Wind Uplift

Protection against wind forces should be one of the fundamental principles of good roof assembly design.

When wind strikes a building, it is deflected around the building's sides and over the roof surface. The result is a positive pressure on the side of the building the wind first contacts (windward side). Lower pressures or negative pressures occur on the building's other sides and over the roof, as shown in Figure A1-1.

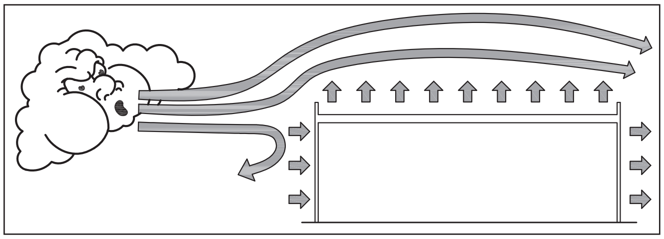

Figure A1-1: Wind forces acting on a building

When designing a building for wind forces, a designer determines theoretical design wind loads using design methods identified in the applicable building code. In the *International Building Code, 2015 Edition* (IBC 2015) and its previous editions, minimum requirements for design wind loads are identified in Chapter 16—Structural Design. IBC 2015 references ASCE 7-10, "Minimum Design Loads for Buildings and Other Structures," for determining design wind loads on buildings, including buildings' roof assemblies.

Using ASCE 7, the design wind load of a hypothetical 1 square roof area in the field of the roof is determined. This design wind load in the field of the roof can then be multiplied by pressure coefficients (GCps) defined in ASCE 7 to determine design wind loads at the roof area's perimeter and corner regions. For low-slope roof assemblies with slopes less than 1½:12, ASCE 7-10 prescribes a pressure coefficient of 1.8 at the roof area's perimeter and 2.8 at the roof area's corners. Figure A1-2 illustrates this relationship.

This relationship shows the premise that design wind loads are typically greater at roof area perimeters and corners than they are in the field of roofs.

The fundamental concept of wind design as it applies to roof assemblies is that the wind-resistance (uplift-resistance) capacity of the roof assembly is greater than

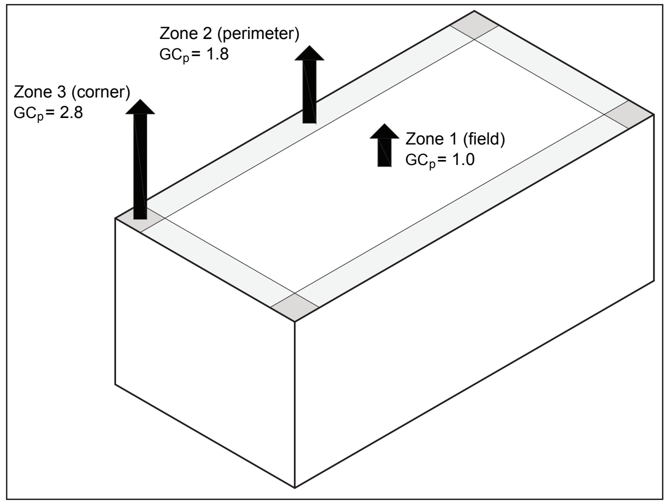

Figure A1-2: Illustration of pressure coefficients for a roof area sloped less than 1½:12

the design wind loads that will occur on a building's roof assembly. This is expressed as:

Design uplift-resistance capacity > Design wind load

Typically, these values are measured in pounds per square foot.

In the event actual wind loads exceed a roof assembly's actual resistance capacity, failure (blow-off) of the roof assembly is possible. Therefore, it is important a building's design wind loads and roof assembly's wind resistance accurately be determined.

Design wind loads are mathematical predictions of anticipated maximum wind loads that apply to a specific building (taking into account configuration, height and size) and location. The widely recognized consensus standard method for determining design wind loads on buildings is ASCE 7, "Minimum Design Loads for Buildings and Other Structures." The 2010 edition of ASCE 7, designated at ASCE 7-10, is referenced in and serves as the technical basis for wind-load determination in the 2012 and 2015 editions of the *International Building Code*.

ASCE 7-10 specifies wind design procedures for buildings and organizes them into two categories: main wind force-resisting systems and component and cladding elements. Main wind force-resisting systems are the structural elements assigned to provide the support and stability for the overall building. Components and cladding are elements of the building envelope that do not qualify as part of the main wind force-resisting system.

ASCE 7-10 also provides two methods to determine minimum design load requirements for buildings: allowable stress design (ASD) method and strength design method. The wind design procedures in ASCE 7-10 result in strength design values; however, roof systems typically are designed using ASD.

ASD and strength design methods take into account applicable load types, such as dead, live, wind, seismic, etc., to ensure the structure's safety under anticipated loading conditions. The individual loads are then combined using load combination equations which include "load factors." Load factors allow for deviations and uncertainties in the analysis and the probability of simultaneously occurring loads. Load factors are applied as coefficients to the individual loads in the load combination equations. The load factor for wind loads is 1.0 when using the ASD method and 1.6 when using the strength design method. Because roof systems typically are designed using ASD, a designer may want to adjust strength design values to ASD values. In doing so, applying a load reduction factor of 0.6 to ASD values may be appropriate.

Design Wind Loads: Requirements for wind loads are found in Chapters 26 to 30 in ASCE 7-10. Chapter 30 specifically addresses components and cladding. This chapter offers the following six methods, referred to as parts, to determine design wind loads:

- Part 1: Low-rise Buildings. This method is applicable to enclosed or partially enclosed buildings less than or equal to 60 feet in height. The building has a flat, gable, multispan gable, hip, monoslope, stepped or sawtooth roof. Wind pressures are calculated from a wind pressure equation.
- Part 2: Low-rise Buildings (Simplified): This method is applicable to enclosed buildings less than or equal to 60 feet in height. The building has a flat, gable or hip roof. This is a simplified method and wind pressures are determined directly from a table.
- Part 3: Buildings with h>60 ft. This method is applicable to enclosed or partially enclosed buildings greater than 60 feet in height. The building has a flat, pitched, gable, hip, mansard, arched or domed roof. Wind pressures are calculated from a wind pressure equation.
- Part 4: Buildings with h≤160 ft. (Simplified). This method is applicable to enclosed buildings less than or equal to 160 feet in height. The building has a flat, gable, monoslope or mansard roof. This is a simplified method and wind pressures are determined directly from a table.
- Part 5: Open Buildings. This method is applicable to open buildings of all heights. The building has a pitched, monoslope or trough roof. Wind pressures are calculated from a wind pressure equation.
- Part 6: Building Appurtenances and Rooftop Structures and Equipment. This method is for determining design wind pressures for component and cladding elements of parapets, roof overhangs or rooftop structures of enclosed and partially enclosed buildings less than or equal to 160 feet in height. Wind pressures are calculated from a wind pressure equation.

Part 1, Part 3, Part 5 and Part 6 involve calculations and concepts that are fairly complex and beyond the scope and intent of this manual. Part 2 and Part 4 are considered simplified methods and apply to many commonly encountered building types. For these reasons, roof system designers are most likely to use Part 2 and Part 4 methods.

Part 2: Low-rise Buildings (Simplified): This method is limited to the following parameters:

- The mean roof height, h, must be less than or equal to 60 feet.
- The building is enclosed and conforms to wind-borne debris provisions.
- The building is a regular-shaped building or structure.
- The building does not have response characteristics making it subject to across wind loading, vortex shedding, and instability because of galloping or flutter, and does not have a site location for which channeling effects or buffeting in the wake of upwind obstructions warrant special consideration.
- The building has a flat roof, a hip roof ≤ 6:12 or a gable roof ≤ 12:12.

For design wind load pressures, the basic equation is:

$p_{net} = \lambda \times K_{zt} \times p_{net30}$

Where:

p_{net} = net design wind pressure (a sum of internal and external pressures) for the field of the roof, in pounds per square foot

λ = adjustment factor from ASCE 7-10's Figure 30.5-1 (determined by mean building height and exposure category)

K_{zt} = topographic factor as defined in ASCE 7-10's Section 26.8

p_{net30} = net design wind pressure for exposure B at building height = 30 ft. Taken from ASCE 7-10's Figure 30.5-1 (determined by the basic wind speed, roof slope, effective roof area and zone)

It is important to note that "p_{net}" determines design wind load pressures for the field of the roof.

Part 4: Buildings With h ≤ 160 ft (Simplified): This method is limited to the following parameters:

- The mean roof height, h, must be less than or equal to 160 feet.
- The building is enclosed or partially enclosed.
- The building is a regular-shaped building or structure.
- The building has a flat roof, gable roof, hip roof, monoslope roof or mansard roof.

For design wind load pressures, the basic equation is:

$p = p_{table} \times EAF \times RF \times K_{zt}$

Where:

p = design wind pressure for the field of the roof, in pounds per square foot

p_{table} = wind pressure from ASCE 7-10's Table 30.7-2 (determined by basic wind speed, roof type, load case and zone)

EAF = exposure adjustment factor from ASCE 7-10's Table 30.7-2 (determined by building height and exposure category)

RF = reduction factor from ASCE 7-10's Table 30.7-2 (determined by effective wind area, roof type and zone)

K_{zt} = topographic factor as defined in ASCE 7-10's Section 26.8

It is important to note that "p" determines design wind load pressures for the field of the roof.

Design parameters and definitions: Part 2 and Part 4 refer to the following design parameters and definitions:

- Mean roof height
- Enclosed building
- Wind-borne debris region
- Regular-shaped building
- Topographic factor
- Risk category
- Basic wind speed
- Exposure category
- Effective wind area
- Wind zones

Mean roof height (h). ASCE 7 uses a building's mean roof height in the calculations. It is defined as the average of the roof eave height and the height to the highest point on the roof surface, except that, for roof angles less than 10 degrees, the mean roof height is permitted to be the eave height.

Enclosed buildings. For design purposes, ASCE 7-10 has three building configuration classifications: open, partially enclosed and enclosed. Part 2: Low-rise Buildings (Simplified) only can be used with enclosed buildings and Part 4: Buildings With h ≤ 160 ft (Simplified) can be used with enclosed and partially enclosed buildings. ASCE 7-10 defines them as follows:

> Open: A building having each wall at least 80 percent open.
>
> Partially Enclosed: A building that complies with both of the following:
>
> 1. The total area of openings in a wall that receives positive external pressure exceeds the

sum of the areas of openings in the balance of the building envelope (walls and roof) by more than 10 percent.

2. The total area of openings in a wall that receives positive external pressure exceeds 4 square feet or 1 percent of the area of that wall, whichever is smaller, and the percentage of openings in the balance of the building envelope does not exceed 20 percent.

Enclosed: A building that does not comply with the requirements for open or partially enclosed buildings.

Wind-borne debris regions. These are areas within hurricane-prone regions where impact protection is required for glazed openings.

Regular-shaped building. A regular-shaped building (or other structure) is a building that does not have an unusual geometrical irregularity in spatial form.

Topographic factor (K_{zt}). The topographic factor takes into account wind speed-up effects that occur at isolated hills, ridges or escarpments that constitute an abrupt change in the general topography. This applies for any exposure category. It is determined by an equation and involves wind design concepts that are particularly complex. Therefore, a structural engineer should be consulted to determine K_{zt}. For buildings that are not located by any abrupt changes in the general topography, using a K_{zt} value of 1.0 is appropriate.

Risk Category. Risk Category is a categorization of buildings and other structures for determining design loads based on the risk associated with unacceptable performance. A building's risk category is determined by its use and occupancy. See Figure A1-3. Risk Category II applies to most common buildings.

Basic wind speed. Basic wind speed is a three-second gust at 33 feet above the ground in Exposure C. ASCE 7-10 has the following three basic wind speed maps based on the risk category of a building (Figures A1-4, A1-5 and A1-6 on pages 556 and 557):

- Figure 26.5-1A—Basic Wind Speeds for Occupancy Category II Buildings and Other Structures

Risk Category of Buildings and Other Structures	Risk Category
Buildings and other structures that represent a low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life. Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure. Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste or explosives) containing toxic or explosive substances where their quantity exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.	III
Buildings and other structures designated as essential facilities. Buildings and other structures, the failure of which could pose a substantial hazard to the community. Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use or dispose of such substances as hazardous fuels, hazardous chemicals or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public if released.[a] Buildings and other structures required to maintain the functionality of other Risk Category IV structures.	IV
[a] Buildings and other structures containing toxic, highly toxic or explosive substances shall be eligible for classification to a lower Risk Category if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.2 that a release of the substances is commensurate with the risk associated with that Risk Category.	

Figure A1-3: Risk Category of Buildings and Structures

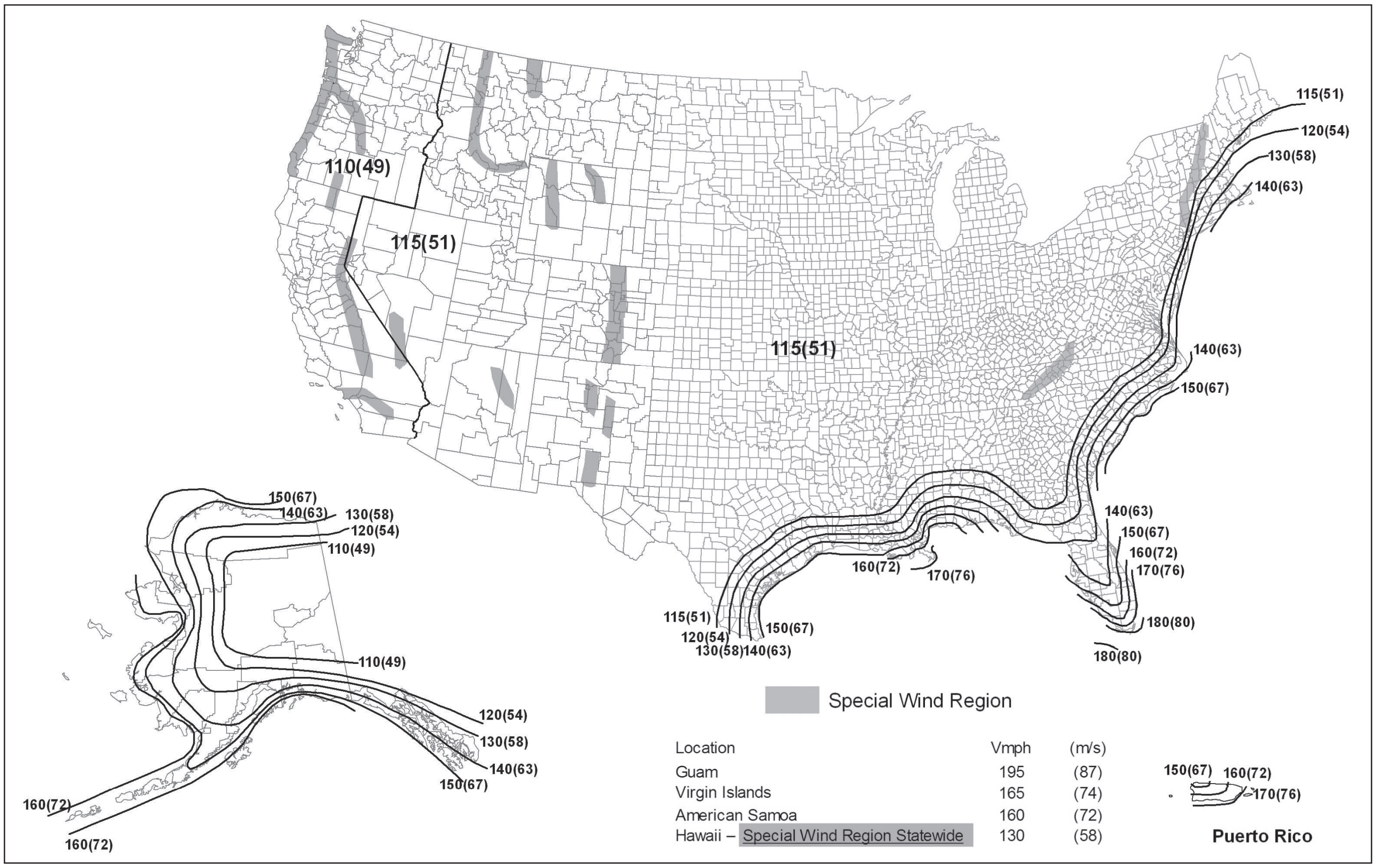

Figure A1-4: Figure 26.5-1A—Basic Wind Speeds for Occupancy Category II Buildings and Other Structures

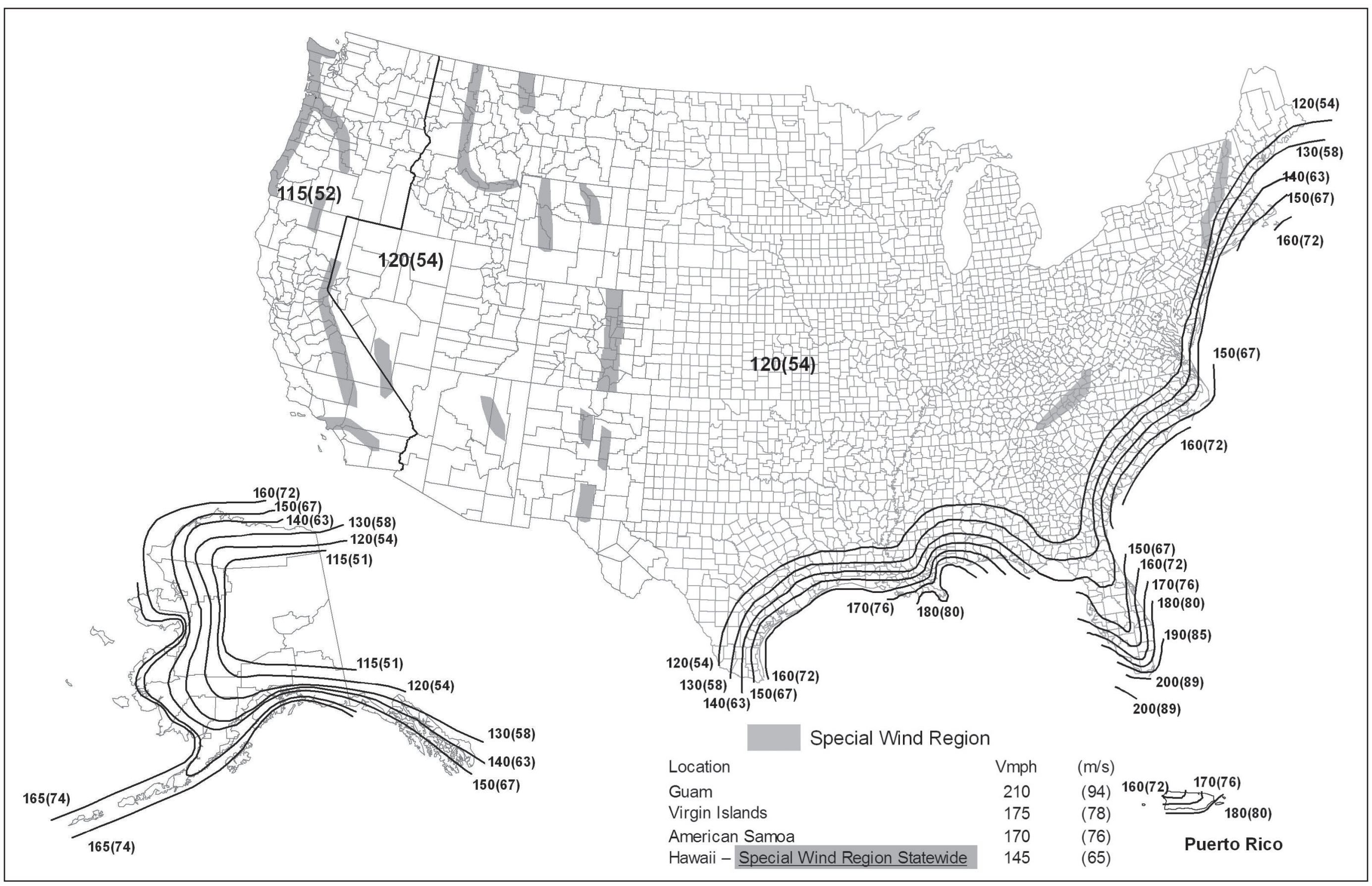

Figure A1-5: Figure 26.5-1B—Basic Wind Speeds for Occupancy Category III and IV Buildings and Other Structures

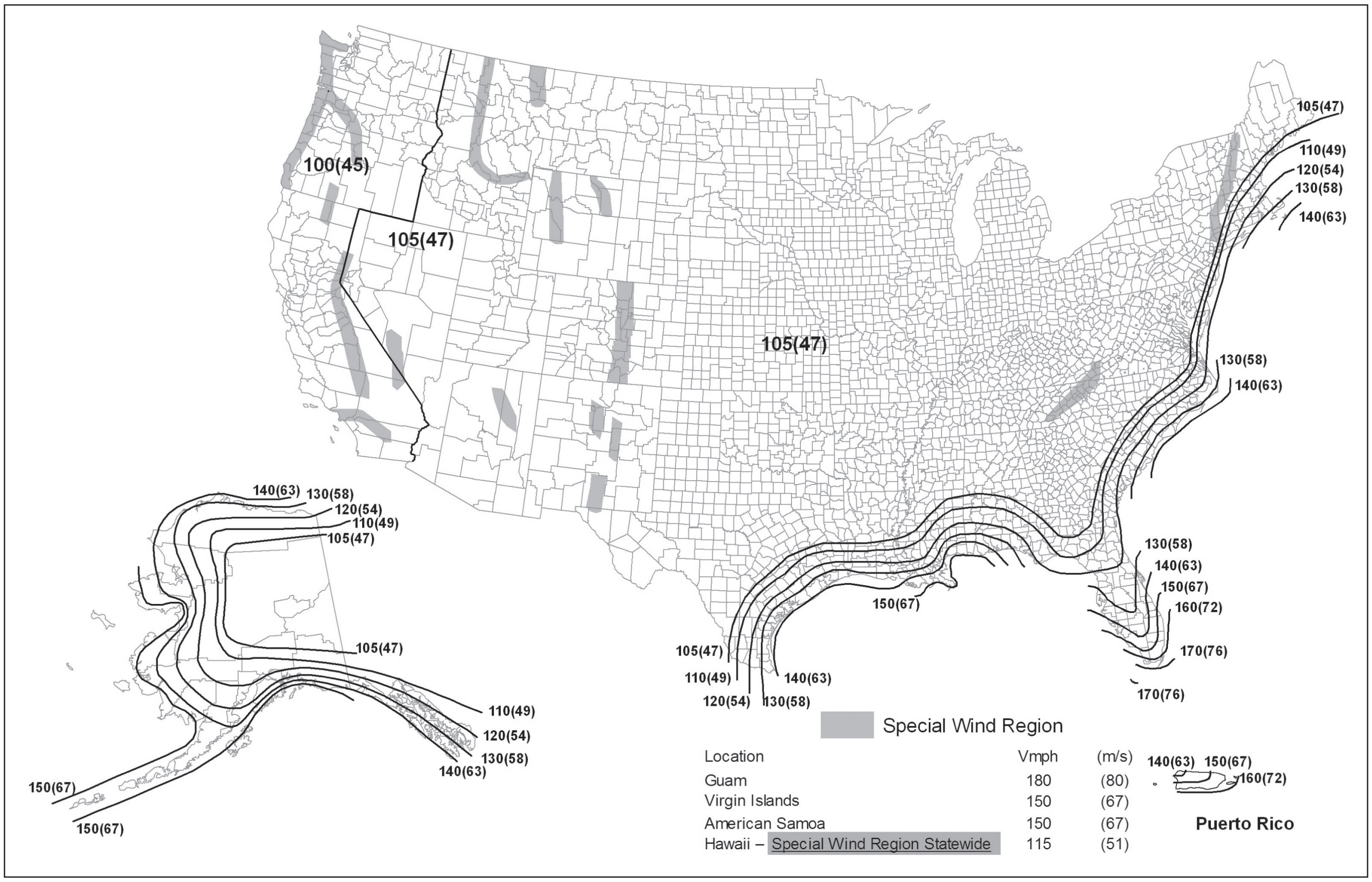

Figure A1-6: Figure 26.5-1C—Basic Wind Speeds for Occupancy Category I Buildings and Other Structures

- Figure 26.5-1B—Basic Wind Speeds for Occupancy Category III and IV Buildings and Other Structures
- Figure 26.5-1C—Basic Wind Speeds for Occupancy Category I Buildings and Other Structures

These basic wind speed maps are based on strength design. The previous edition of ASCE 7 (2005 edition) had a single map based on allowable stress design. Since the maps in ASCE 7-10 are based on strength design, a load reduction factor needs to be applied to convert them to allowable stress design. Since roof systems generally are designed using allowable stress design, applying a load reduction factor of 0.6 to design wind loads may be appropriate.

Exposure category. Exposure is based on surface roughness that is determined by natural topography, vegetation and constructed facilities. ASCE 7-10 has three exposure categories: B, C and D. See Figure A1-7 (on page 558). Generally, Exposure C applies to most areas of the U.S., while Exposure B applies to most urban, suburban and wooded areas, and Exposure D applies to coastline areas.

Effective wind area. Effective wind area is defined as the area secured by a single fastener. ASCE 7-10's Table 30.7-2 includes four effective wind areas, 10, 20, 50 and 100 square feet. For membrane roof systems, 10 square feet is appropriate.

Wind Zones. In ASCE 7-10, three design wind-load values are determined and referred to as being applicable to Zones 1, 2 and 3. Zone 1 refers to a roof's field as determined by Part 2: Low-rise Buildings (Simplified) and Part 4: Buildings with h≤160 ft. (Simplified); Zone 2 applies to a roof's perimeter region; and Zone 3 applies to a roof's corner region. See Figure A1-8 (on page 558).

Design wind load values for perimeter areas (Zone 2) and corners (Zone 3) are higher than the field of a roof (Zone 1). The parameters that affect the determination of the higher design wind load pressures for Zones 2 and 3 are internal and external pressure coefficients (referred to as GC_{pi} and GC_p, respectively). Pressure coefficients are ratios of between actual wind pressures and a computed velocity pressure. Internal pressure coefficient values (GC_{pi}) are based on a building's enclosure classification (enclosed, partially enclosed or open). External pressure

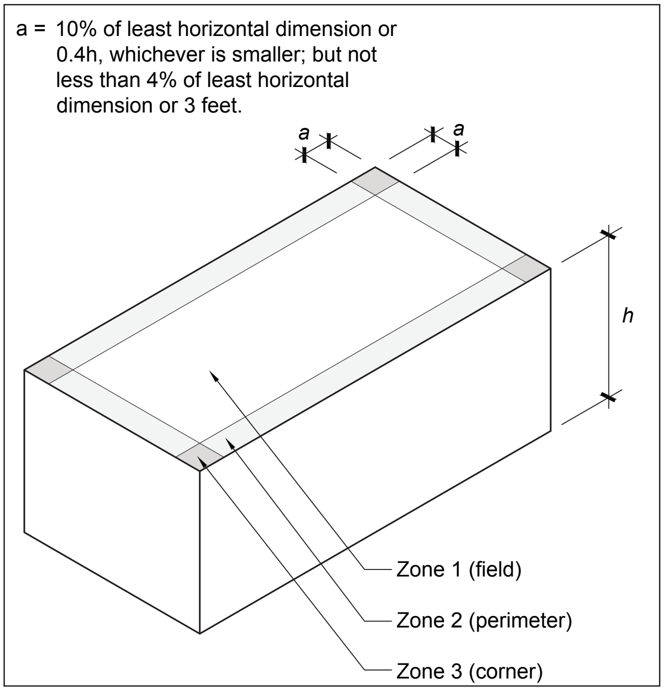

Figure A1-8: Wind zone areas

coefficient values (GC_p) are based on building height, the surface relative to the wind direction, roof slope and roof shape (e.g., flat, gable, hip, shed).

Dimension "*a*". ASCE 7-10 identifies a dimension determined by calculation, referred to as "*a*," that defines the depth of the perimeter and corner zones from the roof area's edges. See Figure A1-8. Dimension "*a*" is 10 percent of the least horizontal dimension of the building or 0.4 times the mean building height, whichever is smaller; but not less than either 4 percent of the least horizontal dimension or 3 feet.

Roof edge parapets may assist in reducing design wind loads acting in the corner regions of the roof area. ASCE 7-10, Part 3: Buildings with h > 60 ft., allows for this reduction only when a minimum 36-inch high parapet occurs at the two outside edges of the specific corner area where the design wind load is being reduced. See Figure A1-9.

Adjustment of Strength Design to Allowable Stress Design (ASD): As previously mentioned, the design wind loads determined by ASCE 7-10 are strength design values. Because roof systems and roof system components generally are designed using the ASD method, a designer can adjust the strength design method's values to ASD method's values. A load-reduction factor is applied as a multiplier to the strength design

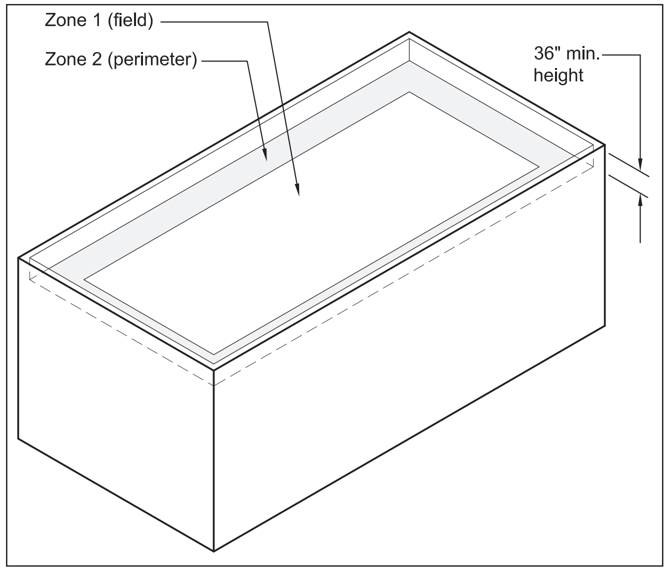

Figure A1-9: Roof edge parapet

values to determine the ASD values. ASCE 7-10 provides a load-reduction factor of 0.6 for this purpose, and the calculation is expressed as follows:

ASD value = Strength design value x 0.6

Determining Minimum Recommended Design Uplift-resistance Capacity: To determine the appropriate minimum recommended design uplift-resistance capacity, multiply the ASD design wind loads by an appropriate safety factor. It would be expressed as follows:

Design Uplift-resistance Capacity = [ASD Design Wind Load] x [Safety Factor]

To reasonably ensure a roof system's wind-resistance capacity is greater than design loads, engineering and wind-design practices call for safety factors to be applied to roof systems' design wind loads. For roof systems, this safety factor accounts for usually anticipated variances in materials and construction and possible deterioration of materials' physical properties as a result of aging. Safety factors for building materials, components and systems typically vary in magnitude based on a number of factors, including materials used and complexity of building system components.

For low-slope membrane roof systems, a minimum safety factor of 2.0 typically is considered appropriate and based on ASTM D6630, "Standard Guide for Low Slope Insulated Roof Membrane Assembly Performance."

However, for a roof assembly with a steel deck and a steel or aluminum metal panel roof system, a safety factor of 1.67 is considered appropriate. This safety factor is recommended in AISI S100, "North American Specification for the Design of Cold-Formed Steel Structural Members" and The Aluminum Association's *Aluminum Design Manual*, Specification for Aluminum Structures section.

Tested Uplift-resistance Capacities: Using these minimum recommended design uplift-resistance capacity values, a user can select an appropriate wind-resistant roof system. Roof systems' tested uplift-resistance load capacities typically are determined by laboratory testing or engineering analysis. The tested uplift-resistance capacity of a roof system should be greater than the minimum recommended design wind-resistance loads for the roof system to be considered appropriately wind-resistant. This is expressed as:

Tested uplift-resistance capacity ≥ Design uplift-resistance capacity

Roof System Design: How a roof system is designed and installed to resist wind uplift depends on the roof assembly. Following are some examples.

- For built-up or polymer-modified bitumen roof systems installed on a nailable deck, the base sheet has to be designed and installed to resist wind uplift.
- For built-up, polymer-modified bitumen or adhered single-ply roof systems installed over an insulated deck, the rigid board insulation has to be designed and installed to resist wind uplift.
- For conventional mechanically attached single-ply membrane roof systems installed over an insulated deck, the rigid board insulation and roof membrane have to be designed and installed to resist wind uplift.
- For induction welded roof systems installed over an insulated deck, the fasteners that secure board insulation to a structural deck are the same fasteners that secure the roof membrane.

In all cases, the corners and perimeters are designed to resist greater wind-uplift loads. The designer is responsible for determining the required fastening patterns at corner and perimeter regions and clearly indicating this information in the project's drawings and specifications. NRCA recommends that designers determine the required attachment patterns based on manufacturer's test data.

For additional information on the attachment of base sheets, rigid board insulation and roof membranes, refer to Chapter 6—Fasteners.

Building Code Requirements: Requirements for structural design are indicated in Chapter 16—Structural Design of *The International Building Code, 2015 Edition*. This chapter necessitates that design loads and other information pertinent to the structural design be shown on the construction documents. Design information should include live, flood, seismic, snow, wind and any other special loads that are applicable to a building. For wind design, the following information should be provided, regardless whether the wind loads govern the design of the lateral force-resisting system of the structure:

- Ultimate wind design
- Risk category
- Wind exposure
- Applicable internal pressure coefficient
- For components and cladding: the design wind pressures in terms of pounds per square foot (psf) to be used for the design of exterior component and cladding materials not specifically designed by the registered design professional.

Designer Responsibility: Designers should not place the responsibility for determining roof system or individual component design wind loads on manufacturers, component suppliers or installers, or roofing contractors. Also, designers' sole reliance on specifying wind speed warranties is not a substitute for code-required wind design data. Such warranties typically do not address consideration of ultimate and nominal design wind speeds, building height, risk category, wind exposure, and external and internal pressure coefficients applicable to the specific building necessary for properly determining roof systems' design wind loads.

Responsibility for properly determining and clearly identifying wind design data, including design wind loads for roof systems, is required by the building code and is that of roof system designers. Roof system designers may retain a structural engineer or qualified consultant to help them fulfill their design responsibilities.

To help designers determine wind loads for commonly encountered low-slope roof systems, NRCA, the Midwest Roofing Contractors Association and North/East Roofing Contractors Association have developed and offer a free online application, Roof Wind Designer.

Roof Wind Designer is a web application that allows users to determine design wind loads using ASCE 7, "Minimum Design Loads for Buildings and Other Structures," 2005 or 2010 editions. Roof Wind Designer is accessible at www.roofwinddesigner.com.