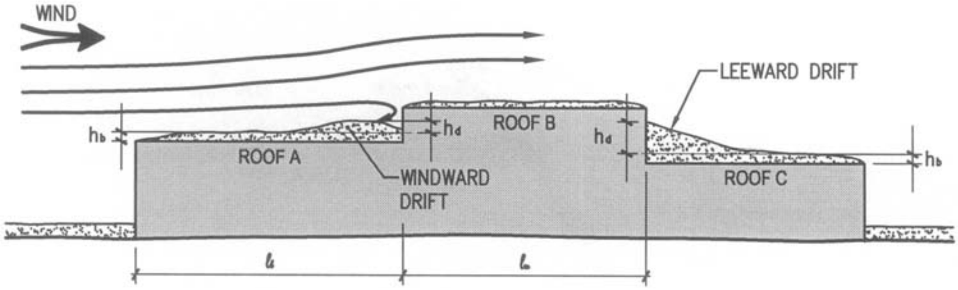

Figure VII-1 Windward and Leeward Snow Drifts

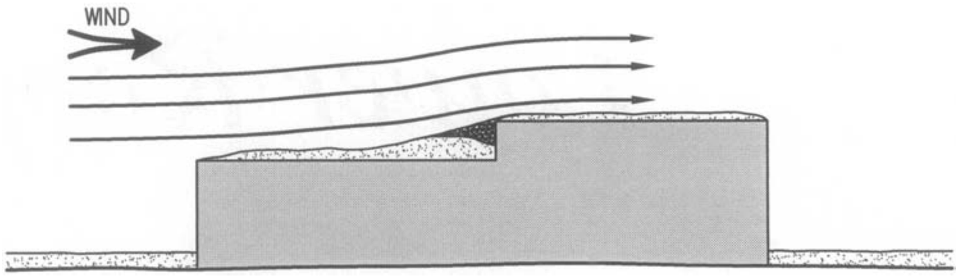

Figure VII-2 Windward Drift Morphing from Quadrilateral to Triangular Shape

Hence, if the windward roof step is easily filled, then both upper and lower upwind roofs serve as the source area for the leeward drift. In such cases, it is conservative to use the sum of the upwind roof lengths as the leeward drift fetch. A more exact approach for roofs with two potential upwind snow sources is presented in Chapter 12.

7.1 Leeward Drift

The roof step relations are empirical, as they are based on an analysis of case histories. For example, the leeward relation is based on an analysis of approximately 350 nominally triangular drifts from insurance company files and other sources (O'Rourke et al. 1985, 1986). Multiple regression analyses suggested the following relationship between the surcharge drift height, h_d, defined as the drift height above the balanced snow, the upwind fetch, ℓ_u, and the observed ground snow load, p'_g, for leeward drifts.

$$h_d = 0.61\sqrt[3]{\ell_u}\sqrt[4]{p'_g + 10} - 2.2 \quad \textbf{(Eq. VII-1)}$$

The relative accuracy of the relation in **Eq. (VII-1)** is shown in **Figure VII-3** wherein observed surcharge heights are plotted versus the predicted drift surcharge height by the regression equation. Note that most of the observed data points fall within a factor of two of the predicted value.

The ground snow load, p'_g, in **Eq. (VII-1)** is the observed case history value, not the 50-yr mean recurrence interval (MRI) value for the site. The

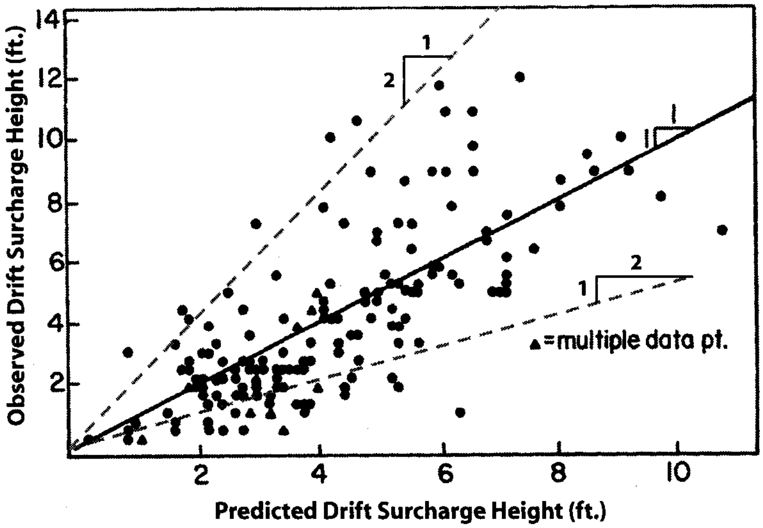

Figure VII-3 Observed Drift Surcharge Height versus Predicted Drift Surcharge Height, per Eq. (VII-1)

Source: O'Rourke et al. 1986.

observed ground snow load is actually less than half the 50-yr value for a majority of the case histories. Although the observed ground snow load was typically less than the 50-yr MRI, the case history database arguably represented appropriate design drifts because more than 40% of the case histories involved structural failure of one kind or another. However, the ASCE 7 Snow Task Committee wanted an equation that used the 50-yr ground snow load because the 50-yr value is already being used in ASCE 7. To utilize the 50-yr value for p_g and to predict reasonable drift heights that were close to those observed in the case histories, the whole relation in **Eq. (VII-1)** was multiplied by a modification factor, α, which is less than one. Hence, the relation for the surcharge drift height became

$$h_d = \alpha\left[0.61\sqrt[3]{\ell_u}\sqrt[4]{p_g+10}-2.2\right] \qquad \textbf{(Eq. VII-2)}$$

where p_g is the 50-yr ground snow load for the site per ASCE 7.

Table VII-1 shows the effect of various values for the modification factor, α. For a modification factor of 0.5, 55% of the observed drifts were larger than the values predicted by **Eq. (VII-2).** On the other hand, for a modification factor of 0.9, only 21% of the observed drift exceeded the predicted values from **Eq. (VII-2).** Based on engineering judgment, the ASCE 7 Snow Task Committee chose a modification factor of 0.7. As such, the predicted drift exceeded the observed drift for about two-thirds of the case histories. Using a reduction factor of 0.7, the relation for the surcharge drift height becomes

$$h_d = 0.43\sqrt[3]{\ell_u}\sqrt[4]{p_g+10}-1.5 \qquad \textbf{(Eq. VII-3)}$$

Table VII-1 Effect of Modifying Factor on Eq. (VII-2)

Modifying Factor α	*Percentage of Case Histories with Observed Drift > Predicted Drift*
1.0	17
0.9	21
0.8	28
0.7	32
0.6	41
0.5	55

where p_g is the 50-yr ground snow load for the site of interest.

Figure 7-9 in ASCE 7-02 is a plot of **Eq. (VII-3).** The width of the drift is prescribed to be four times the surcharge height (i.e., $w = 4\ h_d$) as long as the drift does not become "full." The assumed rise-to-run of 1:4 is based on an analysis of 101 case histories for which both the surcharge drift height and the width of the drift were available. **Figure VII-4** shows a scattergram of the drift height versus drift width data. Considering all the data points, the slope of the regression line is 0.227 (a rise-to-run of 1:4.4). However, when the "full" drifts (drifts that have a total height within 6 in. of the roof elevation) and non-full drifts are separated, the full drifts had a rise-to-run of about 1:5 and the non-full drifts had a slope of about 1:4. This suggests that the drifts initially form with a rise-to-run of about 1:4, and when the drift becomes full, additional snow accumulates at the toe of the drift, resulting in a flatter slope. Hence, as prescribed in Section 7.7.1, if the drift is full (i.e., $h_d = h_c$, where h_c is the space above the balanced snow available for drift formation), then the drift width, w, becomes $4\ h_d^2 / h_c$ with a maximum of $8\ h_c$. The full-drift relation for w was determined by equating the cross-sectional area of a height limited triangular drift (i.e., $0.5\ h_c w$) to the cross-sectional area of a height unlimited drift with the same upwind fetch and ground load (i.e., $0.5\ h_d(4\ h_d)$). The upper limit of $8\ h_c$ for the width of a full drift is based on the concept of an aerodynamically streamlined drift (rise-to-run of approximately 1:8) for which significant additional accumulation is not expected.

Eq. (VII-3) provides the surcharge height of the design drift for leeward wind. To convert height to an equivalent snow load, the density or unit weight of the snow is required. ASCE 7-02 uses the following relationship for the unit weight of snow, γ, in pounds per cubic foot (pcf):

$$\gamma = 0.13 p_g + 14 \leq 30 \text{ pcf} \qquad \text{(Eq. 7-4)}$$

where the ground snow load, p_g, has units of pounds per square foot (psf). This relation was originally developed by Speck (1984). Eq. (7-4) illustrates

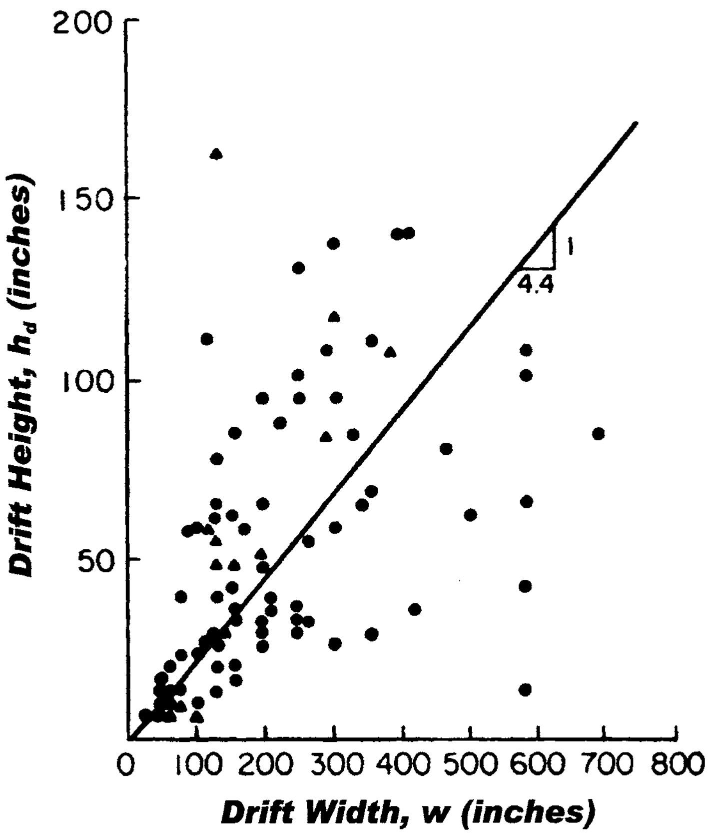

Figure VII-4 Surcharge Drift Height versus Drift Width
Source: O'Rourke et al. 1985.

that the snow density is an increasing function of snow depth. **Figure VII-5** is a plot of snowpack density (pcf) versus snowpack depth (inches) as predicted by the ASCE 7-02 relation (Eq. (7-4)). Due to an upper limit of 30 pcf, the density is constant for depths greater than 49 in. or ground loads greater than 123 psf. At shallower snow depths, the formula yields roughly a 1-pcf increase in density for every 4 in. or so of additional depth.

Figure VII-6 is a plot of snow load (psf) versus snow depth (inches). It includes a density relation from Tabler (1994) for snow before the onset of melt. Notice that these two independently developed unit weight relations provide remarkably similar snow loads for snow depths less than 4 ft. Also, both curves (ASCE 7-02 and Tabler) are convex (i.e., the density or unit weight is an increasing function of depth). This increase is due, at least in part, to self-compaction due to the weight of the overburden snow.

The Tobiasson and Greatorex (1996) relation between 50-yr load and 50-yr depth from **Eq. (II-1)** and **Figure II-1** is shown as a dashed line in **Figure VII-6.** The Tobiasson and Greatorex relation suggests lower loads for the same depth of snow. The differences are due in large part to the nature of the two sets of relations. The ASCE 7-02 and Tabler relations are based on simultaneous measurements of load and depth. On the other hand, the

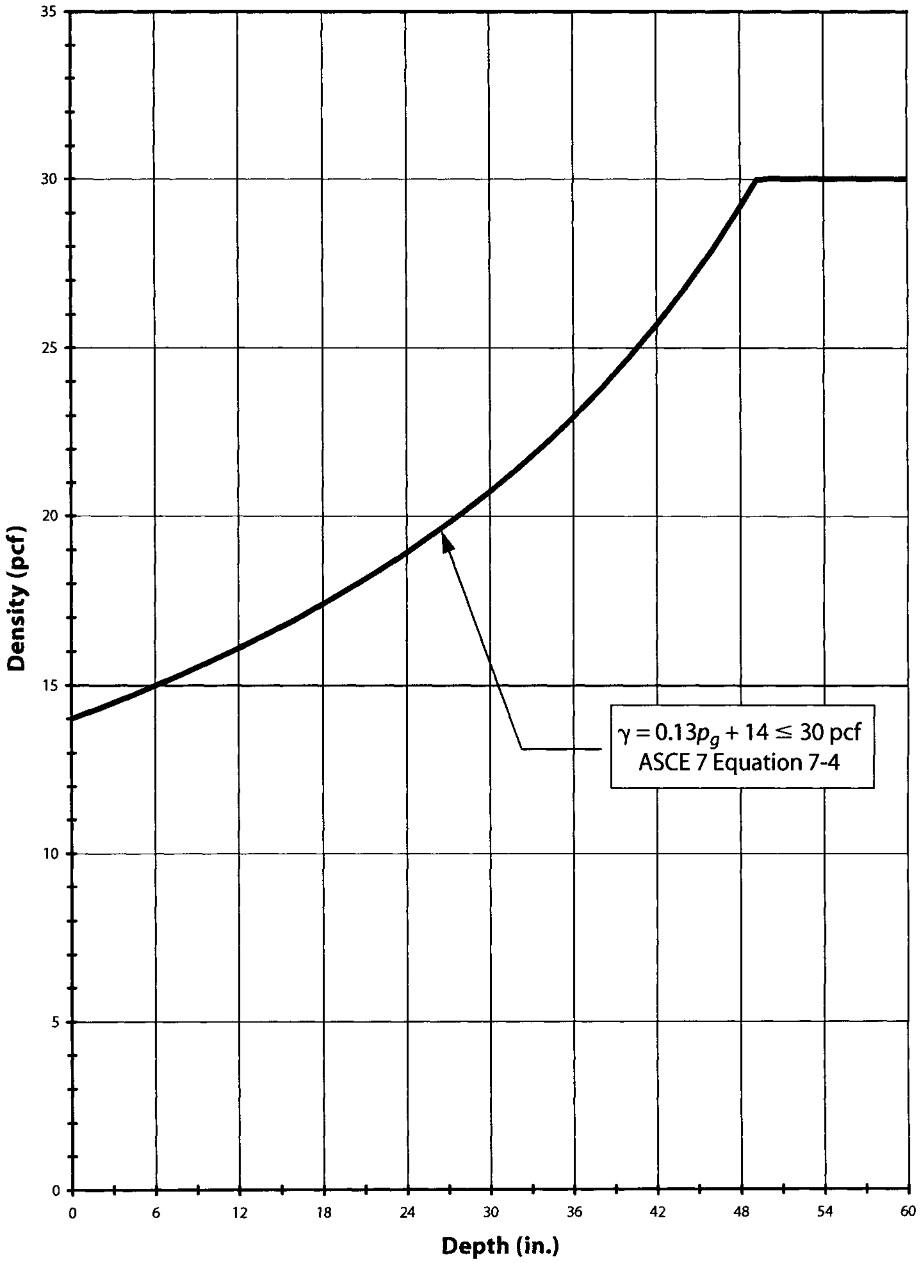

Figure VII-5 Snowpack Density versus Snowpack Depth, per Eq. (7-4)

Tobiasson and Greatorex formula relates a maximum annual snow depth to a maximum annual snow load (50-yr ground snow depth to 50-yr ground snow load). For a common scenario when the maximum depth occurs earlier in the winter than the maximum load, the Tobiasson and Greatorex conversion density for this maximum depth would be less than the actual density when the load reached maximum.

Although the two sets of density relations provide different answers, both are arguably appropriate for their intended purposes. ASCE 7-02 (Eq. (7-4)) and Tabler convert a snow depth at a point in time into a snow load

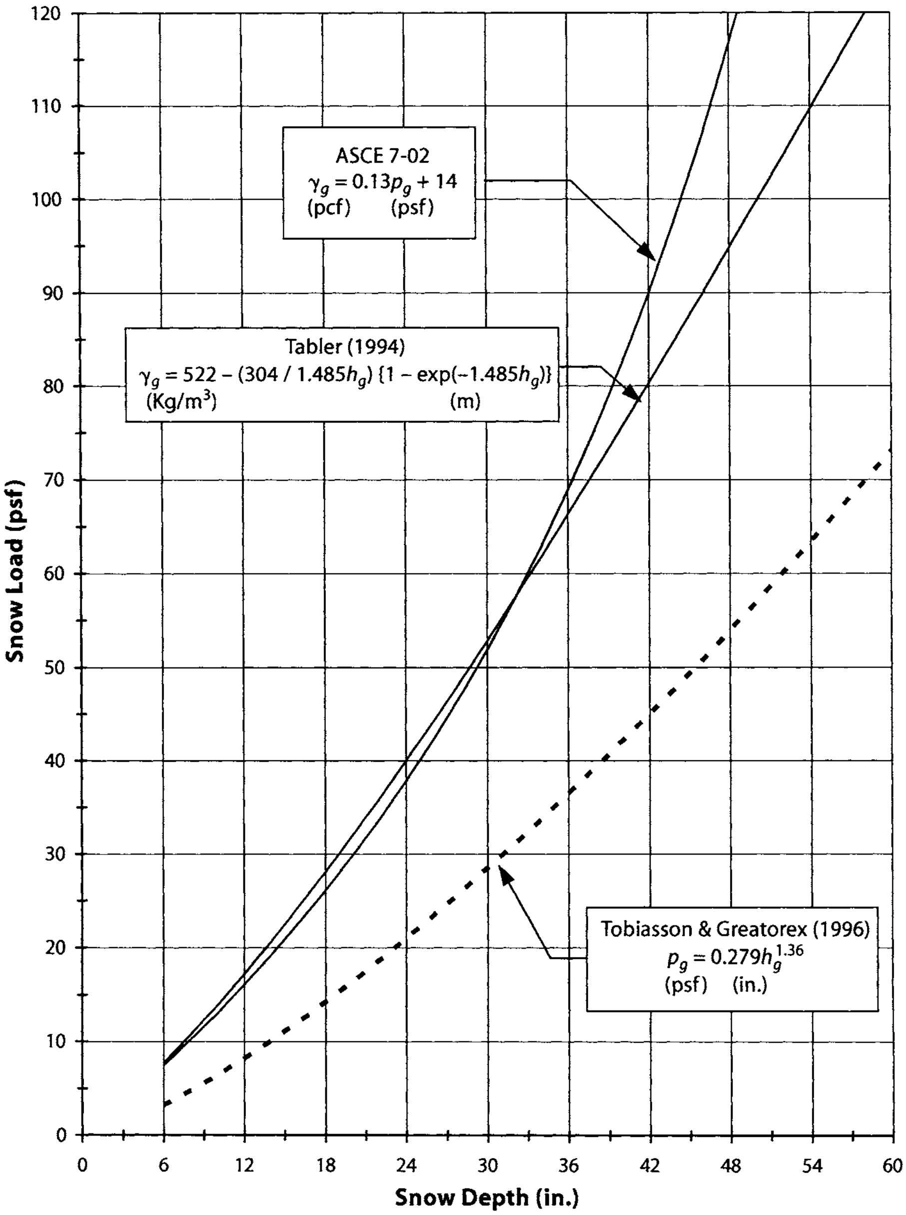

Figure VII-6 Snow Load versus Snow Depth

at the same point in time. Tobiasson and Greatorex (**Eq. (II-1)**) relate a 50-yr snow depth at a point in time to a 50-yr snow load, possibly at another point in time.

Eqs. (VII-1) through **(VII-3)** indicate that the drift size is an increasing function of both the ground snow load and the upwind fetch. In other words, the bigger the snow source, the bigger the drift. However, the increase is not linear. For example, doubling either the upwind fetch or the ground snow load results in less than a doubling of the drift size. This is illustrated in **Figure VII-7,** which is a plot of the ratio of the cross-sectional area of the drift to the upwind snow source area versus the 50-yr ground snow load where the drift area is

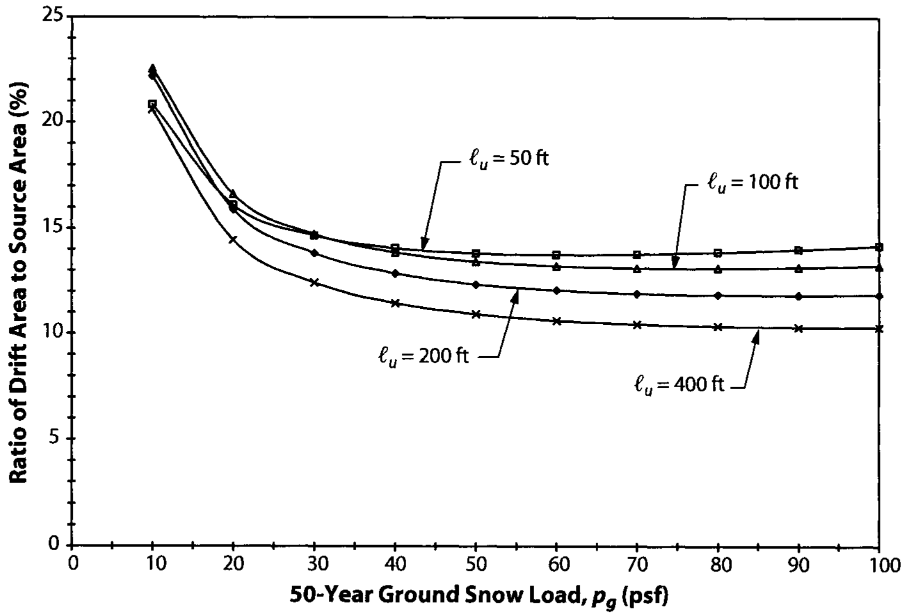

Figure VII-7 Ratio of Drift Area to Source Area versus 50-yr Ground Snow Load

$$\text{Drift Area} = \tfrac{1}{2} h_d w = 2\, h_d^2 \qquad \textbf{(Eq. VII-4)}$$

and the upwind snow source area is

$$\text{Source Area} = \ell_u \frac{p_g}{\gamma} = \frac{\ell_u p_g}{0.13 p_g + 14} \qquad \textbf{(Eq. VII-5)}$$

As shown in **Figure VII-7,** the "design" leeward drift is 10% to 25% of the "design" snow source area. The percentage is a decreasing function of the ground snow load, p_g, and the upwind fetch, ℓ_u, although less so for ℓ_u. Both of these trends are sensible. If the upwind fetch is small or the snowpack depth is shallow, then a typical wind event could easily remove or transport almost all of the snow from the small source area. Hence, it is likely that a significant fraction of a small snow source area could end up in the drift. Conversely, for larger fetch areas and/or deep snowpacks, a smaller percentage of snow is transported. Note that the range of percentages (10% to 25%) in **Figure VII-7** is based on the 50-yr ground snow load, as are those in ASCE 7-02 (see **Eq. (VII-3)** and Figure 7-9). When the ratio of drift area to source area is compared with observed ground snow loads from case studies (**Eq. (VII-1)**) instead of the 50-yr load, the percentages double to roughly 20% to 50%. This occurs because the 0.7 modification factor used in ASCE 7-02 is applied to both the surcharge height, h_d, and the width ($w = 4h_d$) for a given source area. In other words, 20% and 50% of the upwind snow source typically ended up in the case history drifts, while for our code relations, in which the snow is characterized by the 50-yr value, the "design" drift is about 10% to 25% of the "design" upwind source area.

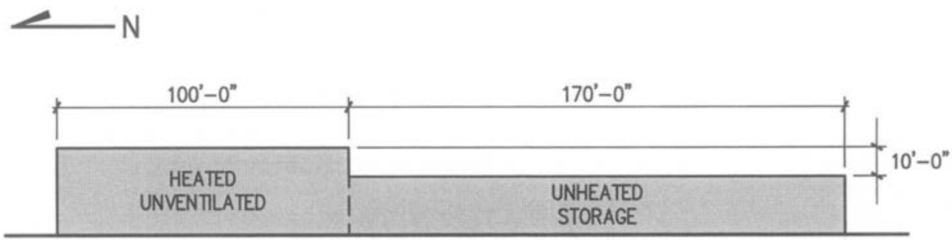

Figure VII-8 West Elevation of Stepped Roof Structure for Ex. 7.1

7.2 Windward Drift

Eq. (VII-3) and Figure 7-9 can be used to determine the windward drift height as well, with some modifications. In **Eq. (VII-3)** and Figure 7-9, ℓ_u is replaced with ℓ_ℓ and then the calculated height is multiplied by 0.75. Case histories suggest that windward steps trap snow less efficiently than leeward steps, resulting in a reduced drift height. More detailed justification for the three-quarters factor is provided in Chapter 8 of this guide. In all cases, the triangular drift surcharge is superimposed on the sloped roof load for the lower roof.

7.3 Example 7.1: Roof Step Drift Load

Determine the design snow loads for the structure in **Figure VII-8.** This ground snow load, p_g, is 40 psf, the heated portion is of ordinary importance, and the site is in flat open country (Terrain Category C) with no trees or nearby structures offering shelter. Both roofs have ¼-on-12 slopes in the east-west direction to internal drains.

Solution

Balanced Load (Upper Roof Level): Because the building is located in Terrain Category C and the upper roof is fully exposed, $C_e = 0.9$ from Table 7-2. For a heated space with an unventilated roof, the thermal factor, C_t, equals 1.0 from Table 7-3 and the importance factor, I, equals 1.0 from Table 7-4. Hence, the upper flat roof snow load is

$$\begin{aligned} p_f &= 0.7 C_e C_t I p_g \\ &= 0.7(0.9)(1.0)(1.0)(40 \text{ psf}) \\ &= 25 \text{ psf} \end{aligned}$$

For a roof slope of ¼-on-12, $C_s = 1.0$ irrespective of roof material/surface. Hence, the balanced sloped roof snow load for the upper roof is also 25 psf.

Balanced Load (Lower Roof Level): As stated in the problem, the site is considered Terrain Category C. The lower roof, however, is sheltered by the presence of the upper level roof. Therefore, the lower roof is classified as partially exposed and $C_e = 1.0$ from Table 7-2. For an unheated space, the thermal factor, C_t, equals 1.2 from Table 7-3. Although this is a storage space, it is not considered prudent to classify this building as a "minor storage facility," as described in Category I in Table 1-1, because of its large footprint. Therefore, the building structure is classified as Category II in Table 1-1 with an importance factor, I, of 1.0 per Table 7-4. Hence, the balanced load on the lower level roof becomes

$$\begin{aligned} p_s &= 0.7 C_e C_t C_s I p_g \\ &= 0.7(1.0)(1.2)(1.0)(1.0)(40 \text{ psf}) \\ &= 34 \text{ psf} \end{aligned}$$

Drift Loads: The snow density is determined from p_g using Eq. (7-4) below:

$$\begin{aligned} \gamma &= 0.13\, p_g + 14 \\ &= 0.13(40 \text{ psf}) + 14 \\ &= 19 \text{ pcf} \end{aligned}$$

The balanced snow depth on the lower level roof is

$$h_b = \frac{p_s}{\gamma} = \frac{34 \text{ psf}}{19 \text{ pcf}} = 1.8 \text{ ft}$$

Hence, the clear height above the balanced snow is

$$h_c = 10 - h_b = 10 - 1.8 = 8.2 \text{ ft}$$

By inspection, $h_c/h_b > 0.2$; therefore, enough space is available for drift formation, and drift loads must be evaluated.

Leeward Drift: For a wind out of the north, the upwind fetch for the resulting leeward drift is the length of the upper level roof ($\ell_u = 100$ ft). Hence, the surcharge drift height is

$$\begin{aligned} h_d &= 0.43\sqrt[3]{\ell_u}\sqrt[4]{p_g + 10} - 1.5 \\ &= 0.43(100 \text{ ft})^{1/3}(40 \text{ psf} + 10)^{1/4} - 1.5 \\ &= 3.8 \text{ ft} \end{aligned}$$

Windward Drift: For a wind out of the south, the upwind fetch for the resulting windward drift is 170 ft. Hence, the surcharge drift height is

$$\begin{aligned} h_d &= 0.75\left[0.43\sqrt[3]{\ell_u}\sqrt[4]{p_g + 10} - 1.5\right] \\ &= 0.75\left[0.43(170)^{1/3}(40 \text{ psf} + 10)^{1/4} - 1.5\right] \\ &= 3.6 \text{ ft} \end{aligned}$$

Thus, the leeward drift controls, and $h_d = 3.8$ ft. Since the drift is not full ($h_c > h_d$), the drift width is four times the drift height:

$$w = 4h_d = 4(3.8 \text{ ft}) = 15 \text{ ft}$$

and the maximum *surcharge* drift load is the drift height times the snow density:

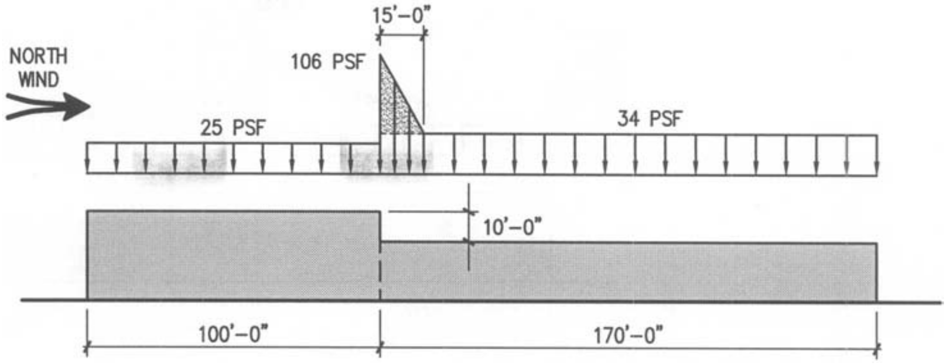

Figure VII-9 Roof Step Snow Loading for Ex. 7.1

$p_d = h_d \gamma = 3.8$ ft (19 pcf) = 72 psf

The total load at the step is the balanced load on the lower roof plus the drift surcharge (34 + 72 = 106 psf), as shown in **Figure VII-9.**

Due to the comparatively large ground snow load ($p_g > 20$ psf), the minimum roof load (Section 7.3.4) is 20 I or 20 psf for both the upper level and lower level roofs, and therefore does not govern. Also, due to the large ground snow load, the rain-on-snow surcharge does not apply (see Section 7.10).

Note that the windward and leeward drift heights are calculated separately, and the larger value is used to establish the design drift loading. This approach (i.e., using the *larger* of the drift heights as opposed to the *sum* of the two drift heights) is specifically mentioned in Section 7.7.1. Based on this design approach, one might assume that wind only blows from one direction throughout the winter season; however, that is not the case. In fact, it is possible to have a 180-degree shift in wind direction during a single storm event. For example, consider a storm that passes from west to east over a site. Due to the counter-clockwise rotation of the wind around the low pressure point, the site initially experiences the wind coming from the south (when the low is located to the west of the site); then, as the low pressure point moves over the site, the site experiences the wind coming from the north (when the low is located to the east).

So it is possible to have both windward and leeward contributions to the same drift formation. The approach of choosing the larger independent value for the design drift loading illustrates the empirical nature of the roof step drift provisions. That is, the leeward case history drifts, upon which the provisions are based, are due to either all leeward drifting or some combination of leeward and windward drifting. Hence, the extent to which leeward and windward drifting are both present is already reflected in the *observed* drift height. Therefore, adding the *design* leeward to the *design* windward would result in unrealistic drifts that are much larger than the observed.