Three-Dimensional Roof Snowdrifts

Purpose

This design guide provides guidance, in the form of three design examples, for three-dimensional (3-D) roof snowdrifts. The procedures identified herein are consistent with the intersecting drift provisions expected in the 2022 edition of the American Society of Civil Engineers (ASCE) standard ASCE 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures.*

Figure 1. Plymouth Elementary School roof area where leeward roof step drift from winds out of the north converged with windward roof step drift from winds out of the west (photo courtesy of school official)

Background

Historically, roof snowdrifts in ASCE 7 have been two dimensional (2-D). For example, the leeward roof step drift was characterized by the drift height at the roof step and by the width or horizontal extent of the triangular drift. This triangular shape remained unchanged everywhere along the roof step (i.e., in and out of the plane). A 2-D triangular drift shape was also prescribed for windward roof step drifts and for parapet wall drifts, with the same triangular drift shape prescribed everywhere along the parapet wall. For gable roofs, a rectangular drift surcharge was prescribed, and the rectangular shape remained unchanged everywhere along the ridge line.

The wind causing snow transport and resulting drift formation was envisioned as perpendicular to the roof step, parapet wall, or ridgeline. For the case of a roof step where leeward and windward drifts (e.g., N-S roof step with the upper level roof to the west) nominally occupy the same roof location, engineers were required to use the larger of the two 2-D drifts (i.e., the leeward drift for wind out of the west or the windward drift for wind out of the east). Note that the roof step drift relations were based on a multiple regression analysis of observed drifts from insurance company files. As such, adding together the leeward and windward drifts would result in a design drift larger than the observed drift.

The first three-dimensional (3-D) drift was introduced in ASCE 7-16. It applies at parapet wall corners and reentrant corners. For the parapet wall corner as sketched in Figure 2, the windward drift along the north wall is based on the N-S roof fetch and decreases in height to the south. The windward drift along the west wall is based on the E-W roof fetch and decreases in height to the east. In the dashed box where the drifts intersected, engineers are required to use the larger of the two drifts, not the sum. This results in a valley line where the two heights match. In Figure 2, to the north and east of the valley line, the north wall drifts governs, while to the south and west, the west wall drift governs.

These drifts are based on wind direction and the resulting snow transport changing by 90 degrees during the drift formation process (e.g., wind out of the south followed by wind out of the east for the 3-D drift in Figure 2). Note that the wind direction during a snowstorm is a function of the site location with respect to the location of the low pressure system. Because of the counterclockwise rotation around the center of the low-pressure system, a building can be subject to prevailing winds that shift direction over time. For example, a building that gets wind out of the east when the low is to the south, will later get wind out of the north when the low is to the east. A "Nor-Easter" in New England can result from a low-pressure system moving from New York City to Boston.

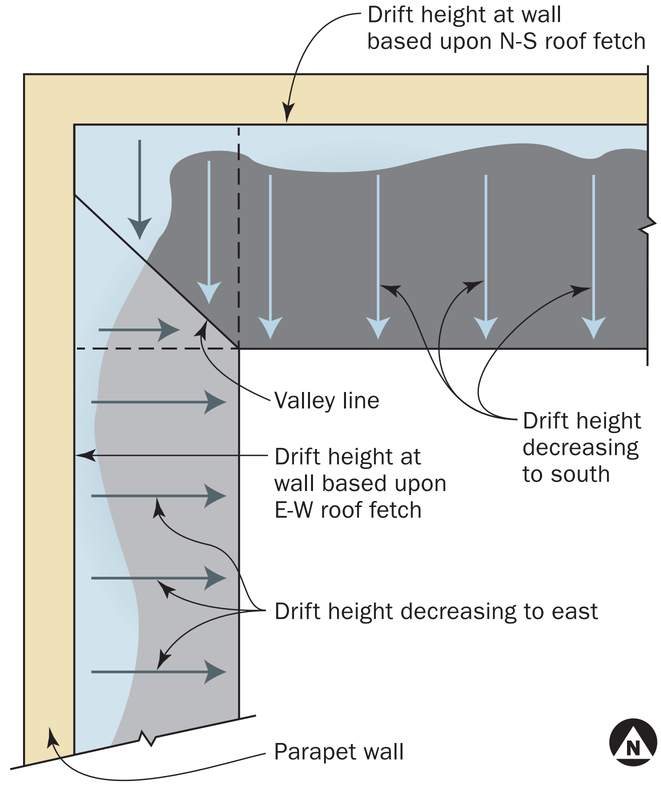

Figure 2. Plan view of 3-D parapet wall corner drift as per ASCE 7-16

The relative importance of 3-D drifts was demonstrated in February of 2015 when a series of heavy snow and wind events resulted in several roof collapses in the Greater Boston area. A Federal Emergency Management Agency (FEMA) team was sent to assess four partial school building collapses; their findings are described in the *Snow Study Summary Report: Observations of Snow Load Effects on Four School Buildings in New England* (FEMA, 2016), which can be downloaded here: https://www.fema.gov/media-library/assets/documents/124838. In all four cases, the partial collapses were due to snowdrift loading. In two of the four cases, the FEMA team observed and documented 3-D drifts. In one case (Mitchell Elementary in Bridgewater, MA), the 3-D drifting was due to a gable roof drift caused by wind out of the north intersecting a windward drift caused by wind out of the west (see Figure 3). In the other case (Plymouth River Elementary in Hingham, MA), the 3-D drifting was due to a leeward roof step drift caused by wind out of the north intersecting with a windward roof step drift caused by wind out of the west.

Note that neither of these two Boston-area 3-D drift conditions could be accounted for using the roof geometries (i.e., parapet wall corners and reentrant corners) specifically addressed by the provisions of ASCE 7-16 Section 7.7.3, Intersecting Drifts at Low Roofs. As a result, the FEMA team recommended the following:

- Develop guidance in the form of a fact sheet or research report to address the following drift loading conditions, which are not adequately addressed in ASCE 7:
  - Combination of over-the-ridge drift loads with roof step drift
  - Distribution of drift loads when the space available for drift formation varies in the direction perpendicular to the upwind fetch
  - Slope of the top surface of snow drift on a gable roof as a function of roof slope
- Use this new drift load guidance as the basis for a future update of ASCE 7

Figure 3. Partial roof collapse at Mitchell Elementary School in Bridgewater, MA, in 2015.
LEFT: Aerial photograph of where gable roof drift from winds out of the north and northeast intersected with windward roof step drift from winds out of the west and northwest leading to roof collapse (red outline shows damage location)
RIGHT: Close-up of roof damage looking east (photo courtesy of RebuildEx)

New Drift Load Guidance

Based on FEMA's 2015 Boston-area observations, additional criteria have been proposed for ASCE 7-22 to determine intersecting drift loads for previously unaddressed roof geometries and conditions. Commentary drafted to accompany the proposed standard changes is included below to explain the new approach. Three drift load design examples follow the commentary to clarify the application of the proposed intersecting drift provisions.

Commentary

The accumulation of drifting snow from perpendicular wind directions can occur concurrently from single or multiple wind and snow events to create an intersecting snowdrift load at reentrant corners. Intersecting drifts can also occur at a roof step where the lower level roof is a gable. If the gable roof is to the east of the upper level roof, a leeward roof step drift is expected for wind out of the west, while a gable roof drift on the north side of the ridge is expected for wind out of the south. The rules for such intersecting drifts are as follows:

1. Consider each 2-D drift separately
2. Assume each 2-D drift has its ASCE-7 shape (observed gable roof drifts are often triangular, yet modeled for simplicity as rectangular)
3. Within the footprints of the two 2-D drifts, use the larger of the two 2-D snow depths

The approach for intersecting drifts proposed for ASCE 7-22 is consistent with that for windward and leeward roof step drifts in Section 7.7.1, Lower Roof of a Structure, of ASCE 7-16 where the larger of these two heights is required for determination of minimum snow loads. Finally, the current and proposed intersecting drift provisions in Section 7.7.3 do not apply to a simple gable subject to the gable roof drifts in Section 7.6.1, Unbalanced Snow Loads for Hip and Gable Roofs. For a simple gable, the two unbalanced loads (actually two drift loads on each side of the ridgeline) do not have overlapping footprints.

While working through the design examples, it is important for the user to keep in mind that ASCE 7-22 may also introduce new procedures for determining various 2-D drifts. Specifically, stakeholders have discussed incorporation of a winter wind parameter into the procedures for determination of the leeward roof step drift height, h_d. Modification of the 2-D windward drift provision is also being considered. Even though the individual 2-D drift provisions may change, the methodology for combining two 2-D drifts into a 3-D intersecting drift is expected to be the same as the methodology presented herein.

Design Example #1

Figure 4 shows a nominally flat 100-foot by 200-foot roof with a reentrant corner at the northwest and a lower level roof below. Determine the intersecting drift for wind out of the east and south (i.e., leeward roof step drifts) if the ground snow load, p_g, is 20 pounds per square foot (psf) and the exposure, thermal, and importance factors are all unity (i.e., $C_e = C_t = I_s = 1.0$).

Solution:

The balanced roof snow load, p_s, is given by

$$p_s = 0.7\ C_e\ C_t\ C_s\ I_s\ p_g$$

where the slope factor, C_s, is 1.0 for a nominally flat roof. Hence,

$$p_s = 0.7\ (1.0)^4\ 20 = 14 \text{ psf}$$

The snow density is given by

$$\gamma = 0.13\ p_g + 14 = 0.13\ (20) + 14 = 16.6 \text{ pounds per cubic foot (pcf)}$$

And, hence, the depth of the balanced snow, h_b, is

$$h_b = p_s / \gamma = 14\ psf / 16.6\ pcf = 0.84\ feet$$

The relation for a leeward roof step drift height is

$$h_d = (I_s)^{1/2}\ [0.43\ (l_u)^{0.33}\ (p_g + 10)^{0.25} - 1.5]$$

where l_u is the upwind fetch in feet.

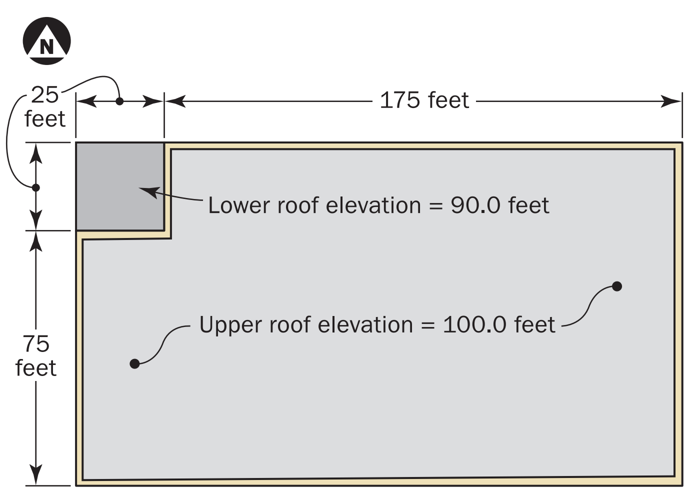

Figure 4. Plan view for Design Example 1

For wind out of the east, (i.e., leeward roof step drift at the west end) the upwind fetch l_u is 175 feet; hence, the drift height for east wind is

$$h_d = (1.0)^{1/2}\ [0.43\ (175)^{.33}\ (20 + 10)^{.25} - 1.5]$$
$$h_d = 4.12 \text{ feet}$$

Note that the space available for drift formation, h_c, is the step height minus the balanced snow depth

$$h_c = 10.0 - 0.84 = 9.16 \text{ feet}$$

Hence, the drift height for east wind is not limited by h_c and the peak east wind drift surcharge is

$$(P_d)_E = h_d\gamma = 4.12\ feet\ (16.6\ pcf) = 68.4\ psf$$

The width of the height unconstrained drift is given by

$$(w)_E = 4\ (h_d)_E = 4\ (4.12) = 16.4 \text{ feet}$$

The total snow load is the balanced load of 14 psf plus the drift surcharge of 68.4 psf or 82.4 psf.

For wind out of the south, (i.e., leeward roof step drift at the north), the upwind fetch is 75 feet; hence, the drift height for south wind is

$$(h_d)_s = 1.0^{.5}\ [\ 0.43\ (75)^{.33}\ (20 + 10)^{.25} - 1.5]$$
$$(h_d)_s = 2.74 \text{ feet}$$

Because this drift height is less than the space available for drift formation, h_c = 9.16 feet calculated above, the width of the drift is 4 (h_d) or 10.9 feet, the drift surcharge is $(h_d)\ \gamma$ or 45.5 psf, and the total snow load for south wind is 14 plus 45.5 or 59.5 psf.

Figure 5 shows a plan view of the intersecting drifts for east and south winds, while Figures 6 and 7 show section views with the drifts in profile. Because the rise to run for both drifts is 1 to 4, the valley line is at 45 degrees in plan. To the north of the valley line, the east wind drift governs while the south wind drift governs for locations to the west of the valley line.

Note that for wind out of the north or west, the windward roof step drifts are much smaller because the upwind fetch for both is only 25 feet.

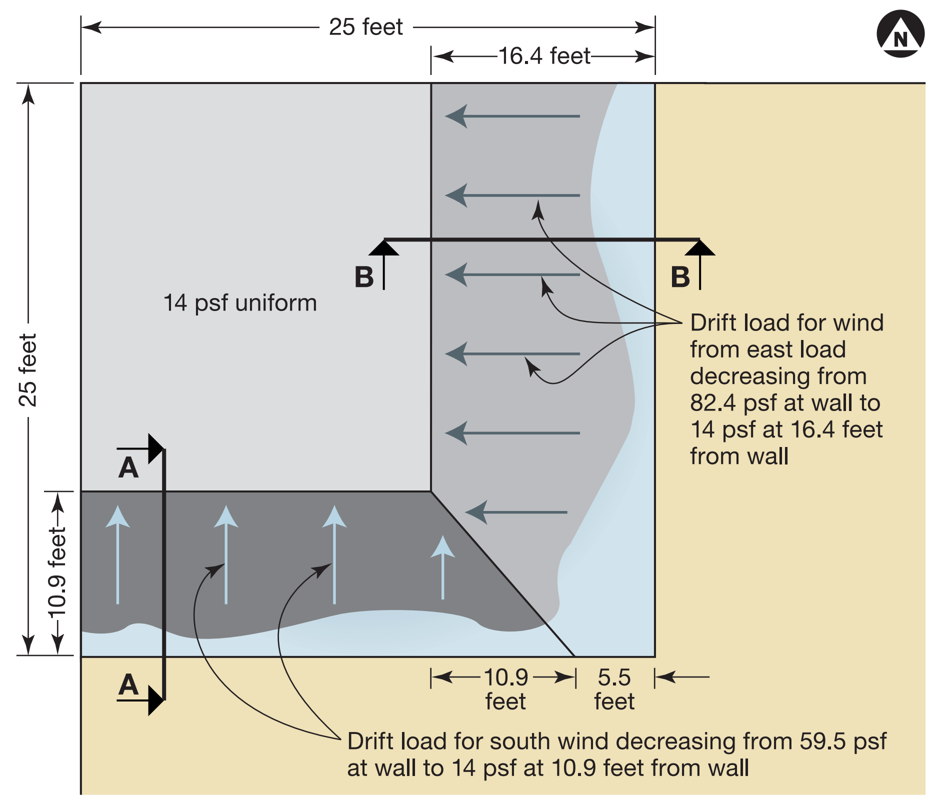

Figure 5. Plan view of intersecting roof step drifts for winds out of the east and south

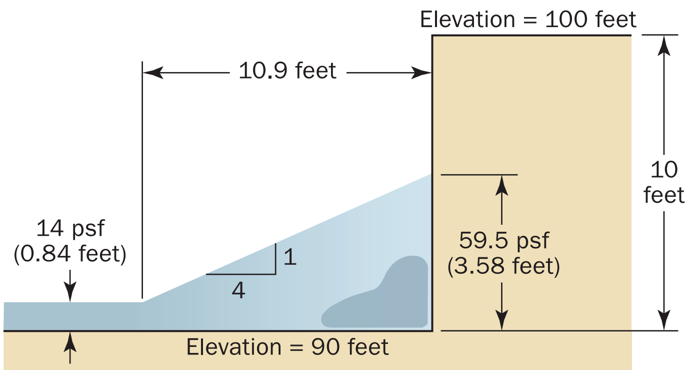

Figure 6. Section A – Elevation view looking east, away from corner

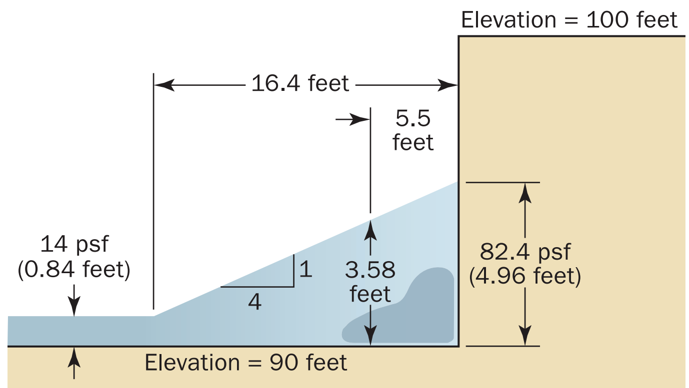

Figure 7. Section B – Elevation view looking north, away from the corner

Design Example #2

Figure 8 shows a nominally flat upper level roof to the west of a lower level gable with a 2 on 12 symmetric roof slope. Determine the intersecting drift loads for winds out of the west and north if the ground snow load, p_g, is 40 psf and $C_e = C_t = I_s = 1.0$.

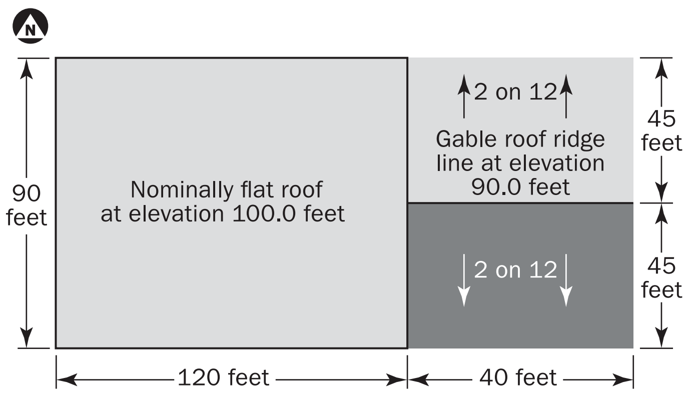

Figure 8. Plan view of multi-level roof in Design Example #2

Balanced Roof Snow Load:

The sloped roof snow load, p_s, is given by

$$p_s = 0.7\ C_e\ C_t\ C_s\ I_s\ p_g$$

Because the gable roof R value is not given, it is unclear from Figure 7.4-1 in ASCE 7-16 whether the roof is unobstructed—slippery or not. This example uses the conservative assumption that it is "all other surfaces" and hence $C_s = 1.0$ for the 2 on 12 slope. Hence,

$$p_s = 0.7\ (1.0)^4\ (40\ \text{psf}) = 28\ \text{psf}$$

From Equations 7.7-1 in ASCE 7-16, the snow density γ is

$$\gamma = 0.13\ p_g + 14 = 0.13\ (40) + 14 = 19.2\ \text{pcf}$$

and the balanced snow depth is

$$h_b = p_s / \gamma = 28 / 19.2 = 1.46\ \text{feet}$$

Wind from the West:

For wind from the west, there is a leeward roof step drift atop the gable with an upwind fetch of 120 feet. Hence, the peak drift height is

$$(h_d)_W = (I_s)^{.5}\ [0.43\ (l_u)^{0.33}\ (p_g + 10)^{.25} - 1.5]$$

or

$$(h_d)_W = (1.0)^{0.5}\ [0.43\ (120)^{0.33}\ (50)^{.25} - 1.5] = 4.13\ \text{feet}$$

Because the drift height plus the depth of the sloped roof snow load (1.46 ft) is less than 10 feet (elevation difference between gable ridge and upper level surface), the west wind drift is not height constrained and the width is

$$W_W = 4\ (h_d)_W = 4\ (4.13) = 16.5\ \text{feet}$$

The west wind peak load (drift plus sloped roof load) is

$$\gamma\ (h_b + (h_d)_W) = 19.2\ (1.46 + 4.13) = 107\ \text{psf}$$

and the peak depth is 5.59 feet.

Wind from the North:

For wind from the north, there is a gable roof drift surcharge to the south of the ridgeline. The upwind fetch is 45 feet. Hence, the peak drift height is

$$(h_d)_N = (1.0)^{0.5}\ [.43\ (45)^{0.33}\ (40 + 10)^{.25} - 1.5] = 2.56\ \text{feet}$$

The roof slope is 2 on 12 or 1 on 6, and hence the slope parameter is s = 6. From Figure 7.6-2 in ASCE 7-16, the surcharge load is

$$h_d\ \gamma / \sqrt{s} = 2.56\ (19.2)/\sqrt{6} = 20.0\ \text{psf}$$

while the horizontal extent is

$$8\ h_d\ \sqrt{s}/3 = 8\ (2.56)\ \sqrt{6}/3 = 16.5\ \text{feet}$$

Figure 9 shows the intersecting drifts caused by winds out of the north and west. Figure 10 shows the west wind leeward roof step drift away from the lower level roof ridgeline, while Figure 11 shows the north wind gable roof drift away from the roof step.

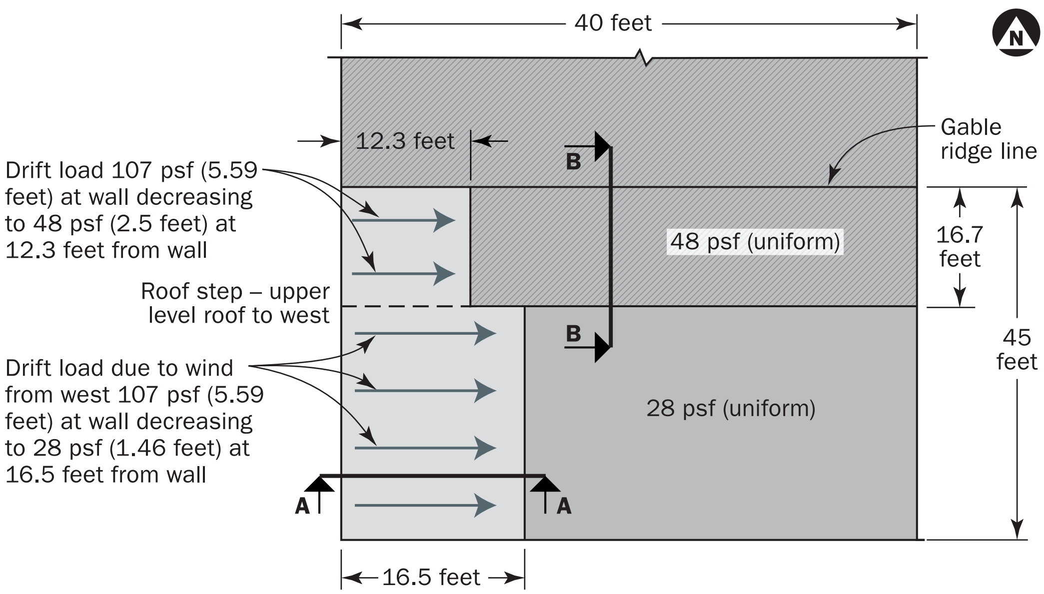

Figure 9. Intersecting drifts on south side of gable roof

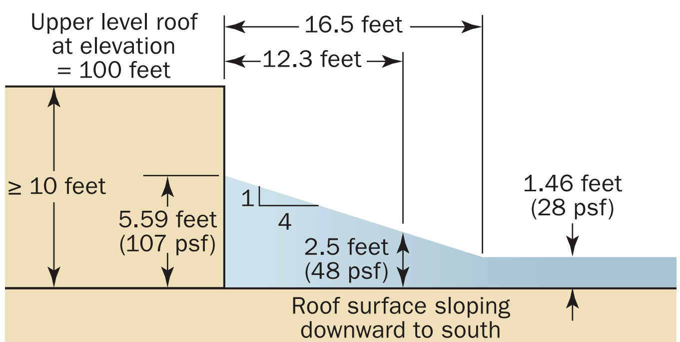

Figure 10. Section A – Elevation view looking north, away from gable ridge line

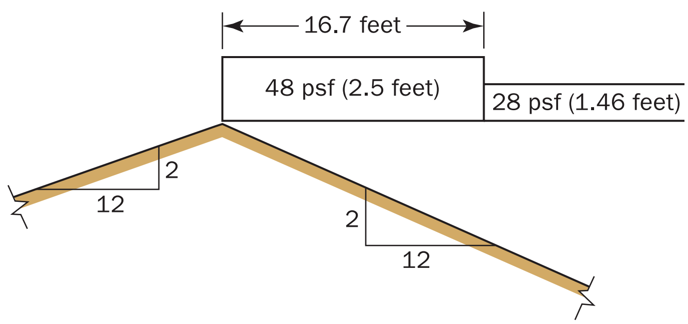

Figure 11. Section B – Elevation view looking east, away from roof step

Design Example #3

Figure 12 shows a T-shaped gable roof, sometimes referred to as an overlaid hip roof. Determine the intersecting drift for winds out of the north and west, for a location with a ground snow load, p_g, of 30 psf and with $I_s = C_e = C_t = C_s = 1.0$.

Balanced Roof Snow Load:

The sloped roof snow load, p_s, is given by

$$p_s = 0.7\, C_e\, C_t\, C_s\, I_s\, p_g$$

$$p_s = 0.7\,(1.0)^4\,(30) = 21 \text{ psf}$$

while the snow density γ is

$$\gamma = 0.13\,(30) + 14 = 17.9 \text{ pcf}$$

Hence, the depth of the balanced or sloped roof snow load is

$$h_d = p_s/\gamma = 21/17.9 = 1.17 \text{ feet}$$

Wind from the North:

For wind from the north, the upwind fetch is 20 feet and the peak drift height is

$$(h_d)_N = (I_s)^{.5}\,[0.43\,(l_u)^{.33}\,(p_g + 10)^{.25}) - 1.5]$$

$$= (1.0)^{.5}\,[0.43\,(20)^{.33}\,(30{+}10)^{.25} - 1.5] = 1.43 \text{ feet}$$

Because the roof slope is 3 on 12 or 1 on 4, the slope parameter s = 4 and the north wind surcharge load is

$$(h_d)_N * \gamma/\sqrt{s} = 1.43\,(17.9)/\sqrt{4} = 12.8 \text{ psf}$$

while the horizontal extent is

$$8\,(h_d)_N * \sqrt{s}/3 = 8(1.43)\,\sqrt{4}/3 = 7.62 \text{ feet}$$

The total load, balanced plus gable drift surcharge, is 21 psf plus 12.8 psf or 33.8 psf.

Wind from the West:

For wind from the west, the upwind fetch for the simple gable south of the intersecting drifts is 20 feet. This yields the same surcharge as calculated above for wind out of the north.

However, for the portion of the N-S ridgeline close to the E-W ridgeline, the west wind upwind fetch is 40 feet and the depth of the resulting roof snowdrift is

$$(h_d)_W = (I_s)^{0.5}\,[0.43\,(l_u)^{.33}\,(p_g + 10)^{.25}) - 1.5]$$

$$= (1.0)^{.5}\,[.43\,(40)^{.33}\,(30{+}10)^{.25} - 1.5] = 2.19 \text{ feet}$$

For s = 4, the west wind surcharge load is

$$(h_d)_W * \gamma/\sqrt{s} = 2.19\,(17.9)/\sqrt{4} = 19.6 \text{ psf}$$

while the horizontal extent is

$$8\,(h_d)_W * \sqrt{s}/3 = 8(2.19)\,\sqrt{4}/3 = 11.7 \text{ feet}$$

The total west wind load, balanced plus gable drift surcharge is 21 psf plus 19.6 psf or 40.6 psf.

Figure 13 shows the intersecting drifts caused by winds out of the north and west.

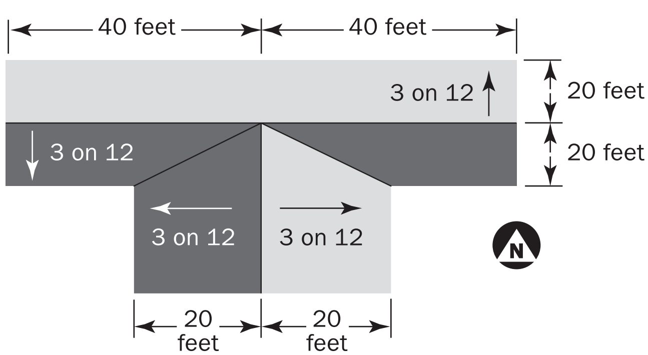

Figure 12. Overlaid hip roof for Design Example #3

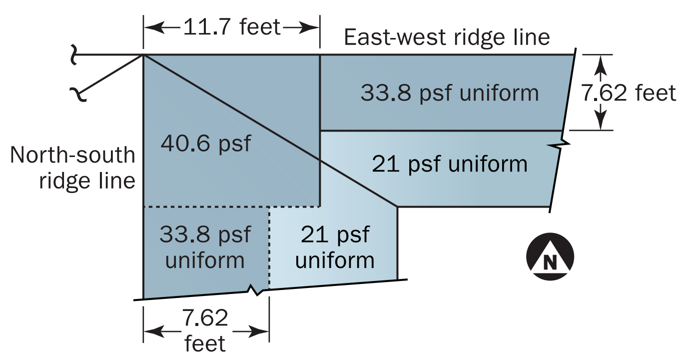

Figure 13. Intersecting drifts south of the E-W ridge, east of the N-S ridge line