) and make them particularly susceptible to freeze.

3.6 Other Roof Loads

3.6.1 Solar (Photovoltaic) Panels

In addition to the dead load imposed on the roof by the weight of the solar panels, solar panel installation can also affect the snow load and rain load on the roof.

1. Snow Loads

Solar panels can impact roof snow loads in two ways:

a. By altering the traditional drifting and sliding snow loads on a roof; for example, the drifting snow at a roof step, or the sliding snow surcharge on a roof below a sloped roof.

b. By creating drifting and sliding snow within, or directly adjacent to, the array of solar panels (inter-row drifting and inter-row sliding).

The installation of solar panels has the potential to reduce traditional drifting and sliding snow loads in some cases and they may be reconfigured or removed at some point in the future. Because of this, it is recommended to include design load cases where it is assumed the solar panels are both in place as intended, and not in place. For example, where the installation of an array of tilted solar panels will reduce the traditional windward snow drift load at a parapet wall, one of the design load cases for the roof framing that would be affected by the traditional windward drift should be based on the assumption that the solar panels are not in place.

Due to the shape of tilted solar panels, the inter-row snow drifting (both windward and leeward of the solar panels) will depend on the assumed wind direction relative the orientation of the solar panels. The inter-row snow drifting will also be affected by the spacing of the solar panel rows. For widely-spaced rows, the drifting at each row is the same as if each row were a single row, which is due to lack of shielding and aerodynamic shade by the upwind rows. For closely-spaced rows, the inter-row drifting will differ from that of the widely-spaced rows due to the affect that upwind rows have on the downwind rows of solar panels.

Inter-row snow drifting can have an effect on traditional snow drifting on the roof. Where the total drift supply area [$A_{dt} = 6\ (h_d)^2$] is not entirely consumed by inter-row drifting, the surplus drift area is used to create the windward snow drift load at a downwind roof step or parapet. If there is an open area between the solar panel array and a roof step or parapet, then the surplus drift area is added to the traditional windward drift (based on the upwind fetch between the roof step or parapet and closest edge of the solar panel array) to create the total windward drift at the roof step or parapet.

Example 7 in Appendix E shows how inter-row drifting can consume the entire total drift supply for a roof area with one assumed wind direction, but not in the opposite direction, and therefore the inter-drift area surplus is added to the traditional windward drift to create the total windward drift at the roof step.

Due to the significant loads associated with traditional drifting and sliding snow and the potential damage they can do, it is advisable to locate solar panels on a roof such that they will not be exposed to these loads.

There are some solar panel installations that will not affect roof snow loading. For example, where the solar panel height is not “significant” (see Section 2.6.2 for more information about the definition of significant) or where solar panels are mounted high enough above the roof surface to negate their effects on drifting snow, roof snow loads are determined without regard to the solar panels; however the weight of the solar panels must be included in the dead load used for the roof design loads.

2. Rain Loads and Drainage

Solar panel installations on roofs can have an adverse effect on roof drainage and rain loads.

Adequate horizontal clearance between the solar panels and roof drains or scuppers is recommended to prevent sun shading and potential freeze-up and ice blockage of the drains and scuppers. The recommended clearance allows maintenance personnel access to check drains and scuppers for damage or clogging.

Elevating solar panels above the design rainwater level, and properly locating solar panel supports will prevent them from blocking roof drains or scuppers or diverting flow.

Solar panels with ballasted support systems can impose significant loads on the roof and should be included in the design loads. This is particularly important when combining the dead load of the ballast with the rain load due to the need to account for the porosity or void ratio for the rain-saturated weight of ballast.

3.7 Additional Considerations

Seepage from water (e.g., rain, snow/ice meltwater) that saturates roof assembly components increases roof loads in a manner not generally considered.

3.8 Use of Other Codes and Standards

3.8.1 Use of ASCE 7

A. Roof Live Load

The roof live load reduction calculation used in this data sheet is a function of tributary area and is based on the ASCE 7-16 reduction factor, R_1, as specified in that standard.

B. Snow and Ice Loads

ASCE 7-16 ground snow loads (P_g) are based on a 2% annual probability of being exceeded (50-year MRI). The recommendations to use several minimum factors (Importance Factor of not less than 1.1, Thermal Factor of not less than 1.1, and Exposure Factor of not less than 1.0), when allowing the use of ASCE 7-16 for the determination of snow loads will ensure the balanced snow loads will be adequate and sufficiently similar to the specific design snow loads recommended in this data sheet.

3.8.2 Use of Eurocode

A. Roof Live Load

The recommendations in this data sheet for the use of the Eurocode when determining minimum roof live loads refer to the recommendations in Section 2.3 where the dead load is less than a threshold value. In some circumstances, a reduction in roof live load is recommended that is a function of the tributary area of the specific building element. This practice of load reduction based on tributary area may be unfamiliar to designers in European countries.

B. Snow and Ice Loads

For the snow load provisions, refer to Eurocode 1, Actions on Structures, Part 1-3: General Actions - Snow Loads (EN 1991-1-3). EN 1991-1-3 uses 50-year ground snow loads, and a recommended minimum snow density of 2 kN/m^3 (12.6 pcf)

Return Period for Ground Snow Loads

Eurocode 1 ground snow maps are based on a return period of 50 years. However, there may be a country-specific code or annex that uses a lesser return period; in these cases, an appropriate factor should be applied to obtain equivalent 50-year ground snow loads (see Section 2.3.3).

Design Situations and Load Combinations

Eurocode 1 (and Eurocode 0, Basis of Structural Design) allow for several types of Design Situation classifications for load combinations that include snow loads. The recommendation to consider 50-year snow and snow-drift loads to be characteristic values of Variable Actions for use in Persistent/Transient design situations, not Accidental or Exceptional design situations, will provide an acceptable design condition.

Exposure and Thermal Coefficients

The use of exposure coefficient (C_e) and thermal coefficient (C_t) not less than 1.0 (the recommended minimum values in Eurocode 1) should adequately address most reasonable unexpected design conditions; for example, where power and heating are lost in a building, or where a building becomes more sheltered due to future adjacent development.

3.9 Human Factor

3.9.1 Snow Monitoring and Removal Plans

It is essential to have snow monitoring and removal plans in place prior to climatic events to ensure the availability of resources, and that proper action is taken to avert potential property damage.

4.0 REFERENCES

4.1 FM Global

Data Sheet 1-2, *Earthquakes*
Data Sheet 1-28, *Wind Design*
Data Sheet 1-35, *Vegetative Roof Systems*
Data Sheet 1-59, *Fabric and Membrane Structures*

4.2 Others

American Institute of Steel Construction (AISC). *Specification for Structural Steel Buildings*. AISC 360-10.

American Society of Civil Engineers (ASCE). *Minimum Design Loads and Associated Criteria for Buildings and Other Structuremeds*. ASCE/SEI 7-02, 7-05, 7-10, and 7-16.

European Committee for Standardization (CEN). *Eurocode 0, Basis of Structural Design*. EN 1990:2002 with 2005 Amendment.

European Committee for Standardization (CEN). *Eurocode 1, Actions on Structures Part 1-1: General Actions: Densities, Self-weight, Imposed Loads for Buildings*. EN 1991-1-1:2002.

European Committee for Standardization (CEN). *Eurocode 1, Actions on Structures Part 1-3: General Actions: Snow Loads*. EN 1991-1-3:2003. EN 12056-1.

European Committee for Standardization (CEN). *Gravity Drainage Systems Inside Buildings, Part 3: Roof Drainage, Layout and Calculation*. EN 12056-3:2000.

International Code Council (ICC). *International Plumbing Code*. 2003 and 2006 editions.

Steel Joist Institute (SJI). *Standard Specifications for LH-Series (Longspan), DLH-Series (Deep Longspan) Joists and Joists Girders and K-series (Open Web) Joists*.

APPENDIX A GLOSSARY OF TERMS

The following discussion of terms is intended to facilitate the use of this data sheet. When using building and plumbing codes, use the interpretations those codes provide.

A.1 Roof Loads and Drainage

A.1.1 Controlled Roof Drains

The design of controlled roof drains is similar to conventional roof drains. The difference is that controlled drains are equipped with restrictive devices to accurately set the flow characteristics to the controlled drainage requirements. The purpose of controlling roof drains is to have the roof serve as a temporary storage reservoir of rainwater (e.g., to prevent flooding of storm sewers).

A.1.2 Design Roof Line

The design roof line is an imaginary line established during the design stage by setting elevations at points of support (i.e., columns or walls) for roof framing members. The design roof line is not the actual roof line because framing members sag under the dead weight of the roof system, and sag additionally under super-imposed live loads such as snow and rain. (See Figs. 2.5.2.1-1 and 2.5.2.1-2)

A.1.3 Ponding and Ponding Cycle

Ponding refers to the retention of water due solely to the deflection of relatively flat roof framing. The deflection permits the formation of pools of water. As water accumulates, deflection increases, thereby increasing the capacity of the depression formed. This phenomenon is known as the “ponding cycle.” The amount of water accumulated is dependent upon the flexibility of the roof framing. If the roof framing members have insufficient stiffness, the water accumulated can collapse the roof.

A.1.4 Design Loads and Load Factors

Design loads are the loads that are used in the structural design of the roof. Design loads can be unfactored (characteristic) or factored. In this data sheet, all recommended loads and design loads are assumed to be unfactored loads unless noted otherwise.

For allowable stress design (ASD), design loads are unfactored and the safety factor or safety margin is determined by using an allowable strength level (or allowable resistance level) substantially less than the full strength.

For Ultimate Limit States (ULS) design (also known as Strength Design, or Load and Resistance Factor [LRFD] Design), design loads are factored using load factors prescribed by codes and standards. For ULS design, the safety factor or safety margin is determined mainly by the factors applied to the loads and to a lesser degree, by reduction factors applied to the structural strength or resistance.

A.1.4.1 Dead Load

The dead load of the roof is the weight of its permanent or fixed components, including supporting members, deck, insulation, roof covering, gravel, and suspended or supported ceilings or equipment, such as heaters, lighting fixtures, and piping, which were anticipated at the time of design.

In some cases, dead loads that were not anticipated are added to existing buildings, or an allowance for future dead loads was included in the design dead load. For the purposes of this data sheet, any portion of the dead load exceeding the design dead load should be subtracted from the design snow, rain, or roof live load; any unused portion of the design dead load may be added to the design snow, rain, or live load.

Dead load is normally expressed in pounds per square foot (lb/ft^2 or psf), kilonewtons per square meter (kN/m^2).

A.1.4.2 Roof Live Load

The live load of the roof is the weight allowance for temporary or movable loads, such as construction materials, equipment, and workers. In some cases, where roofs are accessible to building occupants or the public, and where is it possible for people to congregate (e.g., balcony, rooftop deck, or terrace) an occupancy live load (e.g., 100 psf [4.8 kN/m^2]) is required to be considered as part of the total design load. In other cases, for example the top level of an exposed (uncovered) parking garage, an applicable vehicle live load must be considered. In cases where an occupied or accessible interior floor level or walkway (e.g., catwalk or maintenance platform) is to be suspended from the roof framing, the live load of the occupied level (e.g., 60 psf [2.9 kN/m^2] for an elevated walkway) must be considered.

For occupancy or vehicle live loads, most codes and standards allow for reduction in the live load based on a function of the tributary area for each structural member, or for a reduction in live load as part of the total design load combination. However, the reduction of minimum roof live load (typically 20 psf [1.0 kN/m^2]) are only allowed when permitted by the local building code, and the reduced roof live load used for design purposes should not be less than that recommended in this data sheet.

The live, snow, or rain load represents the superimposed weight that the roof system can support, within allowable design parameters, beyond its own dead load. In cases where re-roofing materials or equipment or structures that were not included in the design dead load are added to the roof system, their weight should be subtracted from the design rain or snow load.

Most building codes and design standards permit reductions in minimum roof live loads, excluding snow or rain loads, based on the tributary loaded areas supported by roof members (joists, beams, etc.). This data sheet restricts live load reductions for lightweight roof constructions. Usually, the minimum roof live load is 20 psf (1.0 kN/m^2) with a reduction to 12 psf (0.6 kN/m^2) for members supporting a tributary area equal to or greater than 600 ft2 (56 m^2) and with reduced roof live loads values based on a linear relationship for tributary areas from 200 ft^2 (19 m^2) to 600 ft^2 (56 m^2).

For example, for a tributary area of 400 ft^2 (37 m^2), the design roof live load (reduced) is 16 psf (0.8 kN/m^2). This means that roofs assumed to have a 20 psf (1.0 kN/m^2) live load capacity, as commonly stated on the roof plan drawings, may actually only have an effective load capacity of 12 psf (0.6 kN/m^2). Usually, only the design calculations identify whether live load reductions have been taken.

When code guidelines for live load reductions are followed, the practical result is the construction of very flexible roofs, highly susceptible to ponding and frequently unable to resist rain or unbalanced snow (drifts) loads. It is likely that live load reductions have been applied to minimum design live loads even in new construction, when rain loads due to drainage system blockage are not considered or appropriately understood.

Live load is usually expressed in pounds per square foot (lb/ft2 or psf), kilo-newtons per square meter (kN/m^2).

A.1.4.3 Total Gravity Load

The total gravity load of the roof is the combination of the dead load plus snow, rain, or roof live loads, excluding wind and earthquake loads. The design total gravity load should be effectively resisted by each of the structural members of the roof system.

A.1.5 Tributary Loaded Area (TA)

The TA is that area of the roof supported by a roof (supporting) member. Tributary loaded areas for typical primary and secondary members are illustrated in Figure A.1.5. For secondary members, such as joists, the TA is the joist length times the joist spacing. For primary members, such as beams, girders, or trusses usually supporting uniformly spaced joists, the TA is the beam or truss length times its spacing. As a rule of thumb, the TA for primary members is the area of a bay (a layout of four columns constitutes a bay) or precisely the product of the average column spacing in each direction. An exception to the rule of thumb is construction with members framed along exterior column lines or along double column lines at expansion joints; then the TA is the member length times one-half the member spacing plus the roof overhang beyond the column centerline.

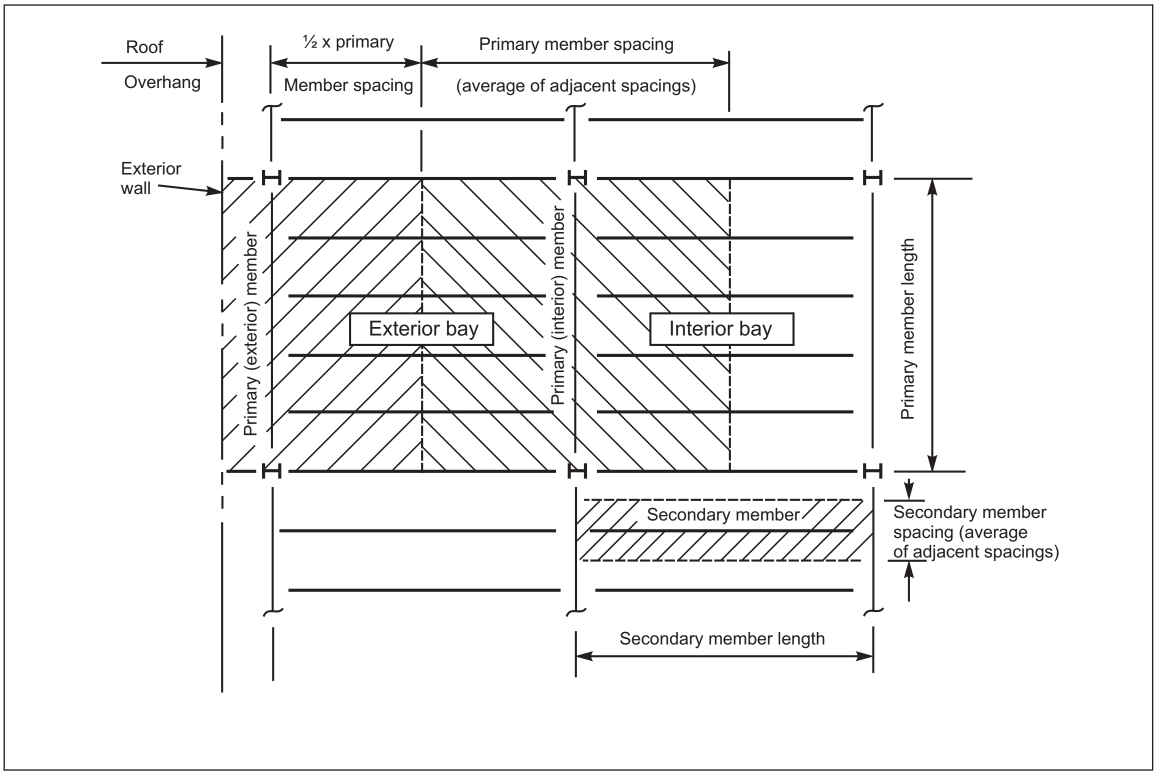


Fig. A.1.5. Typical tributary loaded areas

A.1.6 Roof Strength

Roof strength is the measure of a roof assembly and supporting system's ability to support loads. Total roof strength is the measure of the roof system's ability to support the design dead load plus snow, rain, or roof live loads without exceeding the allowable design parameters. Roof strengths are expressed in psf, kN/m^2.

Steel roof deck manufacturers often provide allowable uniform total load tables in their catalogs. This can be misleading since the strength of members supporting the deck is governed by the design total load and not the load capacity of the roof deck. The supporting members, because of this difference, will usually collapse well before a failure of the deck occurs. The primary determinant of roof strength, therefore, is the roof supporting members with appropriate adjustment for any live load reductions.

A.1.7 Safety Factor

The safety factor of a structural member is the ratio of its strength to its maximum anticipated unfactored design stress (working stress or allowable stress design [ASD]). In steel design using "elastic-design methods," a design stress equal to two-thirds of the minimum yield stress of the material, is often used. This results in a safety factor for yield equal to 1/0.67 or 1.5. Although the initiation of yield may not entail fracture, once the yield stress in bending is reached, the joists and beam will start to deflect significantly (plastic deformation), thereby increasing the potential for substantial ponding and catastrophic failure.

While it is helpful to recognize this safety margin, it is equally important to understand that safety factors are provided for the many uncertainties associated with materials, design, fabrication, installation, and unpredicted loads in excess of design values. The building designer should not compromise or use any portion of the safety margin for design purposes except when permitted for ponding analysis and wind or earthquake load combinations.

Loads in "excess" of design values may occur when based on this data sheet, which establishes design values that reduce the risk of load-induced collapse to an acceptably low limit. The implications of such "excess" loads, however, 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 may cause ponding and perhaps progressive failure. The rain-load to dead-load or snow-load to dead-load ratios of a roof structure are an important consideration when assessing the implications of "excess" loads. If the design rain or snow load is exceeded, the percentage increase in total load is greater for a lightweight structure (all metal, insulated steel deck, or boards-on-joists roof constructions) than for a heavy structure (concrete deck or plank-on-timber constructions). Thus, the lower the safety margin (expressed as a load), the higher the probability for roof collapse due to snow or rain "excess" loads. This fact is supported by loss history.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

October 2021. Interim revision. The following change was made:

A. Clarified the Human Factors section to allow emergency response other than snow removal.

July 2021. Interim revision. The following changes were made:

A. Moved guidance on snow monitoring and removal plans to Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*.

B. Added recommendations for specific design working life and consequence class for the Eurocode.

April 2021. The following significant changes were made:

A. Changed the title of the data sheet to *Roof Loads and Drainage* (was *Roof Loads for New Construction*).

B. Reorganized the document.

C. Updated numerous figures.

D. Added an outline of steps to determine snow load (section 2.4.1.1).

E. Updated the reference sources for ground snow loads for Russia.

F. Clarified the exception for drift formation at elevated roof projections (section 2.4.5.1.C3a).

G. Added reference to FM Approved snow and ice melting devices.

H. Added a new human factor section that includes recommendations for snow monitoring and removal plans.

I. Added definitions of “heavy” and “light” construction to Appendix A, Glossary of Terms.

July 2016. This document has been completely revised. The following changes were made:

A. Added recommendations for snow drift loading at multiple roof steps and roof pockets in Section 2.3.12.

B. Revised snow drift loading at roof projections and parapets in Section 2.3.12.3.

C. Revised design snow load recommendations for Russia in Section 2.3.3.5.

D. Revised ice accretion load recommendation in Section 2.3.15.

E. Added recommendation for the use of snow and ice melting devices in Section 2.3.16.

F. Added recommendations for rain loads on ballasted roofs in Section 2.5.2.7.

G. Revised the recommended rainfall intensity for secondary roof drainage in Section 2.5.4.1.3.

H. Added roof drain pipe protection recommendations in Section 2.5.4.1.8.

I. Added rain load recommendations for drainage at roof edges in Section 2.5.4.1.12.

J. Revised the hydraulic equation for scupper flow in Table 6a.

K. Added recommendation 2.5.4.1.14 for the use of retrofit/replacement roof drains.

L. Revised and simplified the siphonic drainage recommendations, including design rainfall intensity in Section 2.5.4.2.3.

M. Added recommendations for rainwater ingress and weather tightness of roofing in Section 2.6.2.

N. Revised the rain load recommendations when using the Eurocode in Section 2.7.3.2.2.

O. Added new section (Section 2.9) for roof loads on roofs with solar panels.

P. Added clarification on recommended roofs loads regarding unfactored versus factored loads in Section 3.1.A.

Q. Revised and expanded the ground snow load tables for Japan in Tables 12a and 12b..

R. Added Appendix D for best practices and details for siphonic drainage.

S. Added example problem to Appendix E for design snow loads on roofs with solar panels.

October 2012. The following changes were made:

A. Revised and expanded the tables (flow rate versus corresponding hydraulic head) for primary and secondary roof drains.

B. Added new table for flow rate and corresponding hydraulic head for circular roof scuppers.

C. Added new recommendations for ground snow studies where ground loads are not mapped.

D. Added new recommendations regarding partial safety factors (load factors) for Eurocode harmonization.

E. Added new recommendations for ground snow loads in Russia.

F. Revised rainfall intensity maps for the US and Puerto Rico.

G. Revised the roof drainage illustrative problems.

July 2011. Corrections were made to Table 12, Ground Snow Load for Alaskan Locations.

January 2011. Minor editorial changes were made. A note was added to the China snow maps and tables to eliminate uncertainty regarding rounding/converting.

September 2010. The following changes were made for this revision:

- Added recommendations for Siphonic roof drainage, including new plan review guidance.
- Added recommendations for using Eurocode provisions for roof drainage.
- Added recommendations for ground snow loads in China.
- Added background and guidance on rainfall intensity, duration, and frequency (i-D-F).

January 2009. Minor editorial changes were made for this revision.

July 2008. Completely revised. The following outlines the major changes:

Added section that allows the use (with exceptions and changes) of Eurocode 1 for snow loads and roof live loads.

Added section that allows the use (with exceptions and changes) of ASCE 7 for snow loads.

Added updated ground snow load maps for the contiguous United States and ground snow load for Alaska.

Added ground snow load tables for select cities in Korea and Japan (Tables 10 and 11, respectively).

Added recommendations for rain-on-snow surcharge, intersecting snow drifts, drift distribution on dome roofs, and snow/ice load at overhanging eaves.

Added flow chart for the use of live load reduction.

Revised snow drift loads for hip and gable roofs, valley roofs, and roof projections.

Revised sliding snow surcharge on low roofs.

Revised the definition of live load to exclude variable loads such as snow and rain loads.

Accepted using Eurocode EN 12056-3:2000 and rain intensity maps and data for determining rainwater runoff for France, Germany, Netherlands, Switzerland and the United Kingdom.

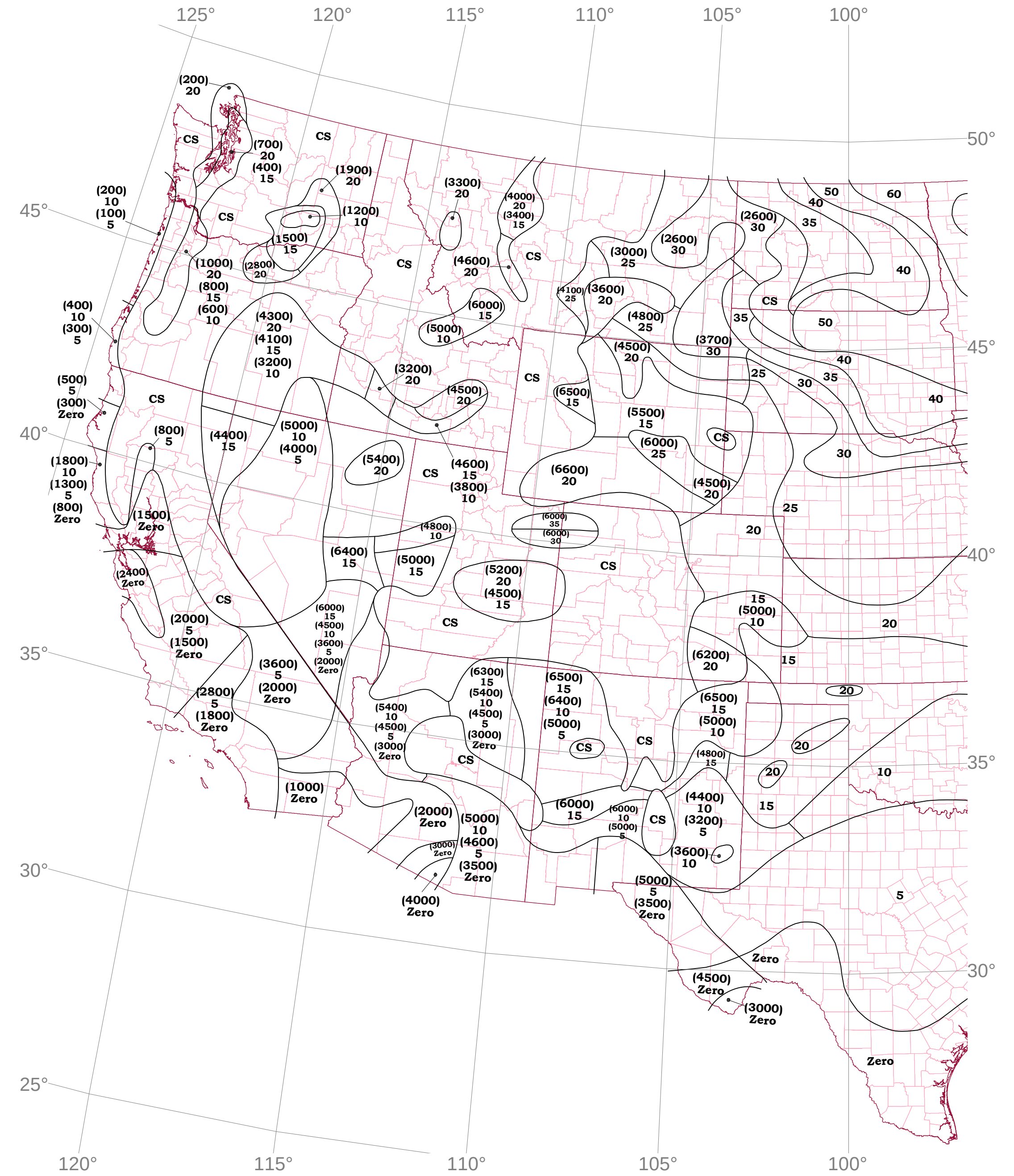
September 2006. Minor editorial changes were done for this revision.

May 2006. Minor editorial changes done for this revision.

September 2004. Minor editorial changes were done for this revision.

January 2001. This revision of the document has been reorganized to provide a consistent format.

APPENDIX C SUPPLEMENTARY INFORMATION



In CS areas, site-specific Case Studies are required to establish ground snow loads. Extreme local variations in ground snow loads in these areas preclude mapping at this scale.

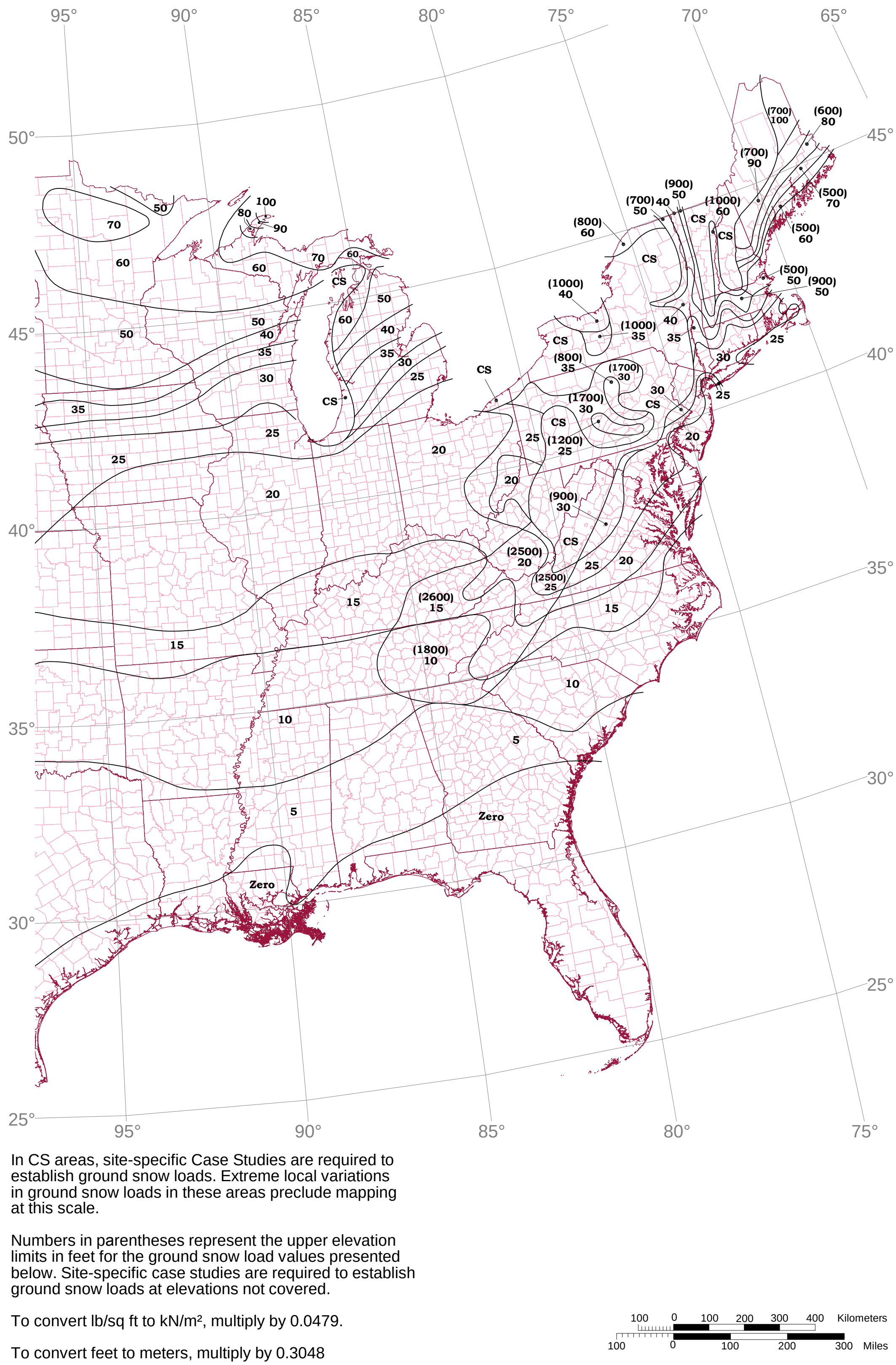
Numbers in parentheses represent the upper elevation limits in feet for the ground snow load values presented below. Site-specific case studies are required to establish ground snow loads at elevations not covered.

To convert lb/sq ft to kN/m², multiply by 0.0479.

To convert feet to meters, multiply by 0.3048

100 0 100 200 300 400 Kilometers
100 0 100 200 300 Miles

Fig. C1. Ground snow load (Pg) in psf for western United States



In CS areas, site-specific Case Studies are required to establish ground snow loads. Extreme local variations in ground snow loads in these areas preclude mapping at this scale.

Numbers in parentheses represent the upper elevation limits in feet for the ground snow load values presented below. Site-specific case studies are required to establish ground snow loads at elevations not covered.

To convert lb/sq ft to kN/m², multiply by 0.0479.

To convert feet to meters, multiply by 0.3048

Fig. C2. Ground snow load (Pg) in psf for eastern United states (to obtain kN/m2, multiply by 0.048)

Table C1. Ground Snow Load (P_g) for Locations in Alaska, psf (kN/m²)

Location	P_g		Location	P_g		Location	P_g	
	lb/ft²	**kN/m²**		**lb/ft²**	**kN/m²**		**lb/ft²**	**kN/m²**
Adak	30	1.4	Galena	60	2.9	Petersburg	150	7.2
Anchorage	50	2.4	Gulkana	70	3.4	St Paul	40	1.9
Angoon	70	3.4	Homer	40	1.9	Seward	50	2.4
Barrow	25	1.2	Juneau	60	2.9	Shemya	25	1.2
Barter	35	1.7	Kenai	70	3.4	Sitka	50	2.4
Bethel	40	1.9	Kodiak	30	1.4	Talkeetna	120	5.8
Big Delta	50	2.4	Kotzebue	60	2.9	Unalakleet	50	2.4
Cold Bay	25	1.2	McGrath	70	3.4	Valdez	160	7.7
Cordova	100	4.8	Nenana	80	3.8	Whittier	300	14.4
Fairbanks	60	2.9	Nome	70	3.4	Wrangell	60	2.9
Fort Yukon	60	2.9	Palmer	50	2.4	Yakutat	150	7.2

Table C2. Ground Snow Load (P_g) for Locations in Korea, psf and kPa

50-Year Ground Snow Load for Select Cities in Korea				
Cities	Location		50-yr Ground Snow Load (kPa)	50-yr Ground Snow Load (psf)
	LONG (E)	LAT (N)		
Seoul	126°58’	37°34’	0.85	18
Incheon	126°38’	37°28’	0.80	17
Suwon	126°59’	37°16’	0.70	15
Cheongju	127°27’	36°38’	1.10	23
Daejeon	127°22’	36°22’	1.15	24
Pohang	129°23’	36°02’	0.90	19
Daegu	128°37’	35°53’	0.80	17
Ulsan	129°19’	35°33’	0.60	13
Masan	128°34’	35°11’	1.00	21
Gwangju	126°54’	35°10’	1.05	22
Busan	129°02’	35°06’	0.85	18
Mokpo	126°23’	34°49’	0.95	20
Icheon	127°29’	37°16’	1.05	22
Cheonan	127°07’	36°47’	0.80	17
Youngju	128°31’	36°52’	1.10	23
Gumi	128°19’	36°08’	1.05	22
Gunsan	126°45’	36°00’	0.95	20
Jeonju	127°09’	35°49’	0.80	17

Note: Snow load is based on a snow weight density of 17.2 lb/ft³ (2.73 kN/m³)

Table C3. Ground Snow Load (P_g) for Locations in Japan, psf and kPa

City	Station Code	Long (E)	Lat (N)	Altitude (m)	Altitude (ft)	50-yr Ground Snow Load (kPa)	50-yr Ground Snow Load (psf)
Abashiri	409	144.278	44.017	38	123	3.76	79
Aburatsu	835	131.407	31.578	3	10	0.10	2
Aikawa	602	138.238	38.028	6	18	1.31	27
Ajiro	668	139.092	35.047	67	219	0.18	4
Akita	582	140.098	39.717	6	21	2.68	56
Akune	823	130.200	32.027	40	132	0.58	12
Aomori	575	140.768	40.822	3	9	6.26	131
Asahikawa	407	142.368	43.772	112	367	4.19	87
Asosan	821	131.073	32.880	1142	3748	2.43	51
Chiba	682	140.103	35.602	4	11	0.58	12
Chichibu	641	139.073	35.990	232	761	1.84	38
Choshi	648	140.857	35.738	20	66	0.18	4
Esashi	428	140.123	41.867	4	12	2.18	46
Fukaura	574	139.932	40.645	66	217	2.50	52
Fukue	843	128.827	32.693	25	82	0.52	11
Fukui	616	136.222	36.050	9	29	6.14	128
Fukuoka	807	130.375	33.582	3	8	0.30	6
Fukushima	595	140.470	37.758	67	221	1.28	27
Fukuyama	767	133.247	34.447	2	6	0.36	8
Fushiki	606	137.055	36.792	12	38	5.72	120
Gifu	632	136.762	35.400	13	42	0.91	19
Haboro	404	141.700	44.362	8	26	5.35	112
Hachijojima	678	139.778	33.122	151	497	0.10	2
Hachinohe	581	141.522	40.527	27	89	2.36	49
Hagi	754	131.392	34.415	6	18	0.46	10
Hakodate	430	140.753	41.815	35	115	2.54	53
Hamada	755	132.070	34.897	19	62	0.91	19
Hamamatsu	654	137.718	34.708	32	104	0.10	2
Hikone	761	136.243	35.275	87	286	1.67	35
Himeji	769	134.670	34.838	38	125	0.34	7
Hirado	805	129.550	33.360	58	190	0.14	3

City	Station Code	Long (E)	Lat (N)	Altitude (m)	Altitude (ft)	50-yr Ground Snow Load (kPa)	50-yr Ground Snow Load (psf)
Kofu	638	138.553	35.667	273	895	1.94	41
Kumagaya	626	139.380	36.150	30	98	0.95	20
Kumamoto	819	130.707	32.813	38	124	0.18	4
Kure	766	132.550	34.240	4	11	0.20	4
Kushiro	418	144.377	42.985	5	15	2.11	44
Kutchan	433	140.757	42.900	176	578	9.65	202
Kyoto	759	135.732	35.015	41	136	0.32	7
Maebashi	624	139.060	36.405	112	368	1.16	24
Maizuru	750	135.317	35.450	2	8	2.29	48
Makurazaki	831	130.293	31.272	30	97	0.48	10
Matsue	741	133.065	35.457	17	55	2.22	46
Matsumoto	618	137.970	36.245	610	2001	1.77	37
Matsuyama	887	132.777	33.843	32	106	0.22	5
Mishima	657	138.925	35.113	21	67	0.18	4
Mito	629	140.467	36.380	29	96	0.50	10
Miyakejima	677	139.522	34.123	36	119	0.10	2
Miyako	585	141.965	39.647	43	139	2.08	43
Miyakonojo	829	131.080	31.730	154	505	0.12	3
Miyazaki	830	131.413	31.938	9	30	0.10	2
Monbetsu	435	143.355	44.345	16	52	3.60	75
Morioka	584	141.165	39.698	155	509	1.94	41
Muroran	423	140.975	42.312	40	131	1.31	27
Murotomisaki	899	134.177	33.252	185	607	0.10	2
Mutsu	576	141.210	41.283	3	10	4.80	100
Nagano	610	138.192	36.662	418	1372	1.67	35
Nagasaki	817	129.867	32.733	27	88	0.28	6
Nagoya	636	136.965	35.167	51	168	0.44	9
Nara	780	135.827	34.693	104	343	0.40	8
Nemuro	420	145.585	43.330	25	83	2.29	48
Niigata	604	139.047	37.912	2	6	2.43	51
Nishigo	740	133.333	36.203	27	87	2.64	55

City	Station Code	Long (E)	Lat (N)	Altitude (m)	Altitude (ft)	50-yr Ground Snow Load (kPa)	50-yr Ground Snow Load (psf)
Shimizu	898	133.010	32.722	31	102	0.10	2
Shimonoseki	762	130.925	33.948	3	11	0.26	5
Shinjyo	520	140.312	38.757	105	345	7.77	162
Shionomisaki	778	135.760	33.450	73	240	0.10	2
Shirakawa	597	140.215	37.132	355	1165	1.54	32
Shizuoka	656	138.403	34.975	14	46	0.10	2
Sukumo	897	132.695	32.920	2	7	0.38	8
Sumoto	776	134.905	34.338	109	359	0.26	5
Suttsu	421	140.223	42.795	33	110	3.70	77
Suwa	620	138.108	36.045	760	2494	1.35	28
Tadotsu	890	133.752	34.275	4	12	0.34	7
Takada	612	138.247	37.105	13	42	11.34	237
Takamatsu	891	134.053	34.317	9	29	0.34	7
Takayama	617	137.253	36.155	560	1838	3.27	68
Tateyama	672	139.865	34.987	6	19	0.16	3
Tokushima	895	134.573	34.067	2	5	0.30	6
Tokyo	662	139.760	35.690	6	20	0.58	12
Tomakomai	424	141.547	42.622	6	21	1.84	38
Tomioka	747	134.822	35.535	3	11	3.90	81
Tottori	746	134.237	35.487	7	23	2.86	60
Toyama	607	137.202	36.708	9	28	5.43	113
Tsu	651	136.520	34.733	3	9	0.26	5
Tsuruga	631	136.062	35.653	2	5	5.35	112
Tsurugisan	894	134.097	33.853	1945	6381	9.58	200
Tsuyama	756	134.008	35.063	146	478	0.80	17
Ueno	649	136.142	34.762	159	522	0.44	9
Urakawa	426	142.777	42.162	33	107	1.06	22
Ushibuka	838	130.027	32.197	3	10	0.50	10
Utsunomiya	615	139.868	36.548	119	392	0.58	12
Uwajima	892	132.552	33.227	2	8	0.42	9
Wajima	600	136.895	37.392	5	17	2.04	43

Table C3. Ground Snow Load (P_g) for Locations in Japan, psf and kPa (continued)

City	*Station Code*	*Long (E)*	*Lat (N)*	*Altitude (m)*	*Altitude (ft)*	*50-yr Ground Snow Load (kPa)*	*50-yr Ground Snow Load (psf)*
Hiroo	440	143.315	42.293	32	106	5.72	120
Hiroshima	765	132.462	34.398	4	12	0.42	9
Hita	814	130.928	33.322	83	272	0.66	14
Hitoyoshi	824	130.755	32.217	146	478	0.46	10
Ibukiyama	751	136.413	35.418	1376	4514	36.22	756
Iida	637	137.822	35.523	482	1582	1.48	31
Iizuka	809	130.693	33.652	37	122	0.52	11
Irako	653	137.093	34.628	6	20	0.20	4
Irouzaki	666	138.843	34.602	55	179	0.12	3
Ishinomaki	592	141.298	38.427	43	139	0.71	15
Iwamizawa	413	141.785	43.212	42	139	6.29	131
Izuhara	800	129.292	34.197	4	12	0.10	2
Kagoshima	827	130.547	31.553	4	13	0.48	10
Kanazawa	605	136.633	36.588	6	19	4.80	100
Karuizawa	622	138.547	36.342	999	3278	2.36	49
Katsuura	674	140.312	35.150	12	39	0.44	9
Kawaguchiko	640	138.760	35.500	860	2821	3.39	71
Kitamiesashi	402	142.585	44.940	7	22	5.84	122
Kobe	770	135.212	34.697	5	17	0.18	4
Kochi	893	133.548	33.567	1	2	0.18	4

City	*Station Code*	*Long (E)*	*Lat (N)*	*Altitude (m)*	*Altitude (ft)*	*50-yr Ground Snow Load (kPa)*	*50-yr Ground Snow Load (psf)*
Nobeoka	822	131.657	32.582	19	63	0.10	2
Obihiro	417	143.212	42.922	38	126	4.63	97
Ofunato	512	141.713	39.063	37	121	0.58	12
Oita	815	131.618	33.235	5	15	0.24	5
Okayama	768	133.917	34.660	3	9	0.22	5
Okunikko	690	139.500	36.738	1292	4239	3.17	66
Omaezaki	655	138.212	34.603	45	147	0.10	2
Onahama	598	140.903	36.947	3	11	0.42	9
Osaka	772	135.518	34.682	23	75	0.26	5
Oshima	675	139.362	34.748	74	243	0.40	8
Otaru	411	141.017	43.182	25	82	5.31	111
Oumu	405	142.963	44.580	14	45	3.81	79
Owase	663	136.193	34.070	15	50	0.10	2
Rumoi	406	141.632	43.945	24	77	5.54	116
Saga	813	130.305	33.265	6	18	0.28	6
Sakai	742	133.235	35.543	2	7	2.26	47
Sakata	587	139.843	38.908	3	10	2.04	43
Sapporo	412	141.328	43.058	17	56	4.52	94
Sasebo	812	129.727	33.158	4	13	0.26	5
Sendai	590	140.897	38.262	39	128	0.74	15

City	*Station Code*	*Long (E)*	*Lat (N)*	*Altitude (m)*	*Altitude (ft)*	*50-yr Ground Snow Load (kPa)*	*50-yr Ground Snow Load (psf)*
Wakamatsu	570	139.910	37.488	212	696	3.55	74
Wakayama	777	135.163	34.228	14	46	0.20	4
Wakkanai	401	141.678	45.415	3	9	5.14	107
Yakushima	836	130.658	30.382	36	119	0.10	2
Yamagata	588	140.345	38.255	153	500	2.82	59
Yamaguchi	784	131.453	34.160	17	55	0.66	14
Yokkaichi	684	136.580	34.938	55	181	0.97	20
Yokohama	670	139.652	35.438	39	128	0.74	15
Yonago	744	133.338	35.435	6	21	2.08	43
Shimizu	898	133.010	32.722	31	102	0.10	2
Shimonoseki	762	130.925	33.948	3	11	0.26	5
Shinjyo	520	140.312	38.757	105	345	7.77	162
Shionomisaki	778	135.760	33.450	73	240	0.10	2
Shirakawa	597	140.215	37.132	355	1165	1.54	32
Shizuoka	656	138.403	34.975	14	46	0.10	2
Sukumo	897	132.695	32.920	2	7	0.38	8
Sumoto	776	134.905	34.338	109	359	0.26	5
Suttsu	421	140.223	42.795	33	110	3.70	77
Suwa	620	138.108	36.045	760	2494	1.35	28

Note: Ground snow loads are based on the recommended unit snow weight densities provided in the guideline of the Architectural Institute of Japan (AIJ).

*Table C4. Ground Snow Load (P_g) for Locations in China**

Cities by Numerical Order								*Cities by Alphabetical Order*							
City No.	City Name	50-Year Ground Snow Load		City No.	City Name	50-Year Ground Snow Load		City No.	City Name	50-Year Ground Snow Load		City No.	City Name	50-Year Ground Snow Load	
		(kN/m^2)	(psf)			(kN/m^2)	(psf)			(kN/m^2)	(psf)			(kN/m^2)	(psf)
1	Urumqi	1.12	23	40	Luoyang	0.64	13	43	Anqing	0.80	17	40	Luoyang	0.64	13
2	Lhasa	0.48	10	41	Hefei	0.96	20	14	Anshan	0.80	17	3	Mohe	1.12	23
3	Mohe	1.12	23	42	Bangbu	0.80	17	42	Bangbu	0.80	17	69	Nanchang	0.80	17
4	Qiqihar	0.64	13	43	Anqing	0.80	17	36	Baoji	0.48	10	50	Nanjing	0.80	17
5	Harbin	0.80	17	44	Fuyang	0.96	20	17	Beijing	0.64	13	52	Nantong	0.48	10
6	Jiamusi	1.12	23	45	Lianyungang	0.64	13	9	Changchun	0.64	13	59	Ningbo	0.64	13
7	Ulanhot	0.48	10	46	Xuzhou	0.64	13	67	Changde	0.80	17	30	Qingdao	0.48	10
8	Hohhot	0.48	10	47	Sheyang	0.48	10	65	Changsha	0.80	17	21	Qinhuangdao	0.64	13
9	Changchun	0.64	13	48	Dongtai	0.64	13	51	Changzhou	0.64	13	4	Qiqihar	0.64	13
10	Jilin	0.64	13	49	Zhenjiang	0.64	13	73	Chengdu	0.32	7	56	Shanghai	0.48	10
11	Fushun	0.96	20	50	Nanjing	0.80	17	75	Chongqing	0.32	7	72	Shaowu	0.64	13
12	Shenyang	0.96	20	51	Changzhou	0.64	13	16	Dalian	0.64	13	12	Shenyang	0.96	20
13	Dandong	0.80	17	52	Nantong	0.48	10	13	Dandong	0.80	17	47	Sheyang	0.48	10
14	Anshan	0.80	17	53	Wuxi	0.80	17	26	Datong	0.48	10	22	Shijiazhuang	0.64	13
15	Jinzhou	0.80	17	54	Suzhou	0.64	13	48	Dongtai	0.64	13	54	Suzhou	0.64	13
16	Dalian	0.64	13	55	Kunshan	0.48	10	74	Dujiangyan	0.32	7	25	Taiyuan	0.64	13
17	Beijing	0.64	13	56	Shanghai	0.48	10	11	Fushun	0.96	20	19	Tanggu	0.64	13
18	Tianjin	0.80	17	57	Jiaxing	0.64	13	44	Fuyang	0.96	20	18	Tianjin	0.80	17
19	Tanggu	0.64	13	58	Hangzhou	0.80	17	71	Ganzhou	0.48	10	64	Tianmen	0.64	13
20	Zhangjiakou	0.48	10	59	Ningbo	0.64	13	77	Guiyang	0.48	10	7	Ulanhot	0.48	10
21	Qinhuangdao	0.64	13	60	Wenzhou	0.64	13	58	Hangzhou	0.80	17	1	Urumqi	1.12	23
22	Shijiazhuang	0.64	13	61	Jinhua	0.96	20	5	Harbin	0.80	17	28	Weifang	0.64	13
23	Xingtai	0.64	13	62	Wuhan	0.80	17	41	Hefei	0.96	20	32	Weihai	0.80	17
24	Yinchuan	0.48	10	63	Yichang	0.64	13	8	Hohhot	0.48	10	60	Wenzhou	0.64	13
25	Taiyuan	0.64	13	64	Tianmen	0.64	13	6	Jiamusi	1.12	23	62	Wuhan	0.80	17
26	Datong	0.48	10	65	Changsha	0.80	17	57	Jiaxing	0.64	13	53	Wuxi	0.80	17
27	Jinan	0.64	13	66	Yueyang	0.96	20	10	Jilin	0.64	13	37	Xi'an	0.48	10
28	Weifang	0.64	13	67	Changde	0.80	17	27	Jinan	0.64	13	23	Xingtai	0.64	13
29	Linyi	0.64	13	68	Jingdezhen	0.96	20	68	Jingdezhen	0.96	20	33	Xining	0.32	7
30	Qingdao	0.48	10	69	Nanchang	0.80	17	61	Jinhua	0.96	20	46	Xuzhou	0.64	13
31	Yantai	0.80	17	70	Jiujiang	0.80	17	15	Jinzhou	0.80	17	35	Yan'an	0.48	10
32	Weihai	0.80	17	71	Ganzhou	0.48	10	70	Jiujiang	0.80	17	31	Yantai	0.80	17
33	Xining	0.32	7	72	Shaowu	0.64	13	39	Kaifeng	0.80	17	63	Yichang	0.64	13
34	Lanzhou	0.32	7	73	Chengdu	0.32	7	76	Kunming	0.64	13	24	Yinchuan	0.48	10

Table C4. Ground Snow Load (P_g) for Locations in China (continued)

Cities by Numerical Order										Cities by Alphabetical Order								
City No.	City Name	50-Year Ground Snow Load			City No.	City Name	50-Year Ground Snow Load			City No.	City Name	50-Year Ground Snow Load			City No.	City Name	50-Year Ground Snow Load	
		(kN/m^2)	(psf)				(kN/m^2)	(psf)				(kN/m^2)	(psf)				(kN/m^2)	(psf)
35	Yan'an	0.48	10		74	Dujiangyan	0.32	7		55	Kunshan	0.48	10		66	Yueyang	0.96	20
36	Baoji	0.48	10		75	Chongqing	0.32	7		34	Lanzhou	0.32	7		20	Zhangjiakou	0.48	10
37	Xi'an	0.48	10		76	Kunming	0.64	13		2	Lhasa	0.48	10		38	Zhengzhou	0.80	17
38	Zhengzhou	0.80	17		77	Guiyang	0.48	10		45	Lianyungang	0.64	13		49	Zhenjiang	0.64	13
39	Kaifeng	0.80	17		78	Zunyi	0.32	7		29	Linyi	0.64	13		78	Zunyi	0.32	7

* Note that the loads in this table include a snow load Importance Factor (I) of 1.2. Snow load values in psf have been converted and rounded-off from snow load values in kN/m^2; therefore, avoid converting from psf to kN/m^2 as this can result in round-off error.

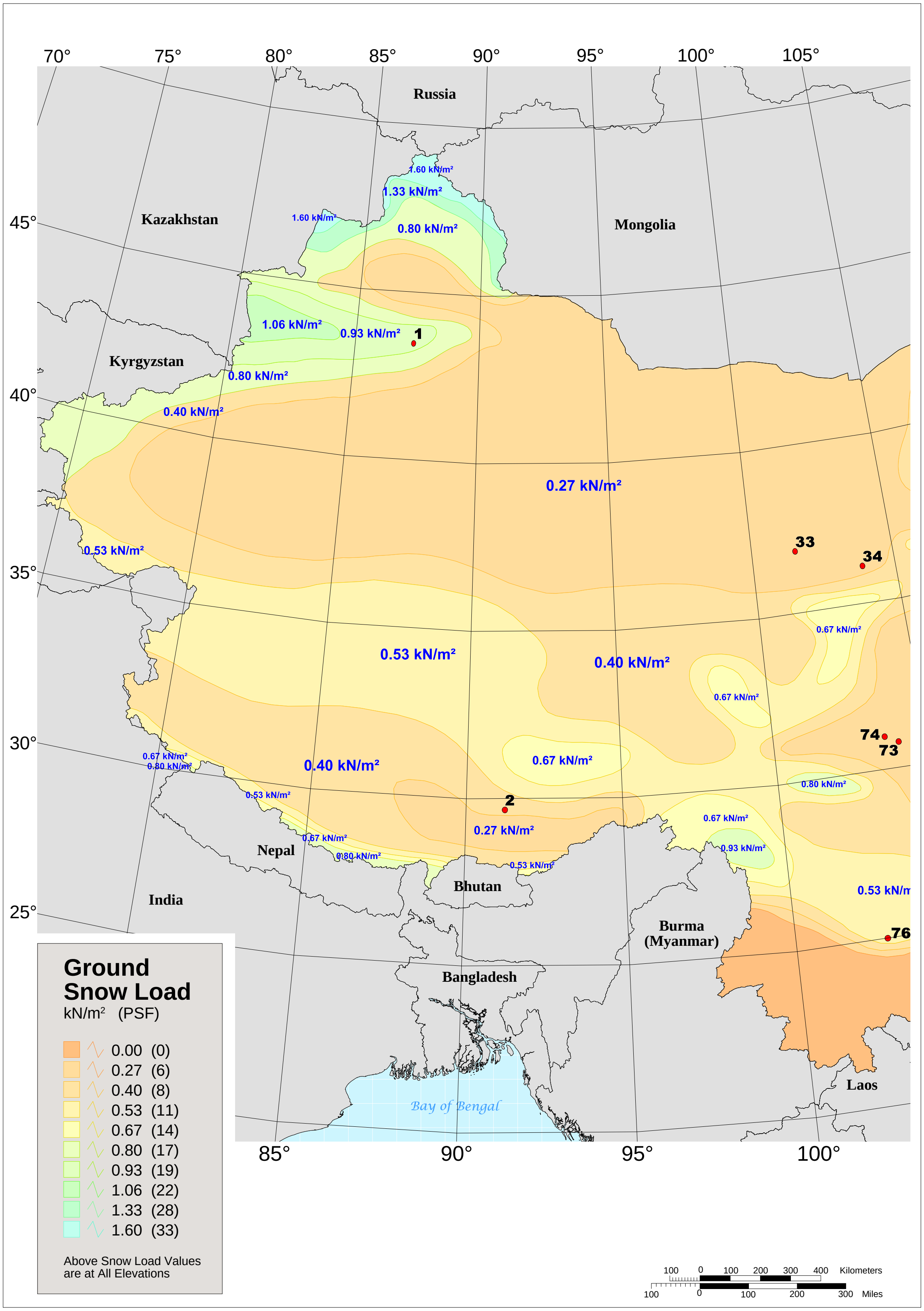


Fig. C3. Ground snow load (Pg) in kN/fm² for Western China

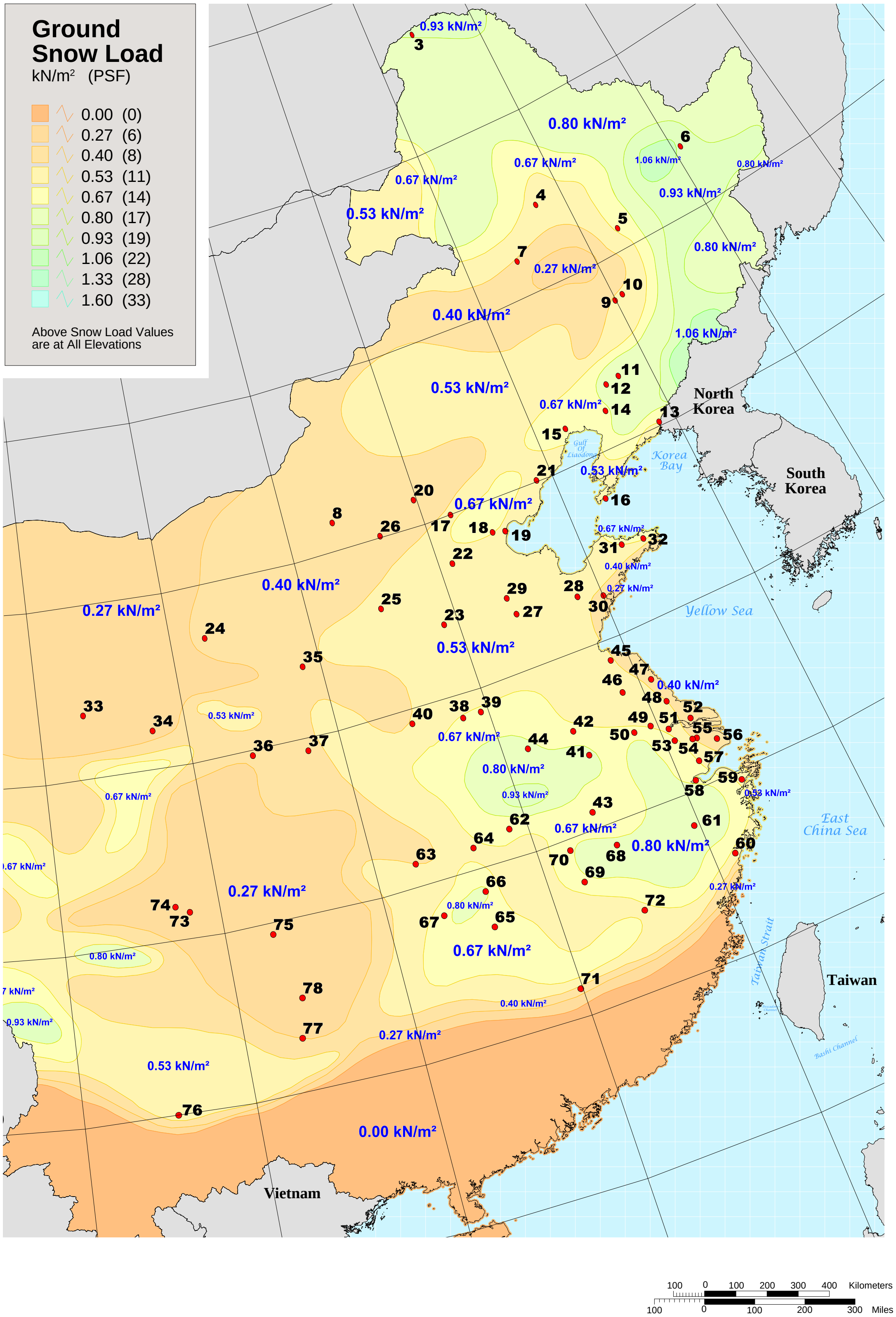


Fig. C4. Ground snow load (Pg) in kN/m² for Eastern China

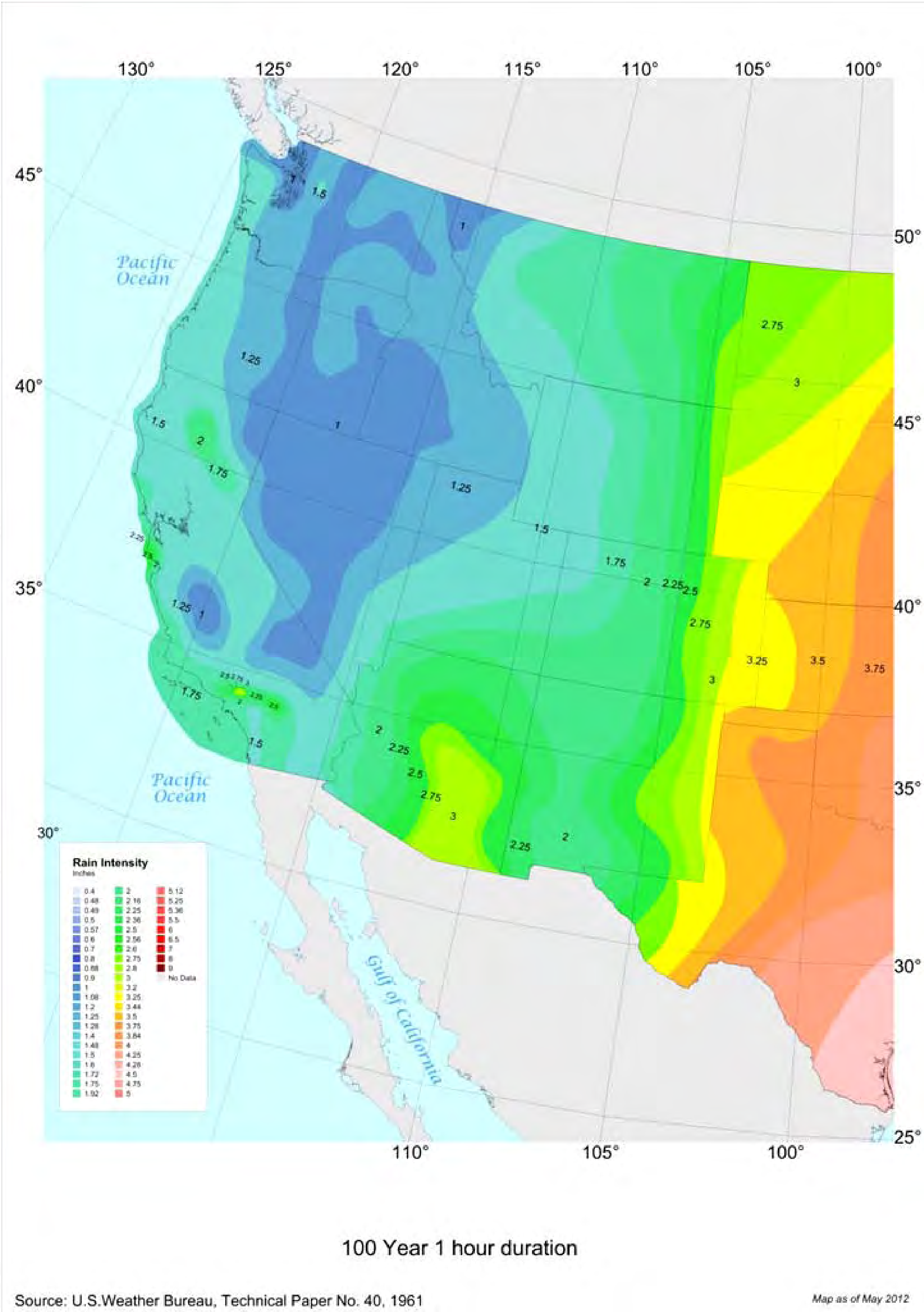


Fig. C5. 100-year, 60-minute Rainfall intensity (i) in inches per hour for the western United States (to convert to millimeters per hour multiply by 25.4)

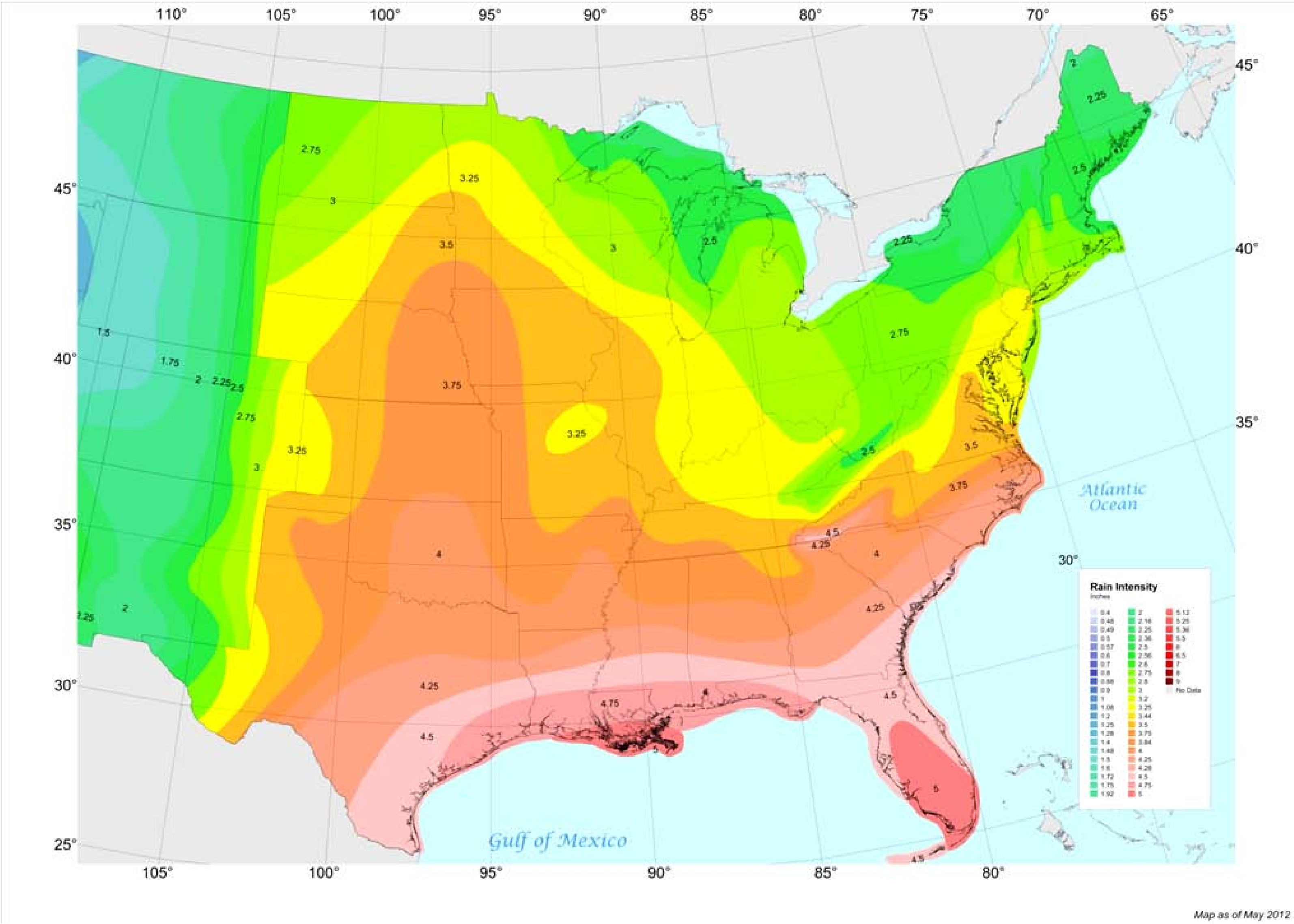


Fig. C6. 100-year, 60-minute Rainfall intensity (i) in inches per hour for the central and eastern United States (to convert to millimeters per hour multiply by 25.4)

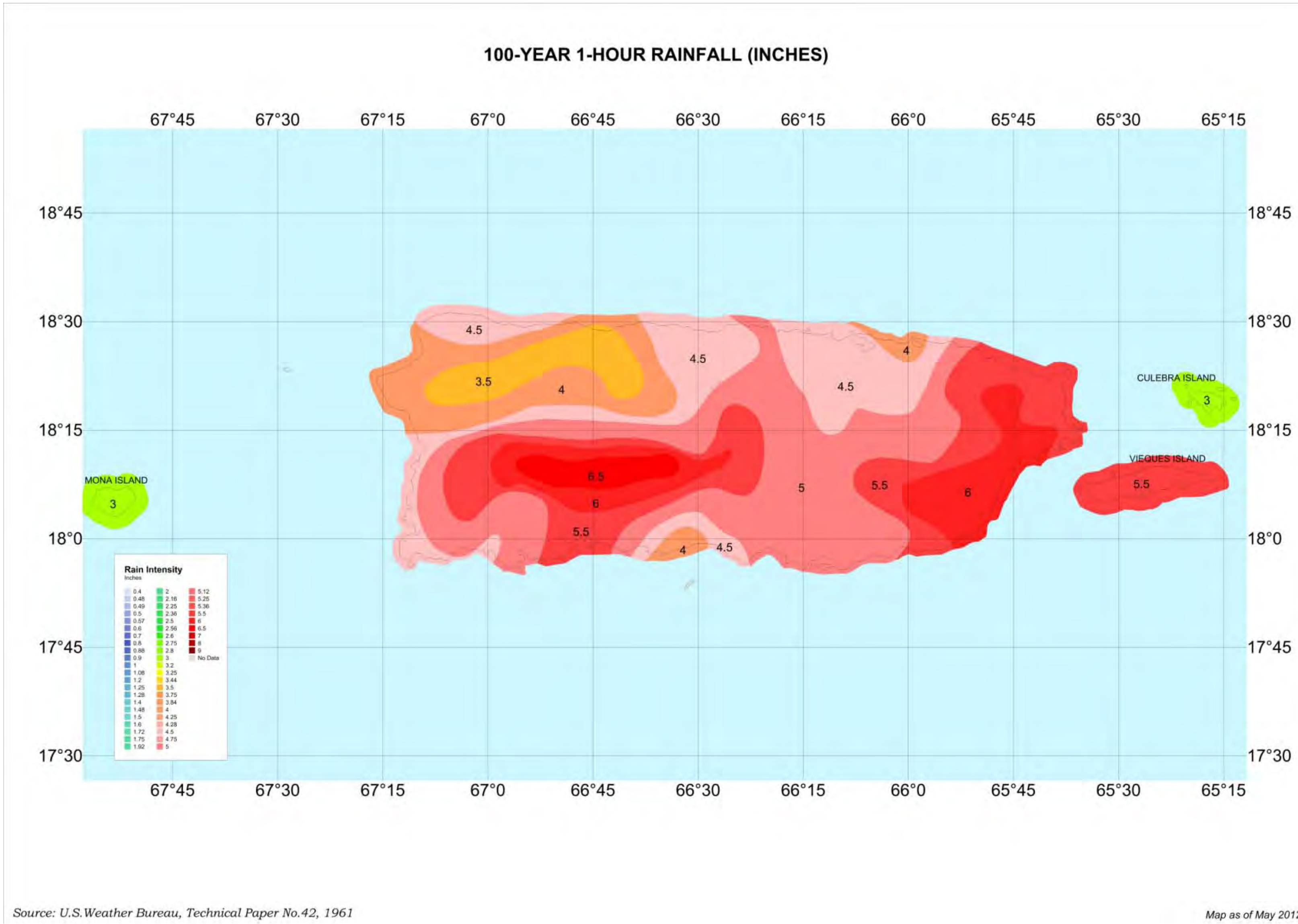


Fig. C7. Rainfall intensity (i) in inches per hour for Puerto Rico (to convert to millimeters per hour multiply by 25.4)

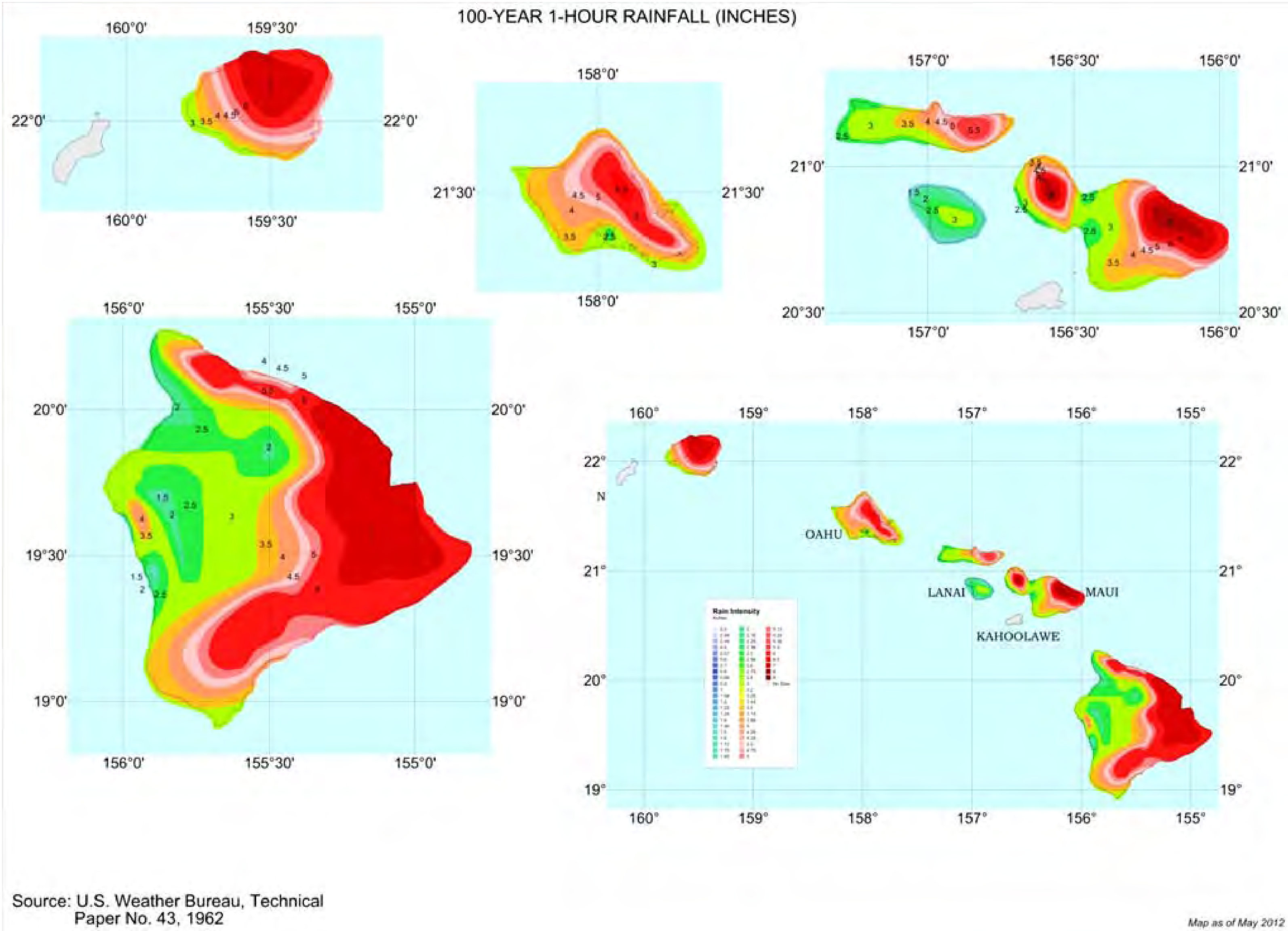


Fig. C8. 100-year, 60-minute Rainfall intensity (i) in inches per hour for Hawaiian Islands (to convert to millimeters per hour multiply by 25.4)

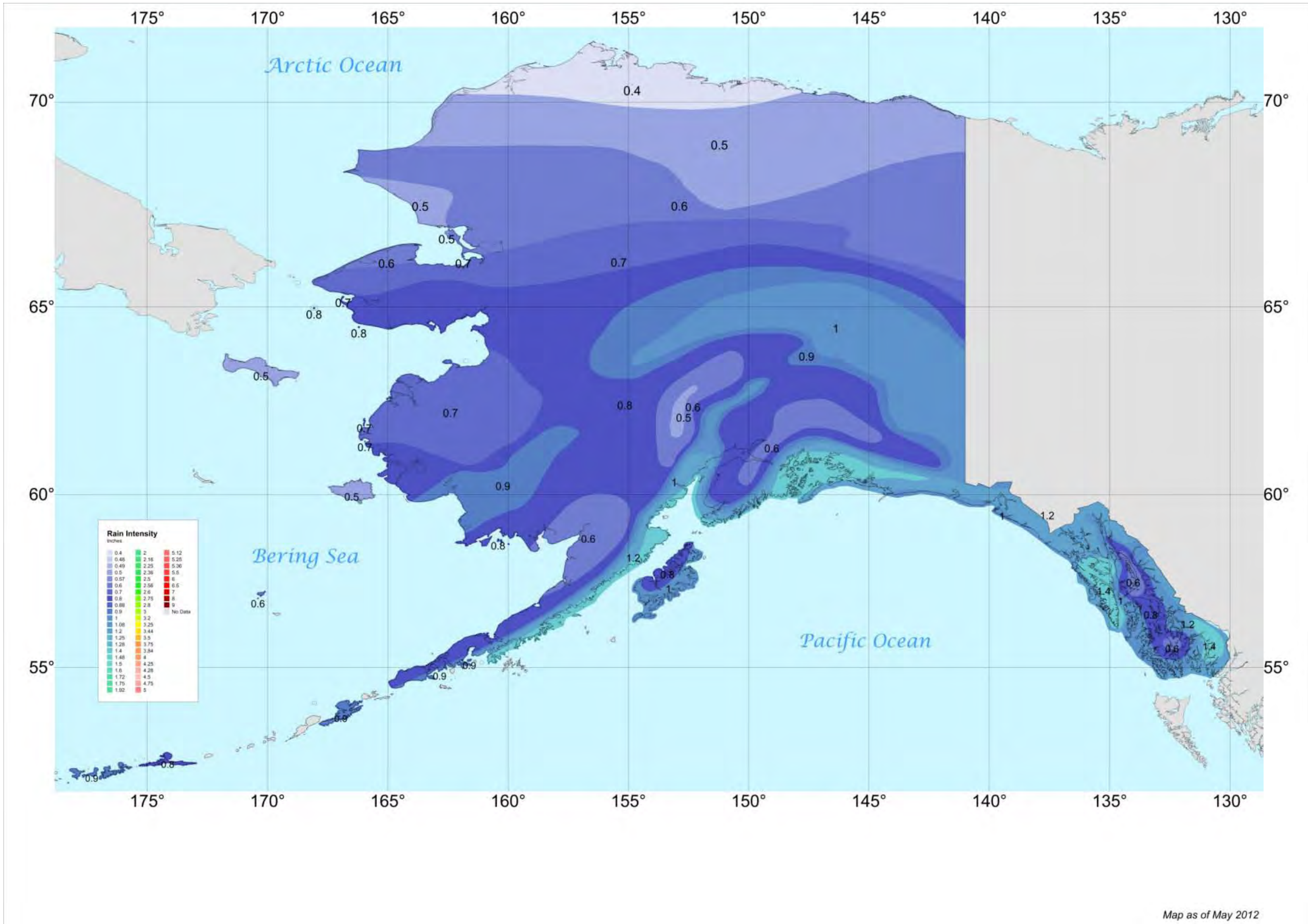


Fig. C9. 100-year, 60-minute Rainfall intensity (i) in inches per hour for Alaska (to convert to millimeters per hour multiply by 25.4).

APPENDIX D SIPHONIC ROOF DRAINAGE: BEST PRACTICES AND SUPPORT SUPPLEMENT

The following guidelines are not recommendations, but are supplemental to the recommendations of Section 2.5.4.2, and are intended to provide background and insight into best practices for siphonic roof drainage systems.

D.1 Disposable (Available) Head

Design disposable head (H_d) is assumed to be the vertical distance from the inlet (rim) of the roof drain to highest elevation (i.e., least vertical distance) of either: (a) the grade elevation at discharge inspection chamber or manhole, (b) the flood elevation, or (c) the elevation of siphonic break (for discharge above grade).

Theoretical disposable head (H_t) is assumed to be the vertical distance from the water level directly upstream of the roof drain to the centerline of siphonic discharge pipe at or below grade.

Either H_t or H_d, whichever provides for the more demanding condition, is used when determining the properties or performance of the siphonic drainage system.

D.2 Disposable and Velocity Head

H_d is typically at least 10% greater than the sum of the residual velocity head (at the last section of siphonic pipe just before the point of discharge) and the head losses.

Efficient siphonic drainage designs will generally have no more than 3 ft (0.9 m) of residual velocity head.

D.3 Head Losses and Head Imbalance

Calculated head losses should account for pipe roughness values for both new and aged conditions, and the roughness values that result in the most demanding condition should be used.

The calculated imbalance in head at the design flow rate between any two roof drains with a common downpipe (stack) and the point of discharge should be no greater than 1.5 ft (0.46m), or 10% of H_d, whichever is less.

D.4 Operating Pressure

Operating pressure (gauge) typically should not exceed 13 psig (90 kPa), or 30 ft (9.2 m) of water column head pressure.

Operating pressure (gauge) typically should be no less than:

(3.5 psi [24.2 kPa]) - (local atmospheric pressure [Patm] accounting for site elevation)

This is equivalent to a maximum negative gauge pressure of approximately 75% of Patm. Values less than Patm are used to account for lower atmospheric pressures that can accompany rain storms, and include a nominal safety margin.

For example:

A. At sea level P_{atm} = 14.7 psi (101.6 kPa), therefore the minimum operating gauge pressure is:

3.5 psi (24.2 kPa) - 14.7 psi (101.6 kPa) = -11.2 psig (-77.4 kPa)

B. At 3000 ft (915 m) above sea level, P_{atm} = 13.2 psi (91.1 kPa), therefore the minimum operational gauge pressure is:

(3.5 psi [24.2 kPa]) - 13.2 psi (91.1 kPa) = -9.7 psig [-67.0 kPa]

At higher elevations, the minimum allowable pressure is greater (less negative) since less atmospheric pressure would allow water in the siphonic pipe system to cavitate more easily, assuming all other conditions equal.

Minimum operating pressures are intended to prevent cavitation, air infiltration at pipe fittings and joints, and pipe overload (buckling or collapsing).

D.5 Operating Velocity

Minimum velocities are intended to ensure efficient priming and full-bore siphonic flow is maintained (tailpipes, horizontal collector pipes, and downpipes), and that sediment is flushed from the piping (tailpipes and horizontal collector pipes).

At the design flow rate, the minimum velocity in tailpipes and horizontal collector pipes should be approximately 3.3 ft/sec (1 m/sec).

The maximum velocity in the siphonic system should be based on maintaining allowable minimum pressures (maximum negative gauge pressures) in the system. Generally, the velocity at design flow should not exceed 20 ft/sec (6 m/s) for the given minimum operational pressure.

D.6 Priming

The siphonic drainage system should be designed to prime (i.e., to begin full-bore siphonic flow) at not more than 1/2 the duration associated with the design rainfall intensity. A reasonable estimation can be made by determining the time required to fill the siphonic system based on the following equation:

$T_f = 1.2\ (V_p)(q_t) \leq 60$ seconds

Where:

T_f = time to fill the system (seconds).

q_t = the flow capacity (cfs or liter/sec) of all the contributing tailpipes when assumed to be acting siphonically, but also independently, and discharging to atmospheric pressure at the collector pipe.

V_p = the volume (cubic feet or liters) of the downpipe (to the point of theoretical siphonic discharge) and the contributing collector pipes.

D.7 Discharge

To ensure the siphonic action is broken where the siphonic drain system discharges (to either the underground storm drain system or the above-ground drainage system), an increaser and larger discharge pipe (at least 10 pipe diameters in length) is typically provided. The larger discharge pipe diameter and adequate flow capacity is based on assuming open-channel flow.

D.8 Tailpipe

To initiate adequately rapid priming, maintain full-bore siphonic flow, and reduce the likelihood of cavitation:

A. The diameter of the tailpipe is not greater than the diameter of the roof drain outlet.

B. Pipe increasers are used only in the horizontal portion of the tailpipe, not in the vertical portion; and that only eccentric (not concentric) increasers are used with the crown (top) of the pipes set flush and the maximum offset at the pipe invert.

C. Bends of 90° are used where transitioning from the vertical to the horizontal portion of the tailpipe (45-degree bends, or substantial slopes in the horizontal portion of the tailpipe, are not acceptable).

D.9 Downpipe (Stack)

At the top of the downpipe, either two (2) 45-degree bends, or a 90-degree bend with a minimum centerline bend radius equal to the pipe diameter, is used where the collector pipe connection is made.

If a reducer is used just after an elbow, an eccentric reducer is used with the pipes set flush at the outside radius of the elbow.

D.10 Critical Buckling Strength of Pipe (P_{crit})

All pipe sections used in siphonic systems must typically withstand a resultant (net) critical buckling pressure of at least three atmospheres based on all of the following conditions:

A. Standard atmospheric pressure at sea level

B. An assumed minimum out-of-roundness (maximum diameter - minimum diameter), or ovality, of one-half the pipe wall thickness

C. Buckling strength based on the creep modulus of elasticity (E_c)

D. Assumed operating temperatures from 40°F (4°C) to 90°F (32°C). Note: For piping that will be heat traced, the pipe temperature should be kept within these assumed operating temperatures.

That is: $P_{crit} \geq 3$ atm (44.1 psi [304.8 kPa]) when considering the conditions listed above.

Table D.10-1. Schedule 40 Pipe Dimensions and Geometric Properties

Schedule 40 (Standard Weight) Pipe									
Nominal Size		Wall Thickness (t)		Inside Diameter (D_I)		Mean Diameter (D_M)		t/D_M	$(t/D_M)^3$ x1000
(inch)	(mm)	(inch)	(mm)	(inch)	(mm)	(inch)	(mm)		
1.5	38	0.145	3.7	1.610	40.9	1.755	44.6	0.0826	0.5640
2	51	0.154	3.9	2.067	52.5	2.221	56.4	0.0693	0.3334
2.5	64	0.203	5.2	2.469	62.7	2.672	67.9	0.0760	0.4385
3	76	0.216	5.5	3.068	77.9	3.284	83.4	0.0658	0.2845
3.5	89	0.226	5.7	3.548	90.1	3.774	95.9	0.0599	0.2147
4	102	0.237	6.0	4.026	102.3	4.263	108.3	0.0556	0.1718
5	127	0.258	6.6	5.047	128.2	5.305	134.7	0.0486	0.1150
6	152	0.28	7.1	6.065	154.1	6.345	161.2	0.0441	0.0859
8	203	0.322	8.2	7.981	202.7	8.303	210.9	0.0388	0.0583
10	254	0.365	9.3	10.020	254.5	10.385	263.8	0.0351	0.0434
12	305	0.375	9.5	12.000	304.8	12.375	314.3	0.0303	0.0278
Nominal Size		Cross Sectional (Open) Area							
(inch)	(mm)	(in^2)	(ft^2)	(mm^2)	(m^2)				
1.5	38	2.03	0.0141	1313	0.0013				
2	51	3.35	0.0233	2164	0.0022				
2.5	64	4.79	0.0332	3087	0.0031				
3	76	7.39	0.0513	4767	0.0048				
3.5	89	9.88	0.0686	6375	0.0064				
4	102	12.72	0.0884	8209	0.0082				
5	127	20.00	0.1389	12900	0.0129				
6	152	28.88	0.2005	18629	0.0186				
8	203	50.00	0.3472	32259	0.0323				
10	254	78.81	0.5473	50848	0.0508				
12	305	113.04	.7850	72929	0.0729				

Table D.10-2. Standard Atmospheric Pressure at Various Elevations

Elevation Above Sea Level		*Pressure Head**		*Pressure*		
(ft)	(m)	(ft)	(m)	(psi)	(kPa)	(atm)
0	0	34.0	10.37	14.7	101.6	1.00
1500	457	32.2	9.82	14.0	96.2	0.95
3000	915	30.5	9.30	13.2	91.1	0.90
4500	1372	28.8	8.78	12.5	86.0	0.85
6000	1829	27.2	8.29	11.8	81.3	0.80
7500	2287	25.7	7.84	11.1	76.8	0.76
*Pressure head is feet (ft) or meter (m) of water column, with an assumed water density of 62.4 Lb/ft^3 (999.6 kg/m^3). Linear interpolation is appropriate.						

If P_{crit} is verified for a certain pipe material and size, a reasonable estimate can be made for a different pipe size (e.g., known values for Schedule 40 pipe, but checking a different but similar SI pipe size) of the same material. P_{crit} is a function of the cube of the ratio of wall thickness to mean diameter [$(t/D_M)^3$] for most pipe sections of concern (i.e., long sections of straight pipe) and therefore the ratio $(t/D_M)^3$ may be used as a factor to determine P_{crit}:

P_{crit} (2) = P_{crit} (1) x |P[$[(t/D_M)^3]_{(2)}$ / $[(t / D_M)^3]_{(1)}$|P]

See Table D.10-1 for values of $[(t / D_M)^3]$ for Schedule 40 pipe.

D.11 Expansion Joints

Expansion joints in siphonic drainage systems are more critical that those in gravity drainage systems due to siphonic system's pressure extremes.

The use of expansion joints in siphonic systems should be avoided since proper connection detailing and adequate long-term performance can be difficult to achieve. If the use of expansion joints cannot be avoided, the following best practices should be used:

A. Thermal expansion and contraction are based on temperature extremes associated with the local climate, building type, and location of building expansion joints; and

B. Expansion joints are rated, with a minimum safety factor not less than 3.0, for both the maximum and minimum siphonic piping operating pressures, and with a critical buckling strength no less than that required of the adjacent siphonic piping; and

C. The expansion joint and connections have smooth inner bores to prevent the accumulation of debris/sediment and to avoid cavitation.

D.12 Pipe Supports and Bracing for Plastic Pipe

Pipe supports and bracing are based on engineering analysis when accounting for all applicable conditions - including, gravity loads, deflections, material creep, siphonic pipe pressures, operational vibrations and fatigue, thermal expansion/contraction, and seismic loading.

For plastic pipe, more stringent pipe supports and bracing are typically needed, and generally should conform to the following minimum requirements:

A. Provide pipe supports every 4 ft (1.2 m) or less.

B. Provide pipe supports at every change in direction (e.g., at pipe elbows).

C. Provide lateral bracing at every 30 ft (9.1 m) or less.

D. Provide lateral bracing at every change in pipe direction.

APPENDIX E ILLUSTRATIVE EXAMPLES AND JOB AIDS

E.1 Snow Loading Illustrative Examples

The following examples illustrate the methods used to establish design snow loads for most of the roof configurations discussed in this data sheet.

Example 1: Determine the balanced and unbalanced design snow loads for a proposed building where the ground snow load is 30 psf (1.4 kN/m^2). It has galvanized steel, insulated panels on an unobstructed gable roof, sloped 8 on 12 (see Fig. E.1-1).

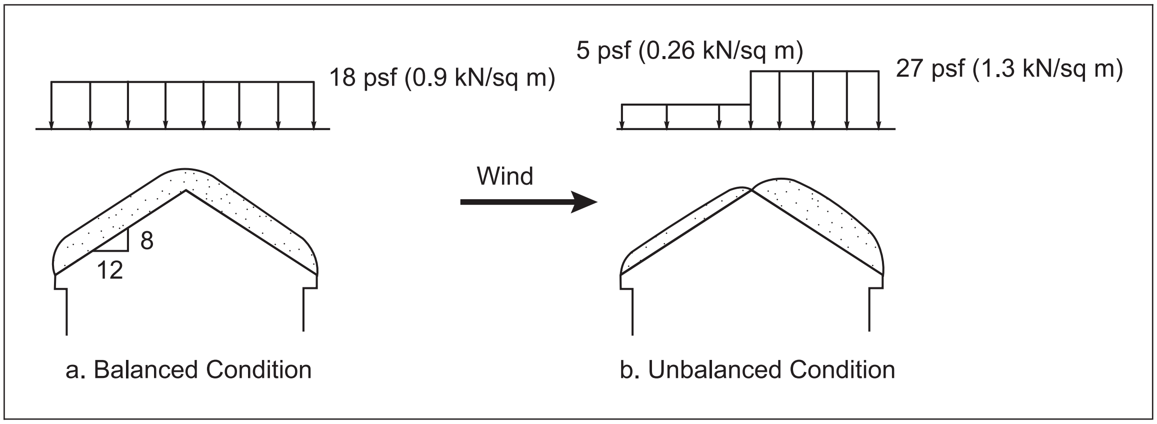


Fig. E.1-1. Design snow loads for Example 1

A. Ground snow load (P_g):

P_g = 30 psf (1.4 kN/m^2)

B. Flat-roof snow load (Section 2.4.3.1)

P_f = 0.9 P_g = 0.9 (30) = 27 psf (1.3 kN/m^2)

C. Sloped-roof (balanced) snow load (Section 2.4.4.1):

$P_s = C_s P_f$ = 0.66 (27) = 18 psf (0.9 kN/m^2)

D. Sloped-roof (unbalanced) snow load — leeward (Section 2.4.4.3):

1.5 P_s = 1.5 (18) = 27 psf (1.3 kN/m^2)

E. Sloped-roof (unbalanced) snow load – windward (Section 2.4.4.3)

0.3 P_s = 0.3 (18) = 5 psf (0.26 kN/m^2)

Example 2: Determine the roof snow load for a proposed curved roof building where the ground snow load is 30 psf (1.4 kN/M^2). The building has an 80 ft (24 m) clear span and 15 ft (4.6 m) rise, circular arc wood deckroof construction with insulation and built-up roofing (see Fig. E.1-2).

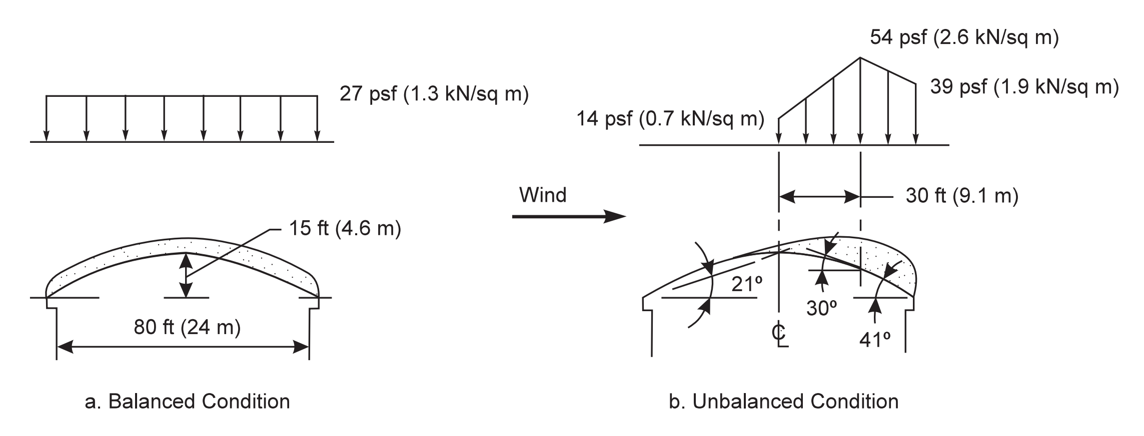


Fig. E.1-2. Design snow loads for Example 2

A. Ground snow load (P_g):

P_g = 30 psf (1.4 kN/m^2)

B. Flat roof snow load (Section 2.4.3.1):

P_f = 0.9 (30) = 27 psf (1.3 kN/m^2)

C. Vertical angle measured from eave to crown (see Fig. E.1-2):

$$\text{Tangent of vertical angle} = \frac{\text{rise}}{\text{½ span}} = \frac{15}{40} = 0.375$$

Vertical angle = 21°

D. Sloped-roof (balanced) snow load:

$P_s = C_s\ P_f$ = 1.0 (27) = 27 psf (1.3 kN/m^2)

where C_s = 1.0 (Table 2.4.4.1 for cold, other surface roof)

E. Unbalanced snow loads (Section 2.4.4.4):

Eave slope = 41° (see Fig. E.1-2)

The 30° point is 30 ft (9.1 m) from the centerline (see Fig. E.1-2).

Unbalanced load at crown w/slope of 30° (Fig. 2.4.4.4-1, Case I):

$0.5\ P_s = .5\ (27) = 14$ psf (0.6 kN/m^2)

Unbalanced load at 30° point (Fig. 2.4.4.4-1, Case II):

$2\ P_s = 2(27) = 54$ psf (2.6 kN/m^2)

Unbalanced load at eave (Fig. 2.4.4.4-1, Case II):

$$2\ P_s \left(1 - \frac{\text{eave slope} - 30°}{40°}\right)$$

$$2 \times 27 \left(1 - \frac{41° - 30°}{40°}\right) = 39 \text{ psf } (1.9 \text{ kN/m}^2)$$

Example 3: Determine the design snow loads for the upper and lower flat roofs for a proposed building to be located in an area where the ground snow load is 35 psf (1.7 kN/m^2). The elevation difference between the roofs is 10 ft (3 m). The upper roof is 200 ft (61 m) wide and the lower roof is 40 ft (12.2 m) wide (see Fig. E.1-3).

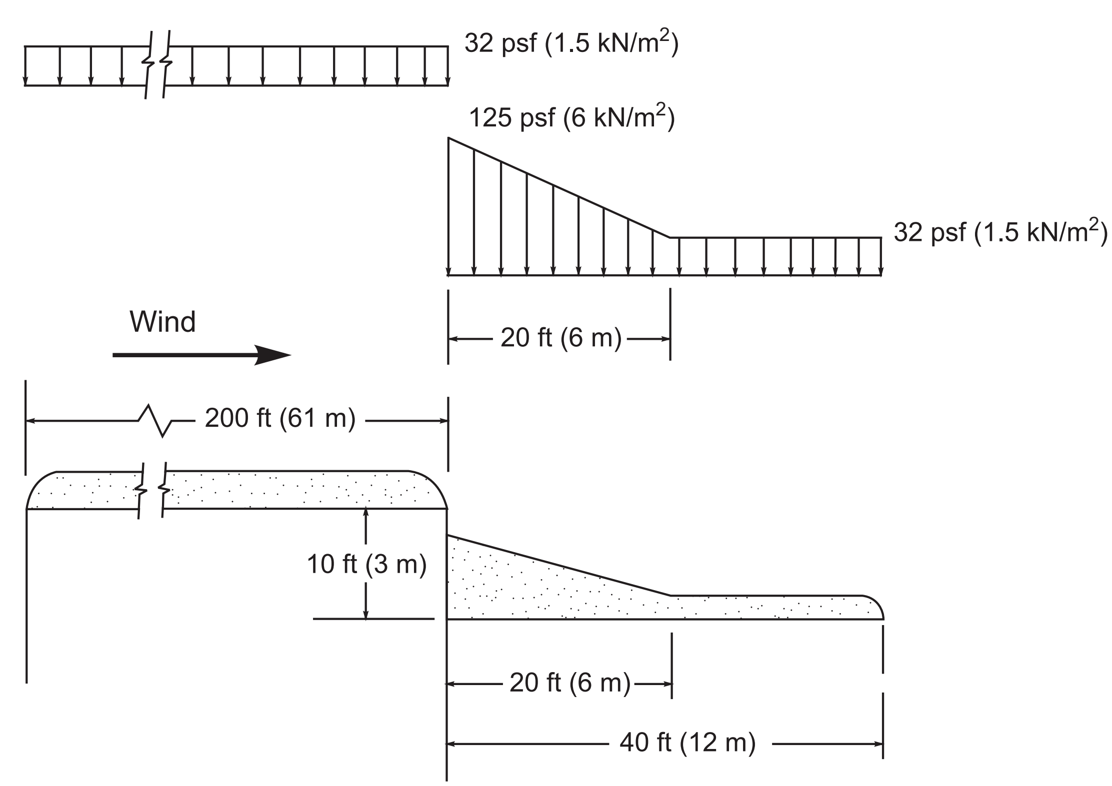


Fig. E.1-3. Design snow loads for Example 3 (Leeward Drifting)

A. Ground snow load (P_g):

$P_g = 35$ psf (1.7 kN/m^2)

B. Flat-roof (balanced) snow load for either roof (Section 2.4.3.1)

$P_f = 0.9\ (P_g) = 0.9\ (35) = 32$ psf (1.5 kN/m^2)

C. Maximum snow load at wall (lower roof) (Section 2.4.5.1):

Max. load at wall = $P_d + P_f \leq h_r \times D$

from Table 2.4.5.1, with P_g = 35 psf and W_b = 200 ft; D = 18.6 pcf and $P_d + P_f$ = 125 psf ≤ 10 × 18.6 = 186 psf

Max snow load (lower roof) = 125 psf (6 kN/m^2)

D. Leeward drift width (Section 2.4.5.1):

$W_d = 4\ h_d$ when $h_d \leq h_c$

from Table 2.4.5.1, with P_g = 35 psf and W_b = 200 ft;

h_d = 5.01 ft

W_d = 4 (5.01) = 20 ft (6.1 m)

E. See Figure E.1-3 for snow loads on both roofs.

Example 4: Determine the design snow loads for the upper and lower flat roofs of the proposed building in Example 3, if the upper roof is 40 ft (12 m) wide and the lower roof is 200 ft (61 m) wide (see Fig. E.1-4). (Note: This roof configuration forms the greatest snow drift by windblown snow across the lower roof (windward drifting) because the lower roof is much wider than the upper roof, see Section 2.4.5.1.[D])

A. Items a and b from Example 3 are applicable.

B. Maximum snow load at wall (lower roof) (Section 2.4.5.1.[D]):

Max. load at wall = ¾ (P_d) + P_f from Table 2.4.5.1, with P_g = 35 psf and W_b = 200 ft;

P_d = 93 psf, P_f = 32 psf

Max snow load (lower roof) = ¾ (93) + 32 = 102 psf (4.9 kN/m^2)

C. Drift width

W_d = ¾ ($4h_d$);

from Table 2.4.5.1, with P_g = 35 psf and W_b = 200 ft; h_d = 5.01 ft

W_d = ¾ (4×5.01) = 15 ft (4.6 m)

D. See Figure E.1-4 for snow loads on both roofs.

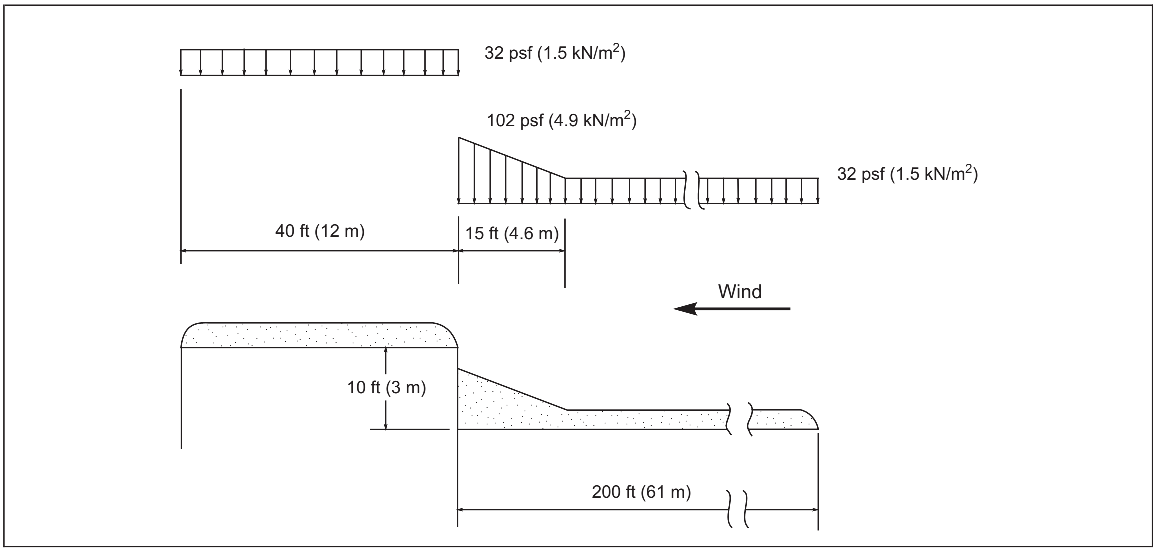


Fig. E.1-4. Design snow loads for Example 4 (Windward Drifting)

E.2 Roof Drainage and Rain Loading Illustrative Examples

The following examples illustrate the methods used to establish design rain loads and roof drainage for some of the roof drainage systems discussed in the data sheet.

These examples represent only the determination of roof rain loads. Other roof design loads, such as roof live load and snow load, also must be evaluated by the structural design engineer to establish the governing design roof load condition.

Example 5: A proposed building has a roof 168 ft (57 m) by 336 ft (102 m), with bay dimensions of 28 ft (9 m) by 28 ft (9 m). The roof has eight 8-in. (200-mm) primary roof drains, with a contributory area of 84 ft x 84 ft (26 m x 26 m) for each drain. The roof edge has a continuous cant 3-1/2 in. (88 mm) high, except a varying height parapet, 10-1/2 in. (267 mm) max where scuppers are shown. The 100-year 1-hour rainfall intensity (i) is 2.75 in./hr (70 mm/hr).

Check the size the primary roof drains and overflow provisions (using scuppers as appropriate), denoting the required hydraulic head at the primary drainage device (drains), and the total head at the overflow provisions (scuppers) and the design rain load to be used by the roof framing designer, when:

The roof is sloped 1/4 in 12 (2%) to the low-point line where roof drains are placed. Overflow drainage is provided by four 24-in. (610 mm) wide scuppers set 2.5 in. (64 mm) above the low-point line at the perimeter of the roof as shown in Figure E.2-1.

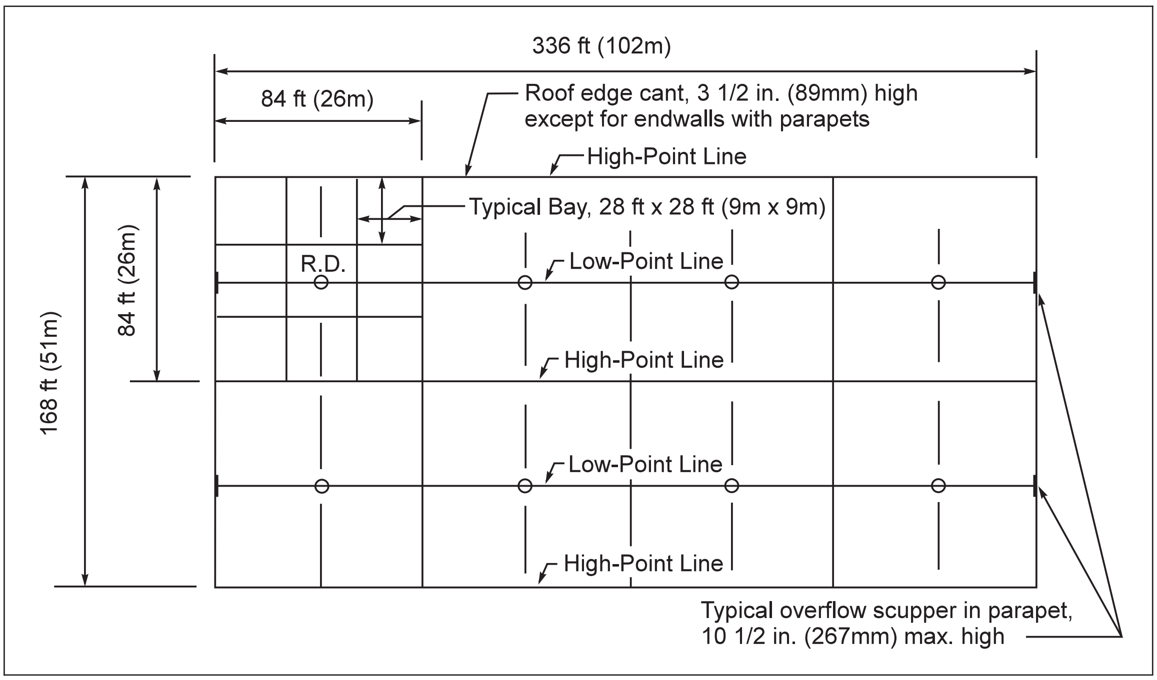


Fig. E.2-1 Sloped roof plan for Example 5

Sloped Roof with Scuppers: see Fig. E.2-1.

A. Items (a) through (d) from Solution (1) are applicable.

B. Minimum number of scuppers needed:

n = A/15,000 sf = 3.8, so 4 scuppers

C. Flow rate needed per overflow scupper (Section 2.5.4.1.[K]):

i = 5.5 in./hr (140 mm/hr)

Q = (0.0104 x i × A)/n = (0.0104 × 5.5 in./hr x 168 ft x 336 ft)/4

Q = 800 gpm (3028 L/min)

D. Overflow scupper size needed (Sections 2.5.4.1.[K]):

From Table 2.5.4.1-2, for a channel-type scupper with width [b] of 24-in. [610 mm], determine the hydraulic head (H) needed for a flow rate (Q) of 800 gpm (3025 L/min):

Q (gpm) = 2.9 x b x $H^{1.5}$ = 2.9 x 24 in. x $H^{1.5}$ = 800 gpm

Solve for H: H = 5.1 in. (130 mm)

According to Section 2.5.4.1.(H), the scupper height (h) should be at least 1 in. (25 mm) higher than the (estimated) water depth H. Therefore, the minimum height of the scupper opening (h) is:

h = 5.1 in. (130 mm) + 1.0 (25 mm) = 6.1 in. (155 mm)

E. Total head at scupper overflow provision (see Fig. 2.5.2.1-2) w/scupper invert set 2.5 in (64 mm) above roof surface:

Total head = hydraulic head (H) + height to scupper invert

Total head = 5.1 in. + 2.5 in. = 7.6 in. (190 mm) ≥ 6 in. (150 mm) minimum head at low points for sloped roofs. (Section 2.5.2.3).

F. Design rain load at low-point line (overflow scuppers) (Section 2.5.2.2):

Design rain load (max) = total head (max) × 5.2 ≥ 30 psf (1.5 kN/m^2)

Design rain load (max) = 7.6 in. x 5.2 psf/in. = 40 psf (1.9 kN/m^2)

G. Design the sloped roof to support a rain load of 40 psf (1.9 kN/m^2) at the low-point lines of the roof decreasing linearly to near zero at 30 ft (9.3 m) away from the drains at the low-point lines. Verify that the roof framing design has been checked for instability due to ponding based on this rain load.

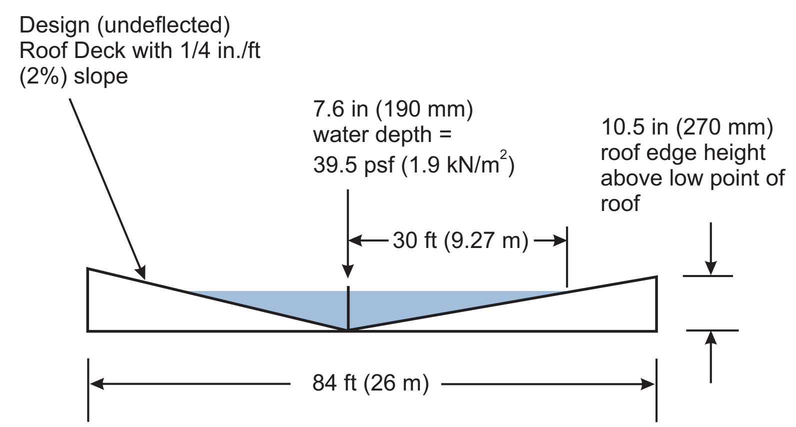


Fig. E.2-2 Sloped roof section for Example 5

Example 6: A proposed building has a roof area 150 ft (46 m) by 300 ft (91 m) with six 6-in. (150 mm) primary roofs drains and six 8-in. (250 mm) secondary (overflow) roof drains located at mid-bay. The overflow drains are placed adjacent to the primary drains with dam set 3 in. (75 mm) above the roof surface. The primary drains have drain bowl diameter of roughly 10.5 in. (270 mm) and the overflow drain dams have a dam diameter of roughly 12.75 in. (325 mm). The roof slopes a minimum of 1/4 in 12 (2%) as shown in Figure E.2-3. The 100-year, 1-hour rainfall intensity (i) is 4.0 in./hr (100 mm/hr).

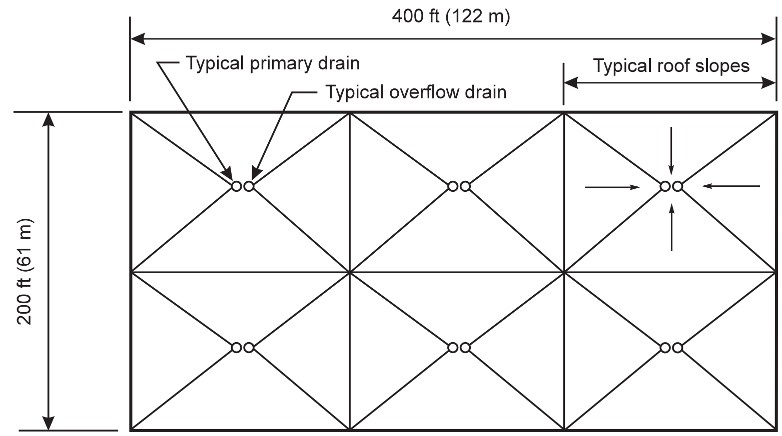


Fig. E.2-3. Roof plan for Example 6

For the given primary and overflow roof drains, determine the hydraulic head and total head, and the resulting design rain load to be used by the roof framing designer.

Primary Drains

A. Rainfall intensity

i = 4.0 in./hr (100 mm/hr)

B. Check minimum number of drains (n):

$n = A / 10{,}000\ ft^2 = 45{,}000\ ft^2/10{,}000\ ft^2 = 4.5$ drains

Therefore using 6 primary drains (and 6 secondary drains) is acceptable.

C. Flow rate needed per drain (primary):

$Q = (0.0104\ i \times A)/n = (0.0104 \times 4.0\ in./hr\ x\ 45{,}000\ ft^2)/6$

Q = 312 gpm (1180 L/min)

D. Check primary drains:

From Table 2.5.4.2-5, for the 6-inch primary drain with Q = 312 gpm (say 300 gpm)

Hydraulic Head = 4 in. (100 mm)

Secondary Drains

A. Rainfall intensity:

i = 8.0 in./hr (200 mm/hr)

B. Check minimum number of secondary drains (n):

$n = A / 10{,}000\ ft^2 = 45{,}000\ ft^2/10{,}000\ ft^2 = 4.5$ drains

Therefore using 6 secondary drains is acceptable.

C. Flow rate needed per drain (secondary):

$Q = (0.0104\ i \times A)/n = (0.0104 \times 8.0\ in./hr\ x\ 45{,}000\ ft^2)/6$

Q = 625 gpm (2380 L/min)

D. Check secondary drains:

From Table 2.5.4.1-7, for the 8-in. secondary drain (and 12.75 in. dam) with Q = 625 gpm,

Hydraulic Head = 3.5 in.

Total Head = 3.5 in. + 3 in. (dam height) = 6.5 in. (165 mm)

E. Determine the design rain load to be used for the roof framing:

The design depth of rainwater is based on the assumption that the secondary drainage system is flowing and the primary drains are completely blocked. Therefore, use 6.5 in. (165 mm) as the minimum design head at the low points of the sloped roof.

Design rain load at roof low points = 6.5 in. x 5.2 psf/in. = 33.8 psf (1.6 kN/m^2). For the roof slope of 1/4 in 12 (2%), at 26 ft (7.9 m) from the drains the rain load will be near zero. Verify that the roof framing design has been checked for instability due to ponding based on this rain load.

E.3 Snow Loads on Roofs with Solar Panels

Example 7. Snow load on Roofs with Tilted Solar Panels

For the roof with solar panels are shown in Figures E.3-1 and E.3-2, determine the snow loads.

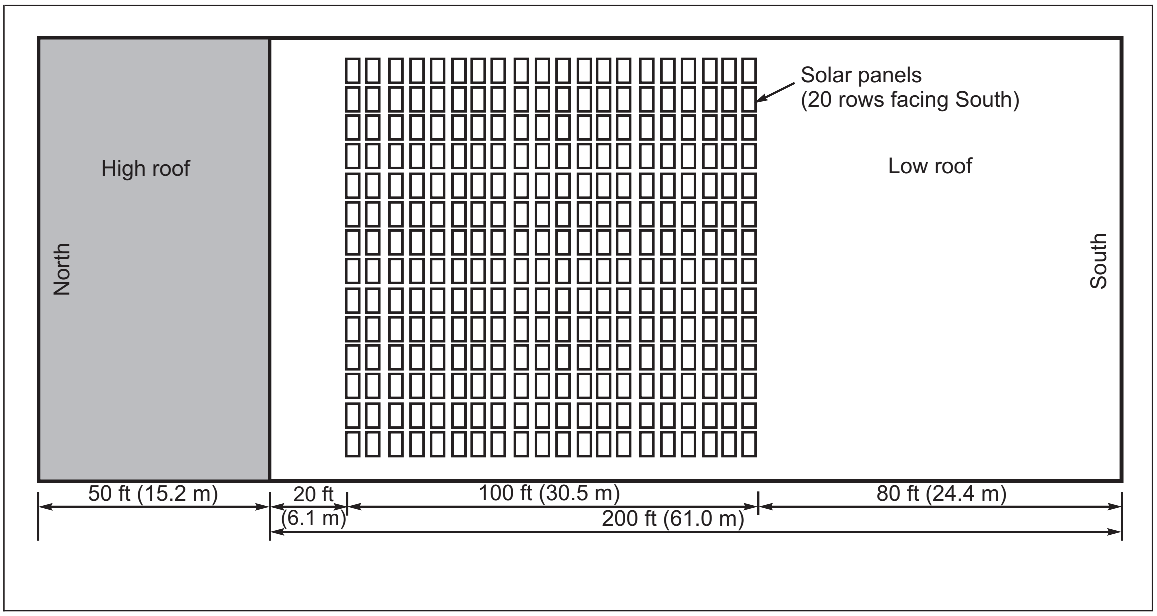


Fig. E.3-1 Plan View of Roof with solar panels

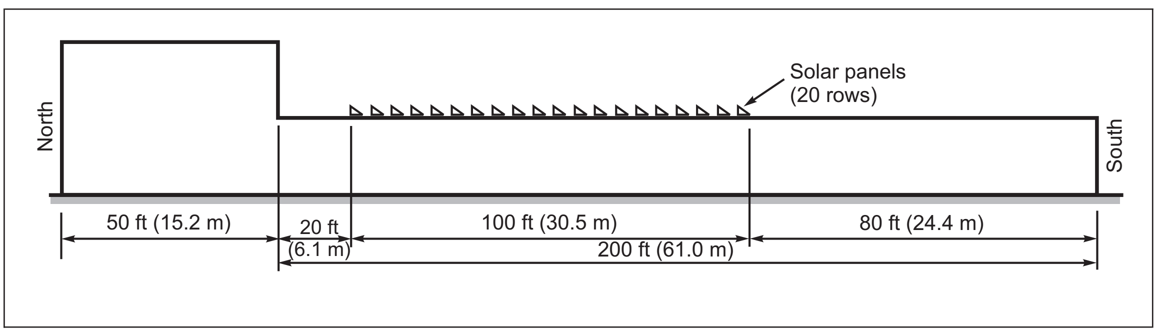


Fig. E.3-2 Elevation view of roof with solar panels

Given:

50-year ground snow load: Pg = 20 psf (0.96 kPa)
Roof slope = 2.1% (¼ in 12)
Roof and solar panel layout as shown
Solar panels are closed back and placed every 5 ft (1.5 m)
Aisle width W_a = 1.5 ft (0.46 m)
Row width W_r = 3.5 ft (1.07 m)
Solar panel height: hr = 2.2 ft (0.67 m)
Solar panel slope = 30°

From Table 2.4.3.1:

Snow density D = 16.6 pcf (2.6 kN/m^3)
Flat roof snow load $P_f = P_g$ = 20 psf (0.96 kPa)
h_b = 1.2 ft (0.37 m)
$h_c = h_r - h_b$ = 2.2 ft (0.67 m) - 1.2 ft (0.37 m) = 1.0 ft (0.30 m)

A. Assume solar panels are not in place.

Balanced + drifting snow load on the low roof at the roof step:

1. Leeward drift (wind blowing from North to South)

   W_b = 50 ft (15.2 m)
   From Section 2.4.5.1 and Table 2.4.5.1:
   h_d = 2.2 ft (0.67 m)
   $W_d = 4\ h_d$ = 8.8 ft (2.7 m)
   P_d = 37 psf (1.8 kPa)

   $P_f + P_d$ = 20 psf (0.96 kPa) + 37 psf (1.8 kPa) = 57 psf (2.8 kPa)

2. Windward (wind blowing from South to North)

   W_b = 200 ft (61.0 m)
   From Section 2.4.5.1 and Table 2.4.5.1:
   h_d = 4.4 ft (1.34 m)
   From Section 2.3.12.4:
   0.75 h_d = 3.3 ft (1.0 m)
   W_d = 4(3.3 ft) = 13.2 ft (4.0 m)
   P_d = 16.6 pcf x 3.3 ft = 55 psf (2.6 kPa)
   $P_f + P_d$ = 20 + 55 = 75 psf (3.6 kPa)

   Windward drifting governs for design snow loads since both the total load (drift + balanced) and drift width are greater than the leeward drifting condition.

B. Drifting snow with solar panels in place

Check significant height:

   Significant height = 1.2 h_b = 1.2 (1.2 ft) = 1.44 ft (0.44 m)
   Solar panel height hr = 2.2 ft (0.67 m) ≥ 1.44 ft (0.44 m)
   Since hr ≥ 1.2h_b, the height is significant.

Check solar panel spacing:

   8h_c = 8(1.0 ft) = 8.0 ft (2.4 m)
   Solar panel aisle space W_a = 1.5 ft (0.46 m) ≤ 8.0 ft (2.4 m)
   Since W_a ≤ 8hc, the solar panels are "closely spaced".

Since the solar panel height is significant, and the rows are closely spaced, inter-row drifting will occur and will affect drifting at the roof step.

1. Wind blowing from South to North

   Upwind fetch W_b = 80 ft (24.4 m)
   h_d = 2.8 ft (0.85 m) from Section 2.4.5.1

a. Windward drift at southern most row (Row 20)

$h_{d1} = h_d/2 = 1.4$ ft (0.43 m), but $h_{d1} \leq h_c$

Therefore:

$h_{d1} = h_c = 1.0$ ft (0.30 m)
$W_{d1} = 4h_{d1} = 4$ (1.0 ft) = 4.0 ft (1.22 m)
$P_{d1} = 16.6$ pcf x 1.0 ft = 17 psf (0.81 kPa)
$P_f + P_{d1} = 20$ psf + 17 psf = 37 psf (1.8 kPa)

Recall $W_r = 3.5$ ft (1.07 m)

Drift Area $A_{d1} = (½)(h_{d1})(W_{d1}) + (½)(h_{d1})(W_r) =$
(½)(1.0 ft)(4.0 ft) + (½)(1.0 ft)(3.5 ft) = 2.0 + 1.75 = 3.75 ft^2

Or

(½)(0.30 m)(1.22 m) + (½)(0.30 m)(1.07 m) = 0.18 + 0.16 = 0.35 m^2

b. Leeward drift at all 20 rows

$h_{d2} = 2(h_d)$ $2/W_a$ = 2(2.8) 2/1.5 ft = 10.5 ft (3.2 m), but $h_{d2} \leq h_c = 1.0$ ft (0.30 m)

Therefore:

$h_{d2} = h_c = 1.0$ ft (0.30 m)
$W_{d2} = W_a = 1.5$ ft (0.46 m)
$P_{d2} = 16.6$ pcf x 1.0 ft = 17 psf (0.81 kPa)
$P_f + P_{d2} = 20$ psf + 17 psf = 37 psf (1.8 kPa)

Drift Area A_{d2} = Uniform drift at aisle = $(h_{d2})(W_{d2})$ = (1.0 ft)(1.5 ft) = 1.5 ft^2 (0.14 m^2)

c. Total Drift Area

Total Drift Area $A_{dt} = 6(hd)^2 = 6(2.8\text{ ft})^2 = 47.0$ ft^2 (4.37 m^2)

d. Rows with Inter-row Drifting

The number of rows (N) with inter-row drifting:

$N = (A_{dt} - A_{d1})/A_{d2}$ = (47.0 - 3.75)/1.5 = 28.8 rows > 20 rows

Or

$N = (A_{dt} - A_{d1})/A_{d2}$ = (4.37 - 0.35)/0.14 = 28.8 rows > 20 rows

Therefore, all rows have leeward inter-row drift, but the total drift is not consumed by inter-row drifting.

e. Windward Drifting at Roof Step

Since the total drift areas is not consumed by inter-row drifting, use the remaining inter-row drift area surplus ($A_{dt} - A_{d1} - NA_{d2}$) to create a windward drift load on the low roof at the roof step by adding it to the windward drift from the 20 ft (6.1 m) open roof area windward of the roof step.

Inter-row drift area surplus = $A_{dt} - A_{d1} - NA_{d2}$ = 47.0 - 3.75 - (20) 1.5 = 13.3 ft^2

Or

$A_{dt} - A_{d1} - NA_{d2}$ = 4.37 - 0.35 - (20) 0.14 = 1.22 m^2

$W_b = 20$ ft (6.1 m)
From Section 2.4.5.1: $h_d = 1.2$ ft (0.37 m)
From Section 2.4.5.1.(D): $0.75h_d = 0.9$ ft (0.27 m),
Wd = 4(0.9 ft [0.27 m]) = 3.6 ft (1.1 m)
Windward drift area = (½)(0.9 ft[0.27 m])(3.6 ft[1.1 m]) = 1.6 ft2 (0.15 m^2)

Total windward drift area = 13.3 ft^2 (1.22 m^2) + 1.6 ft^2 (0.15 m^2) = 14.9 ft^2 (1.37 m^2)

For unrestricted drifts ($h_d < h_c$), the assumed drift slope is 25% (1 in 4), as shown in Figure E.3-3.

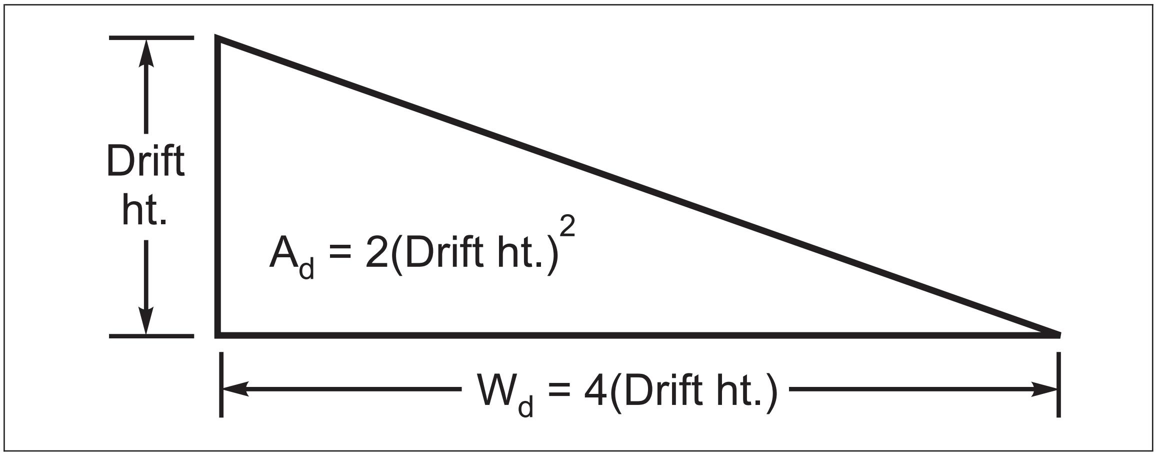


Fig. E.3-3 Unrestricted drift

Drift area = 2(Drift ht.)^2 = 14.9 ft^2 (1.37 m^2)
Solve for Drift ht:
Drift ht = ((14.9 ft^2)/2)$^{0.5}$ = 2.7 ft (0.82 m)

Drift width = 4(2.7 ft [0.82 m]) = 10.8 ft (3.3 m)
P_d = 16.6 pcf (2.6 kN/m^3) x 2.7 ft (0.82 m) = 45 psf (2.15 kPa)
P_f + P_d = 20 psf (0.96 kPa) + 45 psf (2.15 kPa) = 65 psf (3.1 kPa)

2. Wind blowing from North to South

Upwind fetch W_b = 20 ft (6.1 m) + 0.75(50 ft [15.2 m]) = 57.5 ft (17.4 m) h_d = 2.3 ft (0.70 m) from Section 2.4.5.1

a. Windward drift at Row 1

h_{d1} = 0.75h_d = 0.75(2.3 ft [0.70 m]) = 1.7 ft (0.52 m), but $h_{d1} \leq h_c$

Therefore, drift height is “restricted”

W_{d1} = 4(h_{d1})2/h_c = 4(1.7 ft)^2/(1.0 ft) = 11.6 ft (3.5 m), but $W_{d1} \leq 8h_c$

Therefore, use:

W_{d1} = 8h_c = 8(1.0 ft) = 8.0 ft (2.4 m)
h_{d1} = h_c = 1.0 ft (0.3 m)
P_{d1} = (h_c)(D) = (1.0 ft)(16.6 pcf) = 17 psf (0.81 kPa)
P_f + P_{d1} = 20 psf + 17 psf = 37 psf (1.8 kPa)

Cross-sectional area of the windward drift:
A_{d1} =(½)(h_{d1})(W_{d1}) = (½)(1.0 ft)(8.0 ft)= 4.0 ft^2 (0.37 m^2)

b. Leeward drift

h_{d2} = 2(h_d)2/W_a = 2(2.3 ft)^2/1.5 ft = 7.1 ft, but $h_{d2} \leq h_c$ = 1.0 ft (0.30 m)

Therefore, h_{d2} = h_c = 1.0 ft (0.30 m)

W_{d2} = W_a = 1.5 ft (0.46 m)
P_{d2} = 16.6 pcf x 1.0 ft = 17 psf (0.81 kPa)
P_f + P_{d2} = 20 psf + 17 psf = 37 psf (1.8 kPa)

Cross-sectional area of the leeward drift:
A_{d2} = (h_{d2})(W_a)+ ½(h_{d2})(W_r) = (1.0)(1.5)+ ½(1.0)(3.5) = 3.25 ft^2 (0.3 m^2)

c. Total Drift Area

Total Drift Area Adt = 6(h_d)^2 = 6(2.3 ft)^2 = 31.7 ft^2 (2.9 m^2)

d. Rows with Inter-Row Drifting
The number of rows (N) with inter-row drifting:

$N = (A_{dt} - A_{d1})/A_{d2} = (31.7 - 4.0)/3.25 = 8.5$ rows, use 9 rows

Therefore, only 9 rows (Rows 1 through 9) have leeward drift when the wind is blowing North to South.

C. Sliding Snow

The slope of the solar panels is 30° as shown in Figure E.3-4

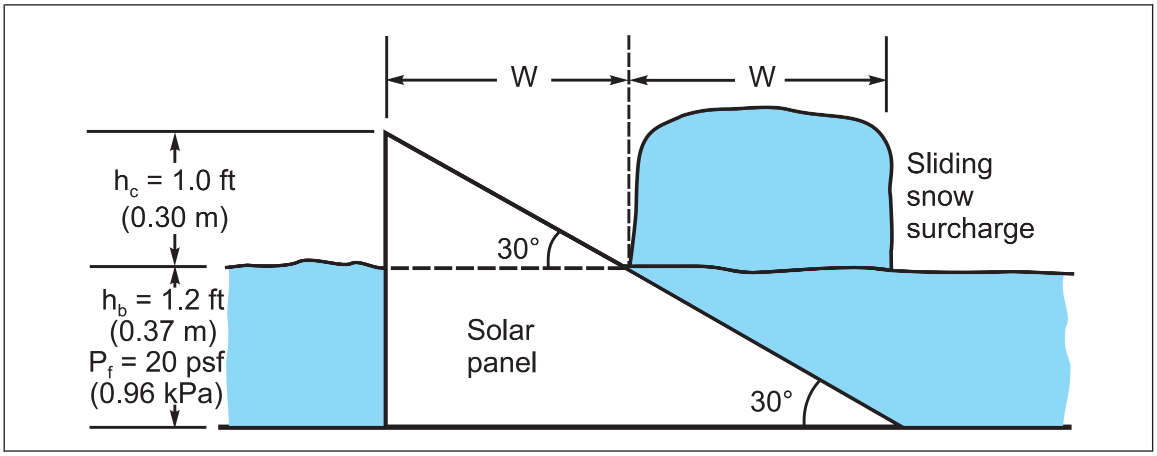


Fig. E.3-4 Sliding snow surcharge load at tilted solar panel

The projected solar panel width (above hb) is: $W = h_c/(\tan 30°) = 1$ ft $/(0.577) = 1.7$ ft (0.52 m)

Since all three criteria are met (significant height [$h_r \geq 1.2h_b$], W > 6 in. (0.15 m), and slope > 1.2°), use sliding snow surcharge.

Sliding snow surcharge = P_f = 20 psf (0.96 kPa)

Total snow load = $2P_f$ = 40 psf (1.9 kPa)

D. Summary

1. With the solar panels not in place:

   The maximum drift at the roof step is a windward drift and maximum total snow load (balanced + drift) on the roof is 75 psf (4.0 kPa).

2. Drifting snow with solar panels in place:

   The maximum total snow load (balanced + inter-row drift) on the roof at the solar panel array is 37 psf (1.8 kPa) for both windward and leeward drifting.

   With the wind blowing from North to South, the inter-row leeward drift occurs at only 9 of the 20 rows of solar panels (Rows 1-9).

   With the wind blowing from South to North, the inter-row leeward drift occurs at all 20 rows of solar panels; and the concurrent windward drift at the roof step results in a maximum total snow load (balanced + drift) on the roof of 65 psf (3.1 kPa).

3. Sliding snow with solar panels in place:

   The maximum total snow load (balanced + inter-row sliding) on the roof at the solar panel array is 40 psf (1.9 kPa).

4. Maximum snow load on face of solar panels:

   The maximum snow load on the face of the solar panels is 40 psf (1.9 kPa) due to balanced snow load plus inter-row sliding snow load.