ANSI/SPRI RP-4 2019

Wind Design Standard for Ballasted Single-ply Roofing Systems

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This standard is for use by architects, engineers, consultants, roofing contractors and owners of low slope roofing systems. This standard specifically does not address existing building drainage capacity or overflow drainage requirements and should not be used for those purposes. It is intended to provide data and guidance necessary to understand the implementation and use of retrofit roof drainage elements. Do not assume all existing buildings have code compliant drainage. SPRI, IT'S MEMBERS AND EMPLOYEES DO NOT WARRANT THAT THIS STANDARD IS PROPER AND APPLICABLE UNDER ALL CONDITIONS.

Table of Contents

1 Introduction

This standard provides a method of designing wind uplift resistance of *ballasted* single-ply roofing systems. It is intended as a design and installation reference for those individuals who design, specify, and install *ballasted* single-ply roofing systems. It shall be used in conjunction with the installation specifications and requirements of the manufacturer of the specific products used in the *ballasted* single-ply roofing system. See Commentary.

The "authority having jurisdiction" is the only source for approval of designs not covered in this document. ASCE 7 gives guidance on how non-standard conditions should be evaluated. See Reference 1 or conduct wind tunnel studies in accordance with ASCE 7 for information to determine requirements for designs or systems not covered.

2 Definitions

Terms defined in Section 2.0 appear in *italics* throughout the standard.

2.1 Ballast

In roofing, *ballast* comes in the form of large stones, (typically river bottom stone ¾ in. to 1½ in. diameter, size No. 4 per ASTMD7655/D7655M "Standard Classification for Size of Aggregate Used as Ballast for Membrane Roof Systems") or paver systems or lightweight interlocking paver systems. *Ballast* is used to provide uplift resistance for roofing systems that are not adhered or mechanically attached to the roof deck. See Commentary.

2.2 Conventional Ballasted Roof System

A *conventional ballasted roof system* consists of membrane or membrane and substrate material (insulation, slip sheet, etc.) loose-laid over a deck using *ballast* to hold the system in place.

2.3 Protected Membrane Ballasted Roof System

A *protected membrane ballasted roof system* consists of a roof deck, with or without insulation, over which the membrane is installed. The membrane is either loosely laid, mechanically attached or adhered to the substrate. Insulation is then installed over the membrane. The insulation is then covered with a water-and air-pervious fabric over which *ballast* is applied.

2.4 Protected Membrane Ballasted Roof System Using a Cementitious Coating Which Has Been Attached to the Insulation as Ballast

The interlocking insulation panels with an attached cementitious material act as both insulation and *ballast*.

2.5 Wind Speed

See Commentary

The Basic *Wind Speed* is the Vult *wind speed* and is the 3-second gust speed at 33 ft. (10 m) above the ground in *Exposure C* as follows:

2.5.1 Risk Category II

Wind Speeds correspond to approximately a 7% probability of exceedance in 50 years. See Attachment I-A.

2.5.2 Risk Category III and IV

Wind speeds correspond to approximately a 3% probability of exceedance in 50 years. See Attachment I-B.

2.5.3 Risk Category I

Wind speeds correspond to approximately a 15% probability of exceedance in 50 years. See Attachment I-C.

2.6 Roof Areas

2.6.1 Corner

The space between intersecting walls forming an angle greater than 45 degrees but less than 135 degrees. See Commentary.

2.6.2 Corner Zone

For roofs having height, h ≤ 60 ft. (18 m), the *corner zone* is defined as the *corner* roof section with sides equal to **α** (see below). For roofs having height, h > 60 ft. (18 m), the *corner zone* is defined as the *corner* roof section with sides equal to 2 × **α** (see below). See Figure 1.

α = 0.4h, but not less than either 4% of least horizontal dimension or 8.5 ft. (2.9 m)

2.6.3 Perimeter Zone

The *perimeter zone* is defined as the *rectangular roof* section parallel to the roof edge and connecting the *corner zones* with a width measurement equal to **α** (see above). See Figure 1.

2.6.4 Field

The *field* of the roof is defined as that portion of the roof surface which is not included in the *corner zone* or the *perimeter zone* as defined above. See Figure 1.

2.6.5 Rectangular Roof

Area located directly above a large opening which has as its width 1.5 times the width of the opening and as its depth 2.0 times the width of the opening. See Figure 2.

2.7 Surface Roughness/Exposure Categories

A ground *surface roughness* within each 45-degree sector shall be determined for a distance upwind of the site as defined in Section 2.7.1, 2.7.2. or 2.7.3. for the purpose of assigning an exposure category.

2.7.1 Surface Roughness/Exposure B

Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger. *Exposure B*: For buildings with a mean roof height of less than or equal to 30 ft. (9.1 m), *Exposure B* shall apply where the ground *surface roughness*, as defined by *Surface Roughness* B, prevails in the upwind direction for a distance greater than 1,500 ft. (457 m). For buildings with a mean roof height greater than 30 ft. (9.1 m), *Exposure B* shall apply where *Surface Roughness* B prevails in the upwind direction for a distance greater than 2,600 ft. (792 m) or 20 times the height of the building, whichever is greater.

2.7.2 Surface Roughness/Exposure C

Open terrain with scattered obstructions having heights generally less than 30 ft. (9.1 m). This category includes flat open country and grasslands. *Exposure C* shall apply for all cases where Exposures B or D do not apply. See Commentary.

2.7.3 Surface Roughness/Exposure D

Flat, unobstructed areas and water surfaces. This category includes smooth mud flats, salt flats, and unbroken ice. *Exposure D* shall apply where the ground *surface roughness*, as defined by *Surface Roughness D*, prevails in the upwind direction for a distance greater than 5,000 ft. (1,524 m) or 20 times the building height, whichever is greater. *Exposure D* shall also apply where the ground *surface roughness* immediately upwind of the site is B or C, and the site is within a distance of 600 ft. (183 m) or 20 times the building height, whichever is greater, from an *Exposure D* condition as defined in the previous sentence. For a site located in the transition zone between exposure categories, the category resulting in the largest wind forces shall be used.

2.7.4 Exception

An intermediate exposure between the preceding categories is permitted in a transition zone provided that it is determined by a rational analysis method defined in the recognized literature.

2.8 Impervious Decks

A roof deck that will not allow air to pass through it. Some examples are poured in-place-concrete, gypsum, and cast-in-place lightweight concrete. See Commentary.

2.9 Pervious Decks

A roof deck that allows air to move through it. Some examples are metal, cementitious wood fiber, oriented strand board, plywood and wood plank. See Commentary.

2.10 Risk Category

A categorization of buildings and other structures for determination of flood, wind, snow, ice, and earthquake loads based on the risk associated with unacceptable performance. See Table I.

2.11 Wind-borne Debris Regions

Areas within hurricane prone areas where impact protection is required for glazed openings.

2.12 Registered Design Professional

An individual who is registered or licensed to practice their respective design profession as defined by the statutory requirements of the professional registration laws of the state or jurisdiction in which the project is to be constructed.

2.13 Peel Stop

A termination device, typically a bar or reinforced membrane strip, installed approximately 12-inches away from the roof edge, parapet wall or angle change. The device is attached with mechanical anchors to the roof deck using fasteners spaced per manufacturers instructions.

Table I: Risk Category of Buildings and Other Structures for Wind Loads

Use or Occupancy of Buildings and 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. **Note:** 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 of ASCE 7-10 that a release of the substances is commensurate with the risk associated with that Risk Category. Buildings and other structures required to maintain the functionality of other Risk Category IV structures.	IV

3 General Design Consideration and System Requirements

All *ballasted* roofing systems shall comply with the following:

3.1 Roof Structure

The building owner shall consult with a *registered design professional* such as an architect, architectural engineer, civil engineer, or structural engineer to verify that the structure and deck will support the *ballasted* roofing system loads including the *ballast* load in combination with all other design loads.

3.2 The building height shall be measured from ground level to the roof system surface at the roof edge. When more than one roof level is involved, each shall have its own design per Sections 4.0 and 5.0; or be designed to the criteria required for the most exposed or highest roof level. See Section 5.6.1 for building height restrictions

3.3 Slope

This Standard is limited to roof slope designs up to 2 in 12 (10 degrees) as measured at the top side of the roof membrane. For slopes greater than 2 in 12, a *registered design professional* experienced in roof wind design shall provide design requirements and the design shall be approved by the authority having jurisdiction.

3.4 Large Openings In A Wall

For buildings having openings in a single exterior wall that in total exceed 10% of the exterior wall area, in the story located immediately below the roof, the roof shall be designed to resist the pressure created when the opening(s) are in their full, open, position. Such conditions shall be designed in accordance with Section 5.1. See Figure 2 and Commentary.

3.5 Positive Pressure Building Systems

When HVAC equipment generates a positive pressure inside a building greater than 0.5 in. (13 mm) of water, the roof system shall be designed to resist the pressure by increasing the wind load requirements in accordance with Section 5.2. See Commentary.

3.6 Rooftop Projections

The roof area at the base of any rooftop projection that extends more than 2 ft. (0.6 m) above the top of the parapet and has one side longer than 4 ft. (1.2 m) shall be designed in accordance with Section 5.3.

3.7 Overhangs, Eaves and Canopies

By their design, overhangs, eaves and canopies are subject to greater uplift forces than the roof surface because of the impact of the air flow up the wall. Such conditions shall be designed in accordance with Section 5.4. See Figure 3.

3.8 Membrane Requirements

The membrane specified for use in the *ballasted* system shall meet the current recognized industry minimum material requirements. See Commentary.

3.9 Single-Ply Membrane Perimeter Attachment

The perimeter attachment used to terminate a roofing system shall be designed per ANSI/SPRI/FM4435/ES-1. This termination system shall be located at the roof perimeter. See Attachment I and Figures 5 A-D and Figure 6A-D. The substrate into which the termination system is anchored shall be capable of withstanding the calculated load. The procedure outlined in Attachment I shall be used to measure pullout strength.

3.9.1 For Angle Changes

A *peel stop* shall be installed within 12 in. (.3 m) of attachments of membranes at angle changes or system type changes.

3.9.2 Parapet Height

The parapet height for conventional *ballasted* roof systems is the distance from the top of the roof system membrane to the top of the parapet. See Figure 5A , D and Commentary.

3.9.3 For Protected Membrane Ballasted Roof Systems, the parapet height is the distance from the top of the insulation to the top of the parapet. See Figures 5B and 5C.

If the lowest parapet height is outside of the defined *corner zone* of the roof, and is less than 70% of the height of the parapet within the defined *corner zone*, then this lower parapet height shall be used for the design. If the lowest parapet is located outside the defined *corner zone* of the roof and is equal to or greater than 70% of the height of the parapet within the defined *corner zone*, then the minimum parapet height within the *corner* segment shall be used for the design. See example in Figure 7.

3.9.4 Edge Flashing (Gravel Stop)

When an edge flashing is used at the building perimeter, the top edge of the flashing shall be higher than the top surface of the *ballast*. Edge flashing shall be designed and installed in accordance with ANSI/SPRI/FM4435/ES-1. See Commentary.

3.9.5 Transition

A *peel stop* shall be installed at the junction of loose-laid roof membranes with adhered or mechanically attached membrane areas.

3.10 High Winds

When the *wind speed* exceeds 140 miles per hour (63 m/s) 3-second gust *wind speed* after all adjustments are applied, the roof design shall be designed by a *registered design professional* using current wind engineering practices consistent with ASCE 7 and the design shall be approved by the authority having jurisdiction. See Commentary.

3.11 Wind-borne Debris

Roofs installed in regions designated by ASCE 7 or the authority having jurisdiction, as *wind-borne debris regions* shall be designed by a *registered design professional* using current wind engineering practices consistent with ASCE 7 and the design shall be approved by the authority having jurisdiction. See Commentary.

3.11.1 *Wind-borne Debris Regions* are areas within 1 mile of the coastal high mean water line where the ultimate design *wind speed* is equal to or greater than 130 m/h (58 m/s), or

3.11.2 In areas where the ultimate design *wind speed* is 140 m/h (63 m/s) or greater or Hawaii.

3.11.3 Exceptions and other limitations can be found in ASCE 7 Sec. 26.12.3.1

3.12 Stone Ballast Requirements

See Commentary.

Stone *ballast* shall not be less than the following:

3.12.1 #4 Ballast

Nominal 1½-inch smooth river bottom stone of *ballast* gradation size #4, or alternatively, #3, #2, or #1 as specified in ASTM D7655/D7655M spread at a minimum rate of 1,000 lbs./100 ft.^{2} (48.80 kg/m^2).

3.12.2 #2 Ballast

Nominal 2½-inch smooth river bottom stone of *ballast* gradation size #2 or alternatively #1, as specified in ASTM D7655/D7655M spread at a minimum rate of 1,300 lbs./100 ft.^{2} (63.50 kg/m^2).

3.12.3 Crushed stone

When the gradation requirements for 3.12.1 and 3.12.2 above are met a protection layer meeting the membrane manufacturer's specifications shall be installed between the membrane and the crushed stone.

3.13 Paver Ballast Requirements

Paver *ballast* not be less than the following:

3.13.1 #4 Ballast

Standard concrete pavers (minimum 18 lb./ft.^{2}; (88 kg/m^2)) or interlocking, beveled, doweled, or contoured fit lightweight concrete pavers (minimum 10 lb./ft.^{2}, (49 kg/m^2)).

3.13.2 #2 Ballast

Concrete pavers (minimum 22 lb./ft.^{2} (107 kg/m^2)); or approved interlocking, beveled, doweled or contoured fit, lightweight concrete pavers (minimum 10 lb./ft.^{2}, (49 kg/m^2)) when documented or demonstrated as equivalent.

3.13.3 For *protected membrane ballasted* systems using a cementitious coating see Section 4.2.2.

4 Design Options

The *ballasted* roof wind designs include, but are not limited to, the generic systems shown below. Other systems, when documented or demonstrated as equivalent with the provisions of this standard, shall be used when approved by the authority having jurisdiction. The designs listed in Sections 4.1 and 4.2 are the minimum specifications. See Commentary.

4.1 Conventional Ballasted Single-Ply Systems

See Commentary.

4.1.1 System 1

The installed membrane shall be *ballasted* with #4 *ballast*. See Section 3.12.1.

4.1.2 System 2

The installed membrane shall be *ballasted* as follows:

4.1.2.1 Corner Zone

The installed membrane in the *corner zone* shall be *ballasted* with #2 *ballast*.
See Section 3.12.2 and Figure 1.

4.1.2.2 Perimeter Zone

The installed membrane in the *perimeter zone* shall be *ballasted* with #2 *ballast*.
See Section 3.12.2 and Figure 1.

4.1.2.3 Field

In the *field* of the roof, the installed membrane shall be *ballasted* with #4 *ballast*.
See Section 3.12.1. #2 *ballast* shall be the minimum size-weight *ballast* used in wind-borne debris areas. See Section 3.12.2.

4.1.3 System 3

Install the system as follows:

4.1.3.1 Corner Zone

In each *corner zone*, an adhered or mechanically attached roof system designed to withstand the uplift force in accordance with ASCE 7 or the local building code, shall be installed in accordance with the provisions for the *corner* location with no loose aggregate placed on the membrane. See Figure 1.

When a protective covering is required, an adhered membrane system shall be used in the *corner zone*. Minimum 22 lb./ft.^{2} (107 kg/m^2) pavers or other material approved by the authority having jurisdiction shall be installed over the adhered membrane. Mechanically fastened membrane systems shall not be used when a protective covering is required.

4.1.3.2 Perimeter Zone

In the *perimeter zone*, an adhered or mechanically attached roof system designed to withstand the uplift force in accordance with ASCE 7 or the local building code, shall be installed, in accordance with the provisions for the *perimeter zone* with no loose stone placed on the membrane. See Commentary.

When a protective covering is required, an adhered membrane system shall be used in the *perimeter zone*. Minimum 22 lb./ft.^{2} (107 kg/m^2) pavers or other material approved by the authority having jurisdiction shall be installed over the adhered membrane. Mechanically fastened membrane systems shall not be used when a protective covering is required.

4.1.3.3 Field

In the *field* of the roof, install #2 *ballast*. See Section 3.12.2.

4.1.4 Transition

A *peel stop* shall be installed at the junction of loose-laid roof membranes with the adhered or mechanically attached membrane areas.

4.2 Protected Membrane Roofing Systems

See Commentary.

The protected membrane roof wind designs include, but are not limited to, the generic systems shown below. Other systems, which comply with the provision of this standard, shall be permitted when approved by the authority having jurisdiction.

4.2.1 Protected Membrane Roofing Systems Using Stone and/or Pavers for Ballast

4.2.1.1 System 1 and System 2

When the design criteria based on *wind speed*, building height, and parapet height and exposure, require a System 1 or System 2 design, the ballasting procedures for that respective system shall be followed. See Sections 4.1.1 and 4.1.2.

4.2.1.2 System 3

When the design criteria, based on *wind speed* and building height, parapet height and exposure require a System 3 design, a minimum 24 in. (0.61 m) parapet height is required and the installation procedures for System 3 as defined in Section 4.1.3 above shall be followed. In addition, the insulation that is installed over the adhered *perimeter zone* and *corner zone* shall be *ballasted* with minimum 22 lb./ft.^{2} (107 kg/m^2) pavers or other material approved by the authority having jurisdiction. Mechanically attached systems shall not be used. See Section 3.9.2 and Commentary.

4.2.2 Protected Membrane Ballasted Roof Systems Using a Cementitious Coating Which Has Been Attached to the Insulation as Ballast

The panels shall be interlocking and weigh a minimum of 4.0 lb./ft.^{2} (20 kg/m^2). A water-and air-pervious fabric is not required in this construction. See Commentary.

For systems utilizing a loose-laid design or a mechanically fastened design, the roof system shall be installed over an *impervious deck* or incorporate an air retarder that is designed to resist the uplift load in accordance with ASCE 7, or the local building code.

4.2.2.1 System 1

When the design criteria based on *wind speed*, building height, and parapet require a System 1 design, the insulation panels with cementitious coating shall be installed over the membrane. For the area within 2 ft. (0.6 m) of the perimeter, minimum 22 lb./ft.^{2} (107 kg/m^2) pavers or other material approved by the authority having jurisdiction shall be installed over the panels.

4.2.2.2 System 2

When the design criteria based on *wind speed*, building height, and parapet require a System 2 design, the insulation panels with cementitious coating shall be installed over the membrane. In addition, for the roof surface within the perimeter and *corner zones*, minimum 22 lb./ft.^{2} (107 kg/m^2) pavers or other material approved by the authority having jurisdiction shall be installed.

4.2.2.3 System 3

When the design criteria based on *wind speed* and building height require a System 3 Design, the roof design shall be based on a *registered design professional's* design method and approved by the authority having jurisdiction. See Commentary.

5 Design Provisions

5.1 Large Openings in a Wall

See Section 3.4 and Commentary.

When the total area of all openings in a single exterior wall is between 10 and 50 percent of that wall area in the story located immediately below the roof, a *rectangular roof* area over the opening shall be designed as a *corner zone* of the respective System 2 or System 3 designs. System 1 designs shall use the *corner zone* specifications of a System 2 design for the *rectangular roof* area. See Figure 2.

When the total area of all openings in a single exterior wall exceeds 50 percent of that wall area in the story located immediately below the roof, the roof shall be designed as part of an open structure. Under these conditions, the rooftop, as identified in the Design Table II A-F as a System 1 design, shall be upgraded to the next level of resistance to the wind. That is, a System 1 design shall be upgraded to a System 2 design, a System 2 design shall be upgraded to a System 3 design, and a System 3 design shall be upgraded to a roof system that is designed to resist the uplift loads in accordance with ASCE 7—or the local building code. The *rectangular roof* area over the opening shall be designed as a *corner zone*.

5.2 Positive Pressure in Building Interior

See Section 3.5.

When positive pressure conditions between 0.5 (15 mm) and 1.0 in. (30 mm) of water are present in a building, the applicable roof system design, as identified in the Design Table II A-F, shall be upgraded to a higher level of resistance to wind. Under these conditions, the roof top *wind speed* shall be increased by 10 mph (4.5 m/s) from the basic *wind speed* from the wind map. See Attachment I A-C. Under these conditions a building roof located in a 115 mph (51 m/s) wind zone shall be upgraded to 125 mph (56 m/s) etc. Installation shall follow all of the requirements for the higher design wind. When positive pressures are greater than 1.0 in. (30 mm) of water, the design of the roof shall be based on a *registered design professional's* design method and approved by the authority having jurisdiction.

5.3 Rooftop Projections

See Section 3.6.

When rooftop projections rise 2 ft. (0.6 m) or more above the parapet height and have at least one side greater than 4 ft. (1.2 m) in length, the roof area that extends 4 ft. (1.2 m) out from the base of such projections shall have the same design as the *corner zone* of the roof.

5.4 Overhangs, Eaves and Canopies

See Section 3.7.

5.4.1 *Impervious Decks*

When a deck is impervious, overhangs, eaves and canopies shall be defined as the following:

The overhang or eave shall be considered the *perimeter zone* of the applicable design. See Figure 3. The entire canopy area shall be designed as a *corner zone* of the applicable design.

5.4.2 ***Pervious Decks***

When the deck is pervious, the design of the entire overhang, eave or canopy area shall be upgraded to the *corner* design of the next level system for wind resistance over the applicable design. See Figure 4. For this situation, the entire overhang, eave or canopy of a System 1 design shall be upgraded to a System 2 *Corner* design; the entire overhang, eave or canopy of a System 2 Design shall be upgraded to a System 3 *Corner* design; the entire overhang, eave or canopy of a System 3 design shall be designed to the System 3 *Corner* design.

In addition, the main roof area extending in from the overhang or eave shall be *ballasted* to the applicable system design as though the overhang did not exist. This means the appropriate *corner* and *perimeter zone*s are to be *ballasted* in accordance with Section 4.0 in addition to the overhang or eave area treatment as described above. See Figure 4.

5.5 Risk Category

ASCE 7 provides *wind speed* maps based on the *risk category* for the buildings being roofed. Find the *wind speed* from the appropriate map (Attachment I A–D) and install the appropriate system using the Design Table II A–F.

5.6 Restrictions for Aggregate Surfaced Ballasted Roofs

See Commentary to Design Tables A–F.

5.6.1 When building height exceeds 150 ft. (46 m), the roof shall be designed by a *registered design professional* using current wind engineering practices consistent with ASCE 7 and the design shall be approved by the authority having jurisdiction. See Commentary C5.6. for design procedure guidance when the building height exceeds 150 ft. (46 m).

5.6.2 When parapet heights are less than 1 ft. (0.3 m), aggregate *ballasted* systems shall be limited to buildings less than 75 ft. (23 m) tall.

6 Determination of Ballasted System Roof Design

To determine the *ballast* design for a given building, the following process shall be followed. See Commentary.

6.1 Based on the building location and *risk category*, the basic design *wind speed* shall be determined from Attachment I A–D following *Surface Roughness/Exposure* from Section 2.7.

6.2 The building height shall be determined by following Section 3.2 and the parapet height from Sections 3.9.2 and 3.9.3.

6.3 Knowing the *wind speed*, building height, parapet height, *Risk Category* and *Surface Roughness/ Exposure*, determine the system design (1, 2 or 3) using the appropriate Design Table II A-F.

6.4 Having determined the System from the Design Table II A–F, use Section 4, Design Options, to determine the ballasting requirements based on the type of roof system; Conventional or Protected Membrane.

6.5 Section 5 Design Provisions shall be reviewed to determine the necessary enhancements to the systems' ballasting requirements. These provisions are the accumulative addition to the base design from the Design Table II A–F.

7 Maintenance

Maintenance shall be the responsibility of the building owner. See Commentary.

Table II

See Commentary

A. From 2.0 inch High Gravel Stop to Less Than 6.0 inch High Parapet
Maximum Allowable Wind Speed (MPH)

Bldg. Ht. Ft.	System 1 Exposure		System 2 Exposure		System 3 Exposure	
	C*	B*	C*	B*	C*	B*
0–15	110	130	140	140	140	140
>15–30	100	105	140	140	140	140
>30–45	95	100	125	140	140	140
>45–60	90	95	120	140	140	140
>60–75	90	95	115	140	140	140
>75–90	No	No	No	No	No	No
>90–105	No	No	No	No	No	No
>105–120	No	No	No	No	No	No
>120–135	No	No	No	No	No	No
>135–150	No	No	No	No	No	No

B. For Parapet Heights from 6.0 to Less than 12.0 inches
Maximum Allowable Wind Speed (MPH)

Bldg. Ht. Ft.	System 1 Exposure		System 2 Exposure		System 3 Exposure	
	C*	B*	C*	B*	C*	B*
0–15	115	140	140	140	140	140
>15–30	100	125	140	140	140	140
>30–45	100	115	125	140	140	140
>45–60	90	110	120	140	140	140
>60–75	90	100	115	140	140	140
>75–90	No	No	No	No	No	No
>90–105	No	No	No	No	No	No
>105–120	No	No	No	No	No	No
>120–135	No	No	No	No	No	No
>135–150	No	No	No	No	No	No

*Refer to Section 2.7 for exposure definitions

[3]Wind speed reference see Section 2.5

miles per hour	100	105	110	115	120	125	130	135	140	145	150	155	160
meters per second	45	47	49	51	54	56	58	60	63	65	67	69	72

C. For Parapet Heights From 12.0 to Less Than 18.0 Inches
Maximum Allowable Wind Speed (MPH)

Bldg. Ht. Ft.	System 1 Exposure		System 2 Exposure		System 3 Exposure	
	C*	B*	C*	B*	C*	B*
0–15	125	140	140	140	140	140
>15–30	105	130	140	140	140	140
>30–45	100	120	130	140	140	140
>45–60	95	110	120	140	140	140
>60–75	90	105	115	140	140	140
>75–90	90	105	115	140	140	140
>90–105	90	100	115	125	140	140
>105–120	85	100	105	125	125	140
>120–135	No	No	No	125	125	140
>135–150	No	No	No	120	125	140

D. For Parapet Heights From 18.0 to Less Than 24.0 Inches
Maximum Allowable Wind Speed (MPH)

Bldg. Ht. Ft.	System 1 Exposure		System 2 Exposure		System 3 Exposure	
	C*	B*	C*	B*	C*	B*
0–15	140	140	140	140	140	140
>15–30	115	135	140	140	140	140
>30–45	105	120	140	140	140	140
>45–60	100	115	120	140	140	140
>60–75	95	110	115	140	140	140
>75–90	90	105	115	140	140	140
>90–105	90	100	115	125	140	140
>105–120	90	100	115	125	140	140
>120–135	85	95	115	125	140	140
>135–150	No	No	No	125	140	140

*Refer to Section 2.7 for exposure definitions

[3]Wind speed reference see Section 2.5

miles per hour	100	105	110	115	120	125	130	135	140	145	150	155	160
meters per second	45	47	49	51	54	56	58	60	63	65	67	69	72

E. For Parapet Heights From 24.0 to Less Than 36.0 Inches
Maximum Allowable Wind Speed (MPH)

Bldg. Ht. Ft.	System 1 Exposure		System 2 Exposure		System 3 Exposure	
	C*	B*	C*	B*	C*	B*
0–15	140	140	140	140	140	140
>15–30	120	140	140	140	140	140
>30–45	105	125	140	140	140	140
>45–60	100	115	125	140	140	140
>60–75	95	110	115	140	140	140
>75–90	95	105	115	140	140	140
>90–105	90	105	115	125	140	140
>105–120	90	100	115	125	140	140
>120–135	85	100	115	125	140	140
>135–150	85	95	115	125	140	140

F. For Parapet Heights From 36.0 to Less Than 72.0 Inches
Maximum Allowable Wind Speed (MPH)

Bldg. Ht. Ft.	System 1 Exposure		System 2 Exposure		System 3 Exposure	
	C*	B*	C*	B*	C*	B*
0–15	140	140	140	140	140	140
>15–30	130	140	140	140	140	140
>30–45	115	135	140	140	140	140
>45–60	105	120	130	140	140	140
>60–75	100	115	125	140	140	140
>75–90	95	110	125	140	140	140
>90–105	95	105	125	140	140	140
>105–120	90	105	125	140	140	140
>120–135	90	100	125	140	140	140
>135–150	85	100	125	140	140	140

*Refer to Section 2.7 for exposure definitions

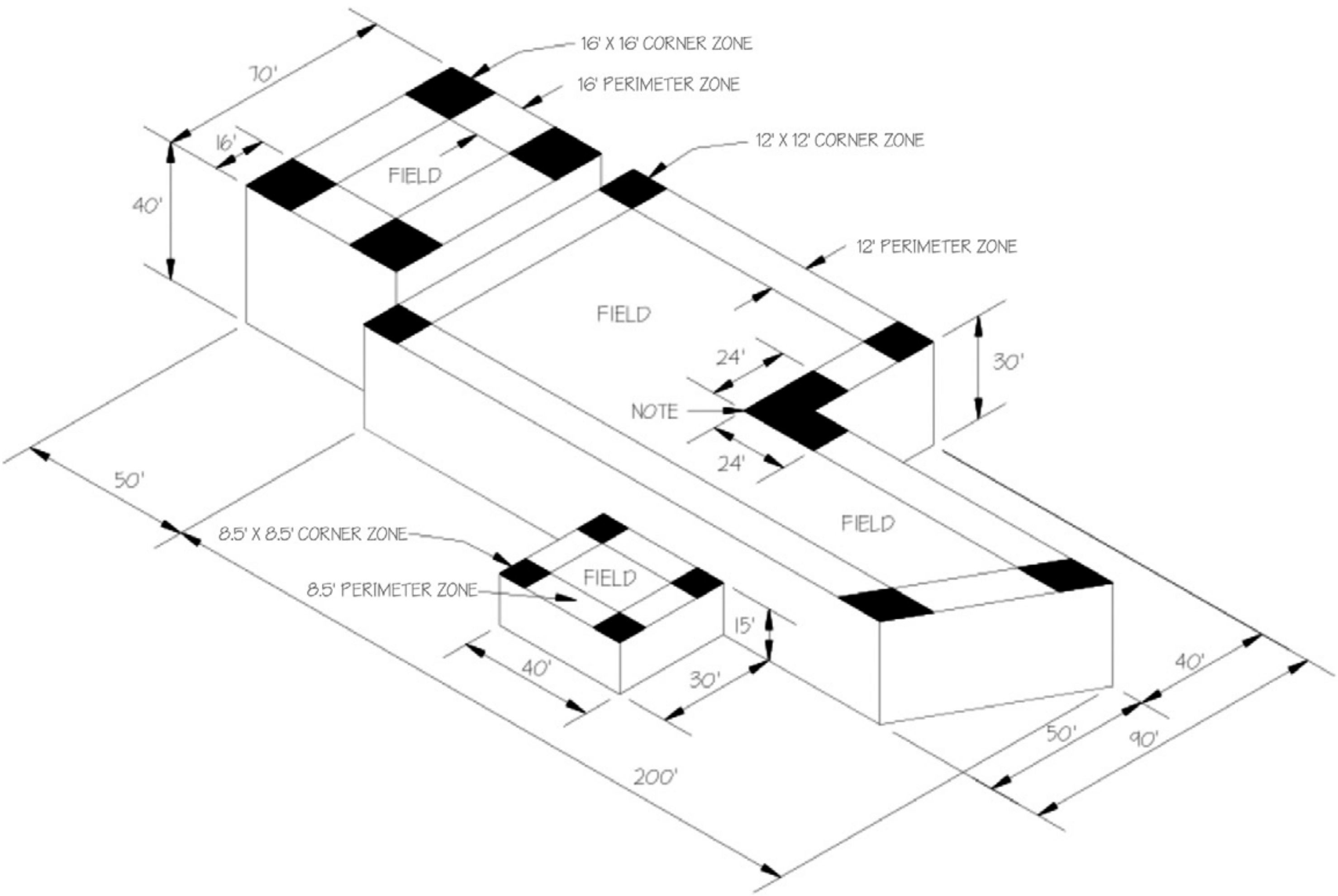
[3]Wind speed reference see Section 2.5

miles per hour	100	105	110	115	120	125	130	135	140	145	150	155	160
meters per second	45	47	49	51	54	56	58	60	63	65	67	69	72

Note: Any building not fitting the above Design Tables shall be treated as a special design consideration requiring review by a *registered design professional* and approval by the authority having jurisdiction.

Figure 1

Roof Layout
Systems 2 and 3



Note: Reentrant corners are larger than other corners.

	Low Roof	Main Roof	High roof
Roof Height	15 ft.	30 ft.	40 ft.
40% of Building Height	6.0 ft.	12 ft.	16 ft.
Corner Length	8.5 ft. (a)	12 ft.	16 ft.
Perimeter Width	8.5 ft. (a)	12 ft.	16 ft.

Figure 1

Roof Layout System 2 & 3
Metric Dimensions

	Low Roof	Main Roof	High Roof
Roof Height meters	4.6 m	9 m	12 m
40% of Building Height	2 m	3.6 m	5 m
Corner Length	2.6 (a) m	3.6 m	5 m
Perimeter Width	2.6 (a) m	3.6 m	5 m

2.6 m minimum controls

Other Dimensions

Description	IP	Metric m
High Roof		
Corner	16 ft. × 16 ft.	5 m × 5 m
Perimeter	16 ft.	5 m
Width	70 ft.	21.3 m
Height	40 ft.	12 m
Main Roof		
Corner	12 ft. × 12 ft.	3.6 m × 3.6 m
Perimeter	12 ft.	3.6 m
Height	30 ft.	9 m
Re-entrant Corner	24 ft. × 24 ft.	7.3 m × 7.3 m
Off set	40 ft.	12 m
Width	90 ft.	27.4 m
Length	200 ft.	61 m
Low Roof		
Corner	8.5 ft. × 8.5 ft.	2.6 m
Perimeter	8.5 ft.	2.6 m
Width	30 ft.	9 m
Height	15 ft.	4.6 m

Figure 2

Large Openings in a Wall
When the sum of various openings (w × h)
is greater than 10% of the wall area

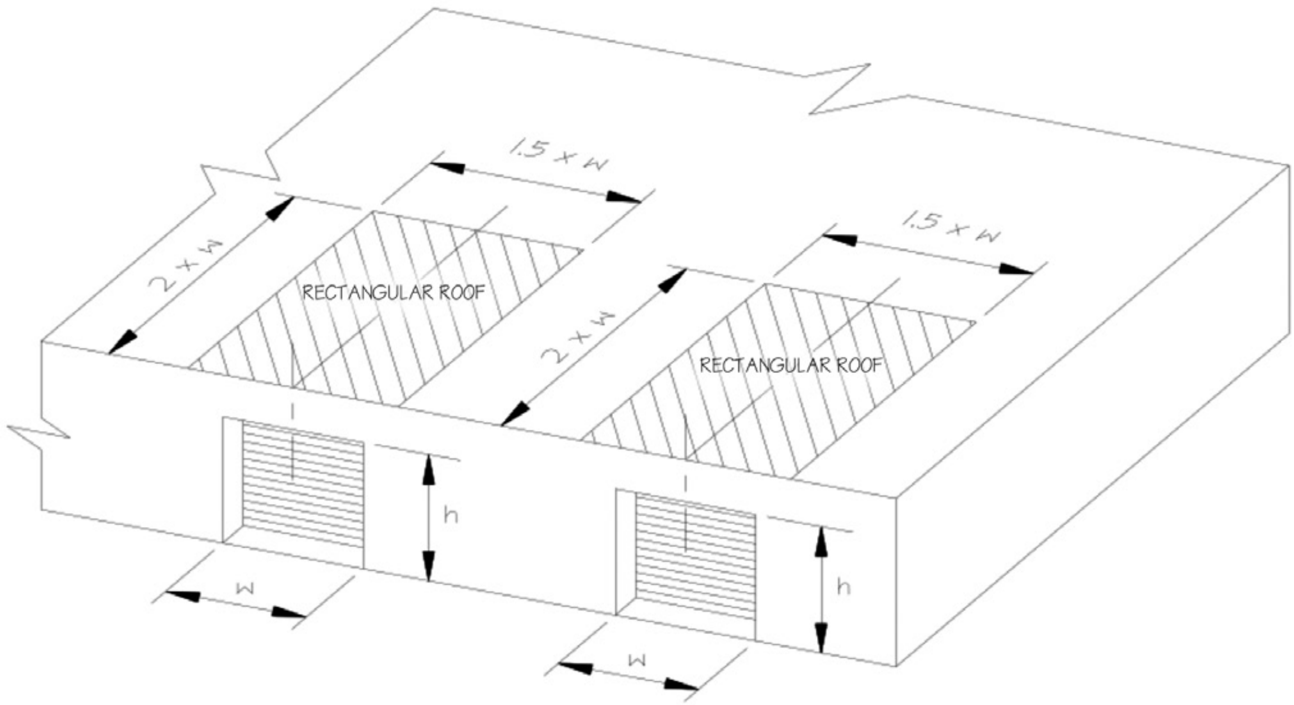
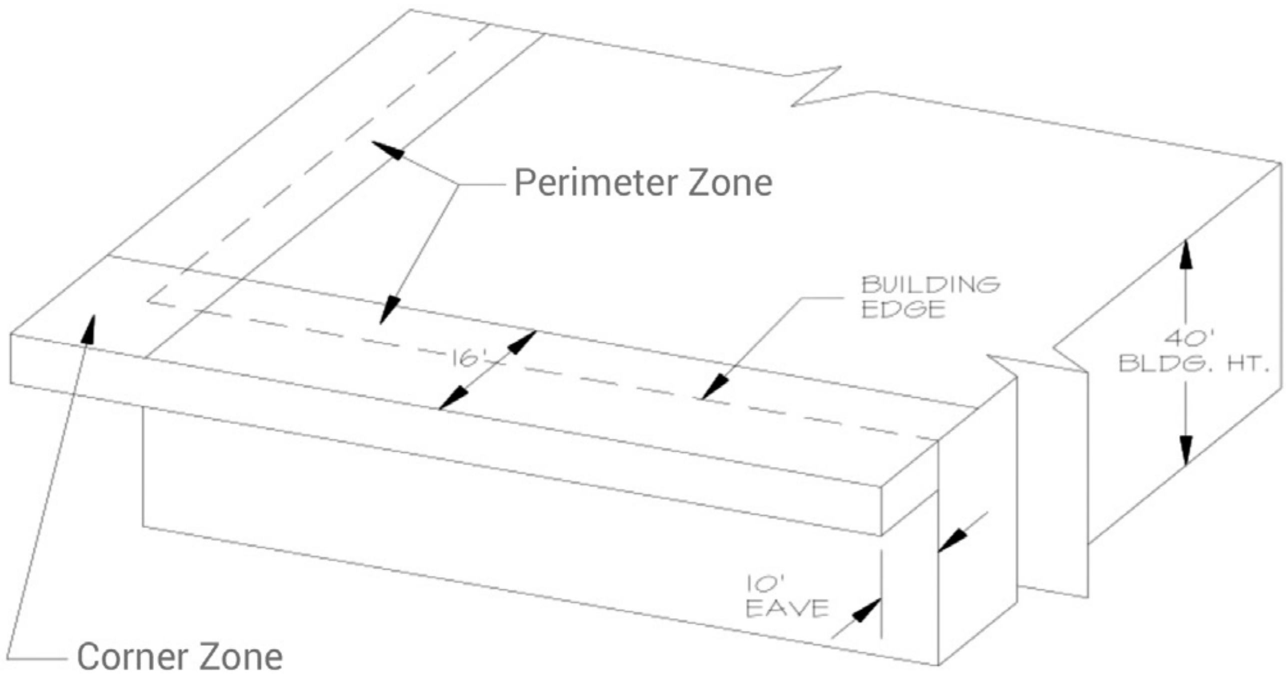


Figure 3

Overhangs, Eaves and Canopies Impervious Decks
For Systems 2 and 3



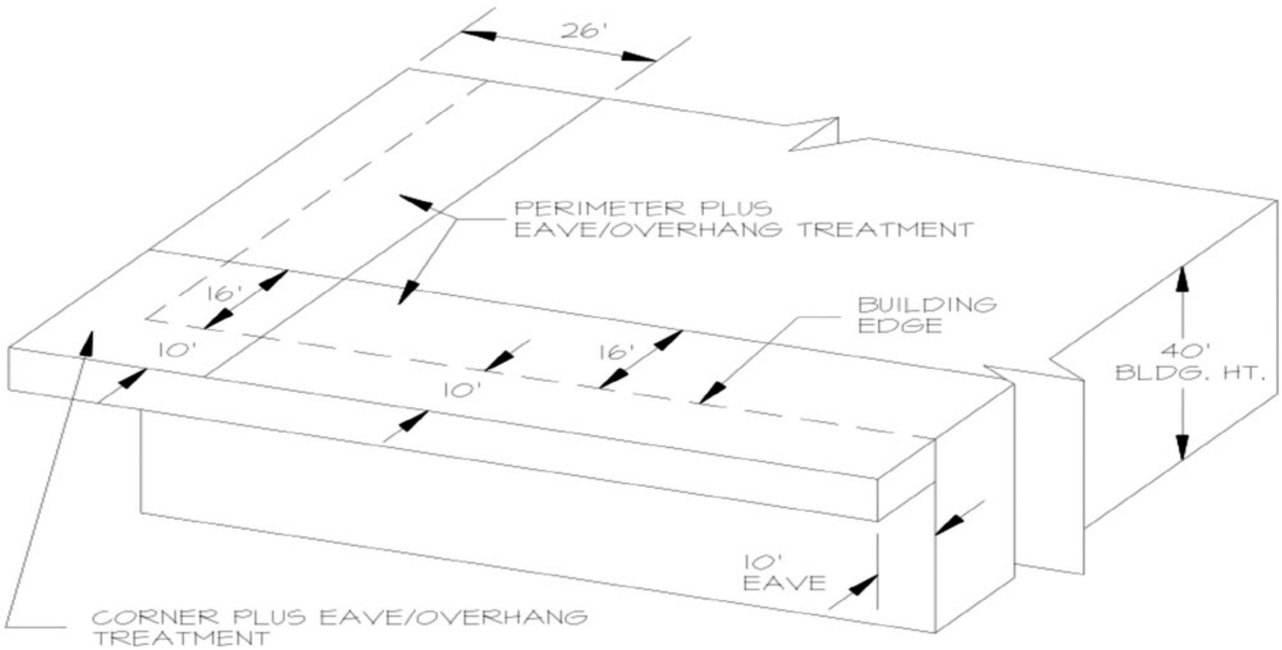
Eave = 10 ft.

Corner Zone = .4 × the building height (or 8.5 ft. (2.6 m) minimum)
16 ft. for this example

Perimeter Zone = .4 × the building height (or 8.5 ft. (2.6 m) minimum)
16 ft. for this example

Figure 4

Overhangs, Eaves and Canopies Pervious Decks
For Systems 1, 2 and 3



Eave = 10 ft.

Corner area = .4 × the building height plus the overhang area
(or 8.5 ft. (2.6 m) minimum)
26 ft. for this example

Perimeter area = .4 × the building height plus the overhang area
(or 8.5 ft. (2.6 m) minimum)
26 ft. for this example

Figure 5 A and B

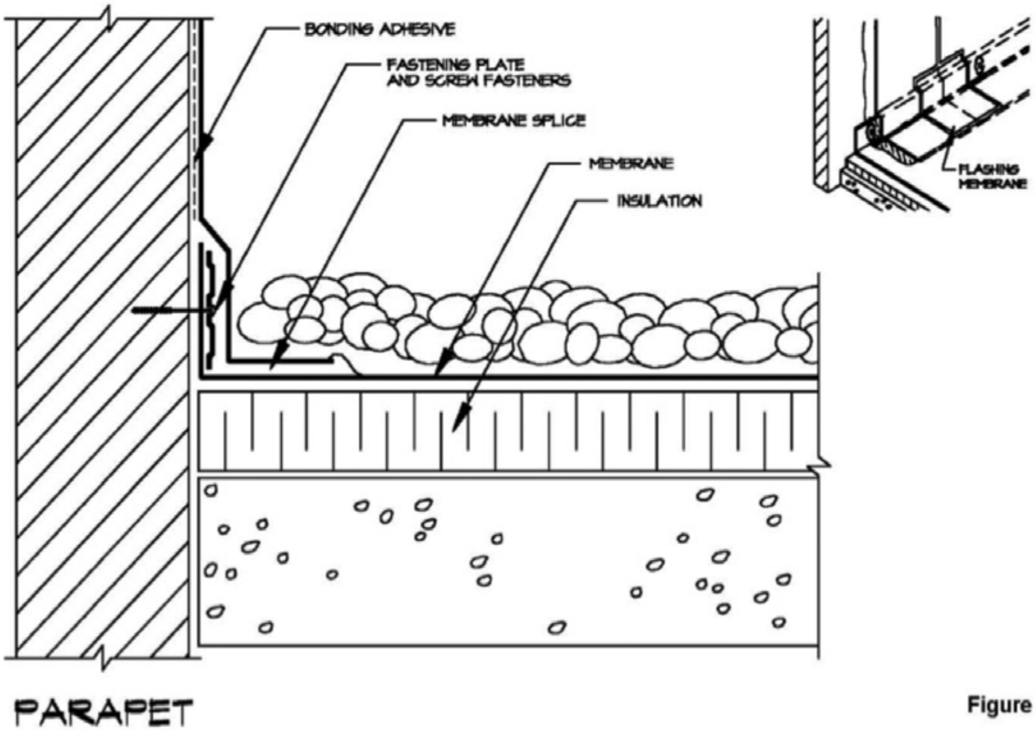


Figure 5A

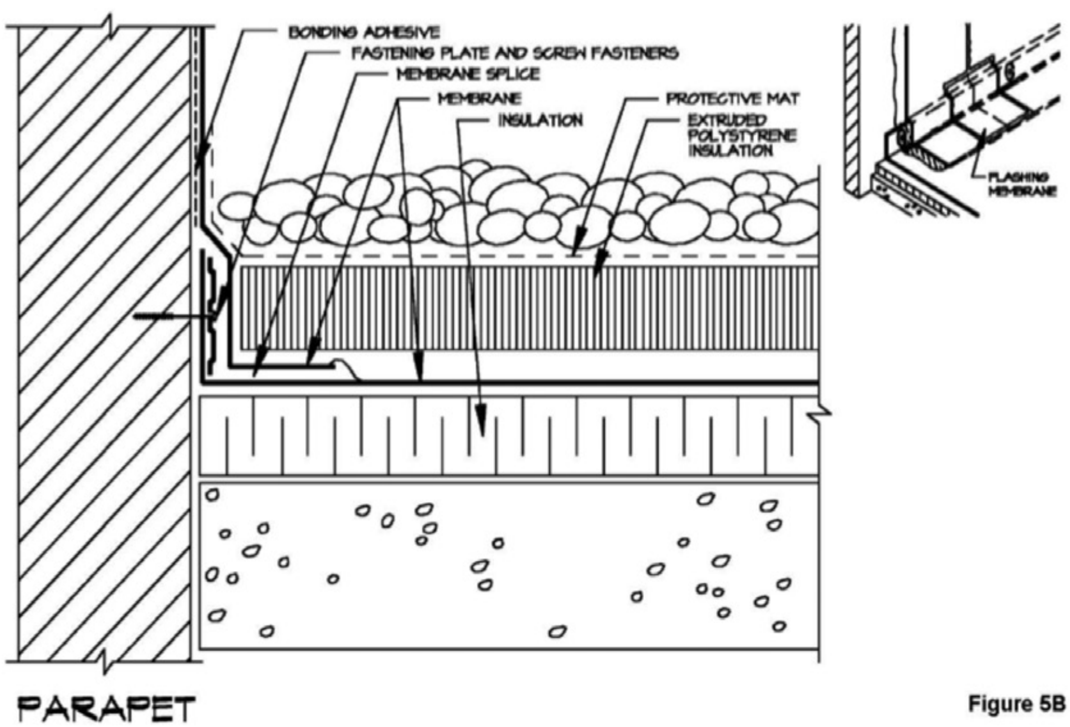
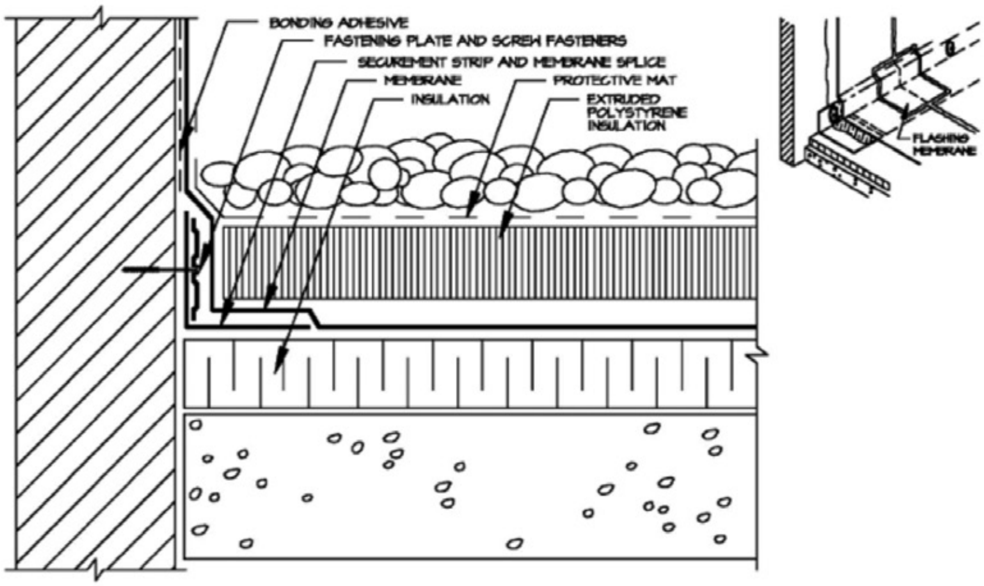
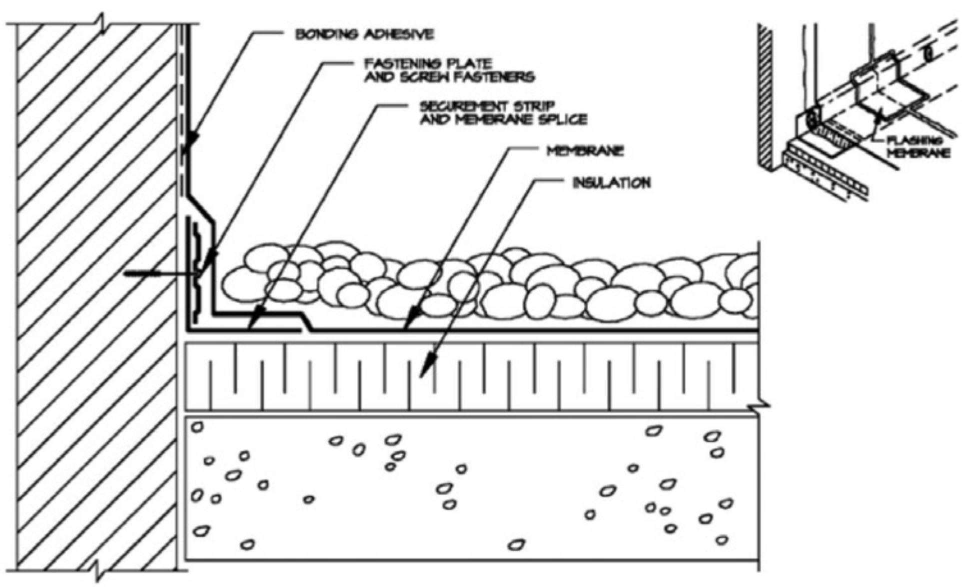


Figure 5B

Figure 5 C and D



PARAPET



PARAPET

Figure 6 A and B

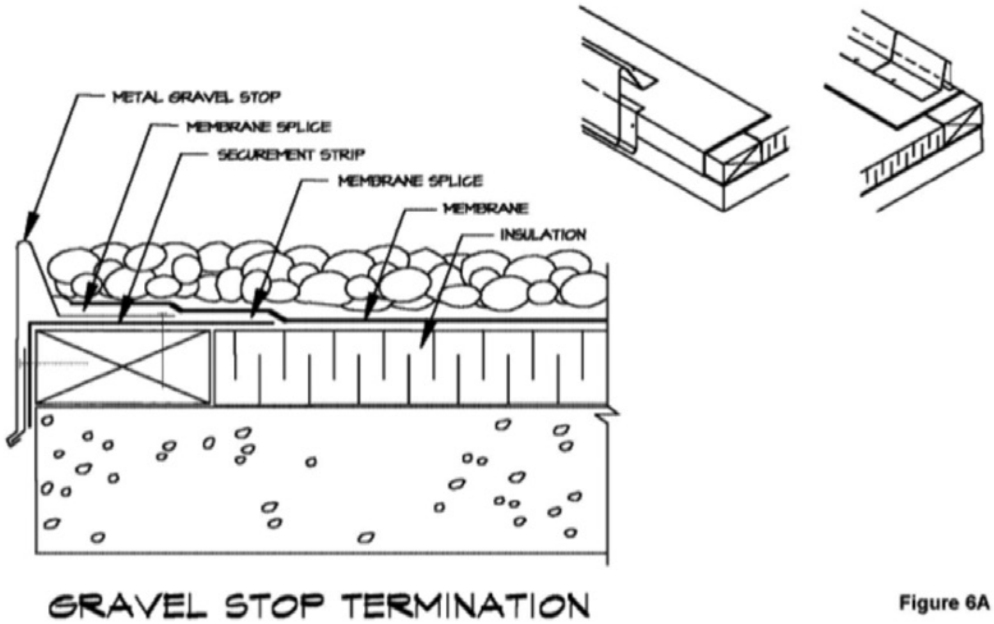


Figure 6A

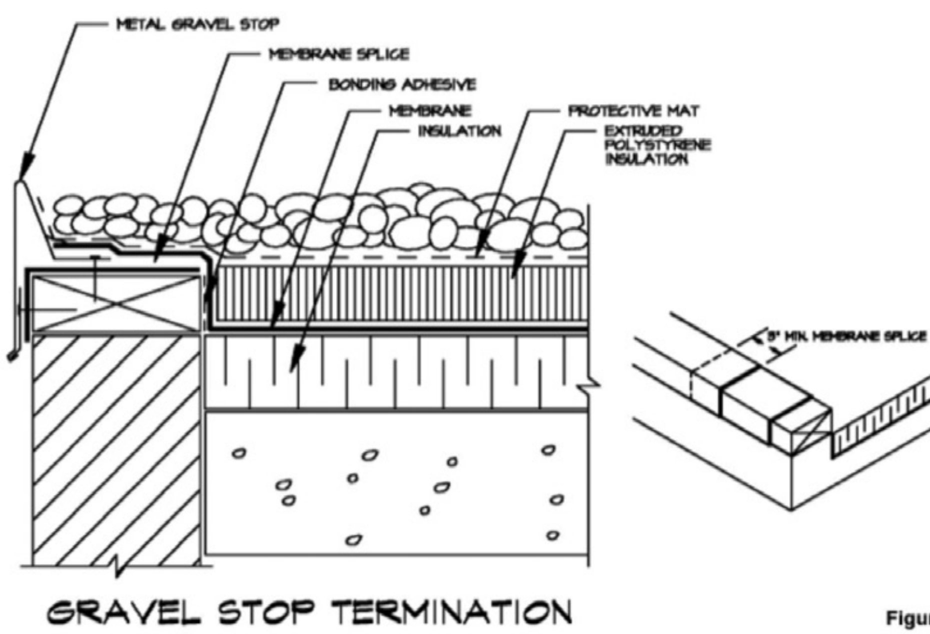


Figure 6B

Figure 6 C and D

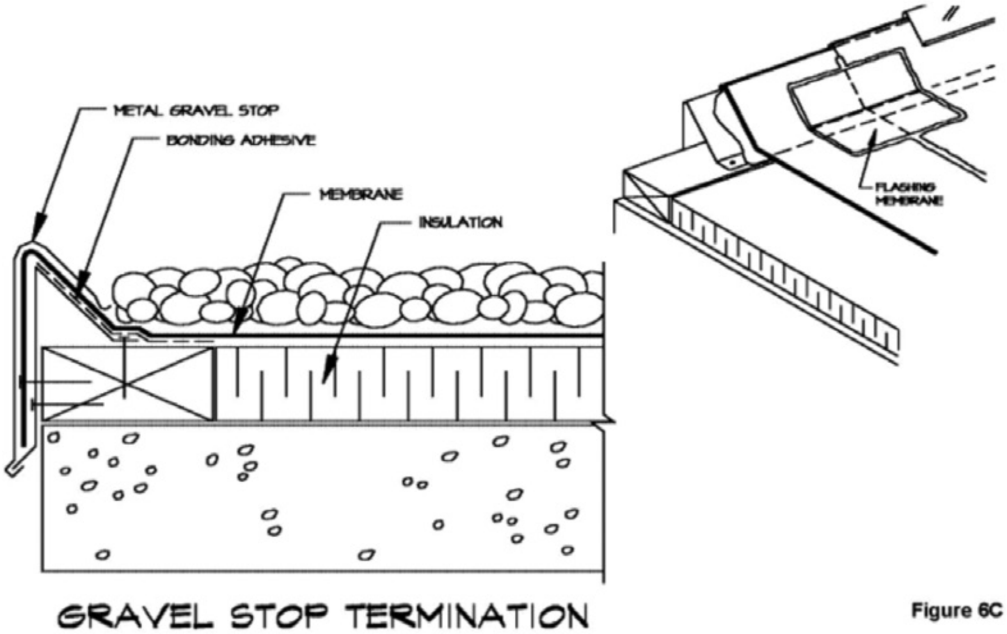


Figure 6C

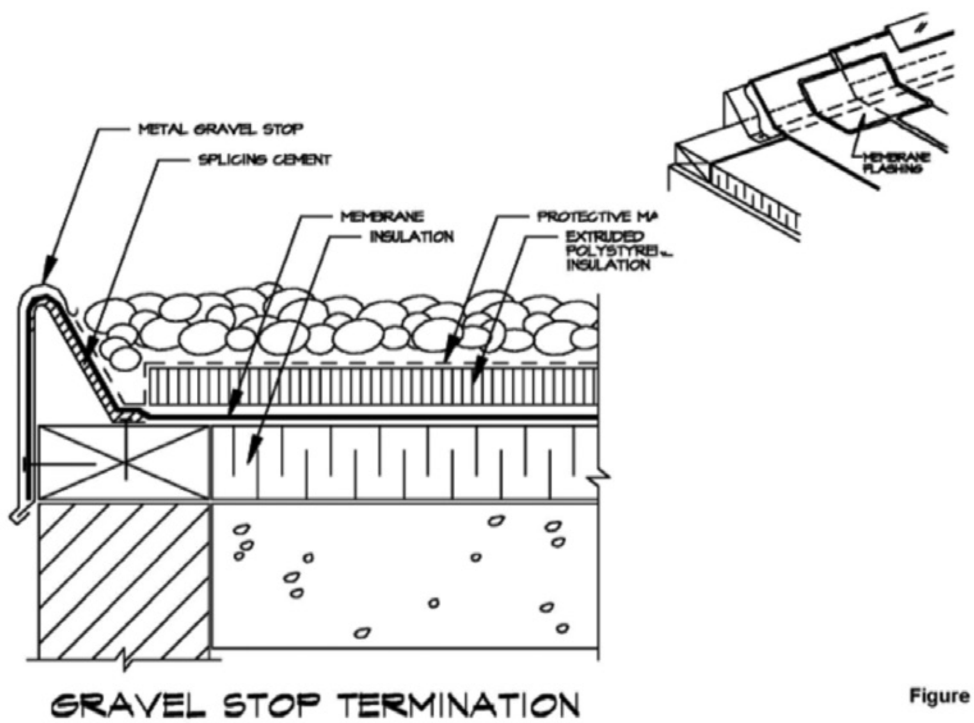
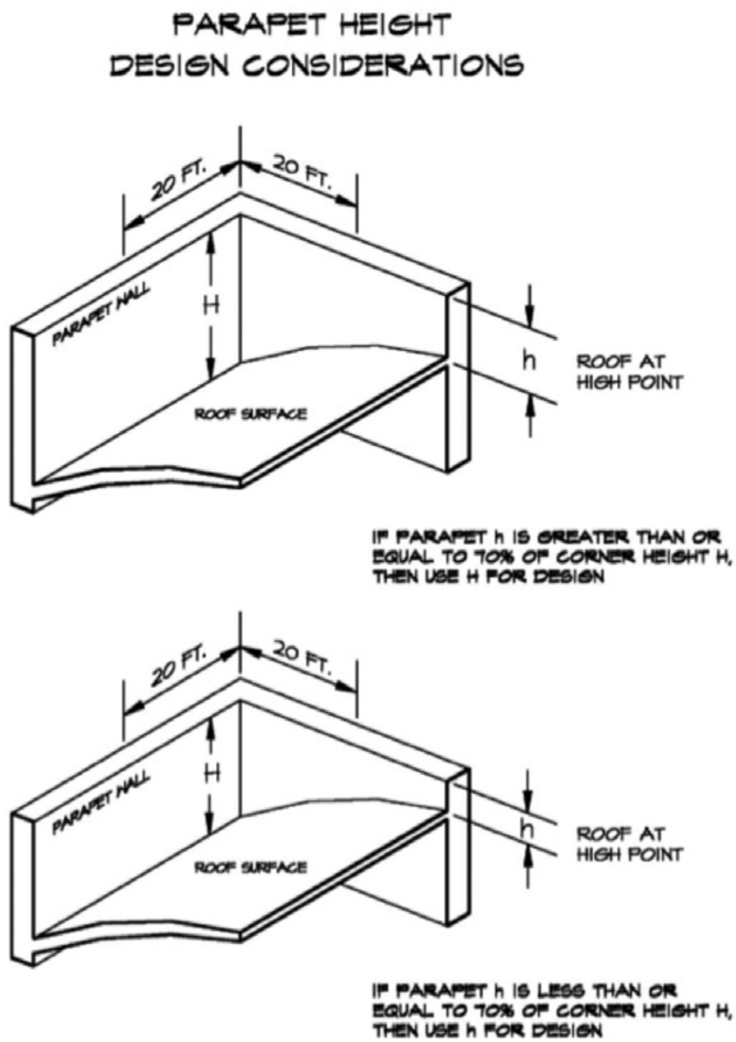


Figure 6D

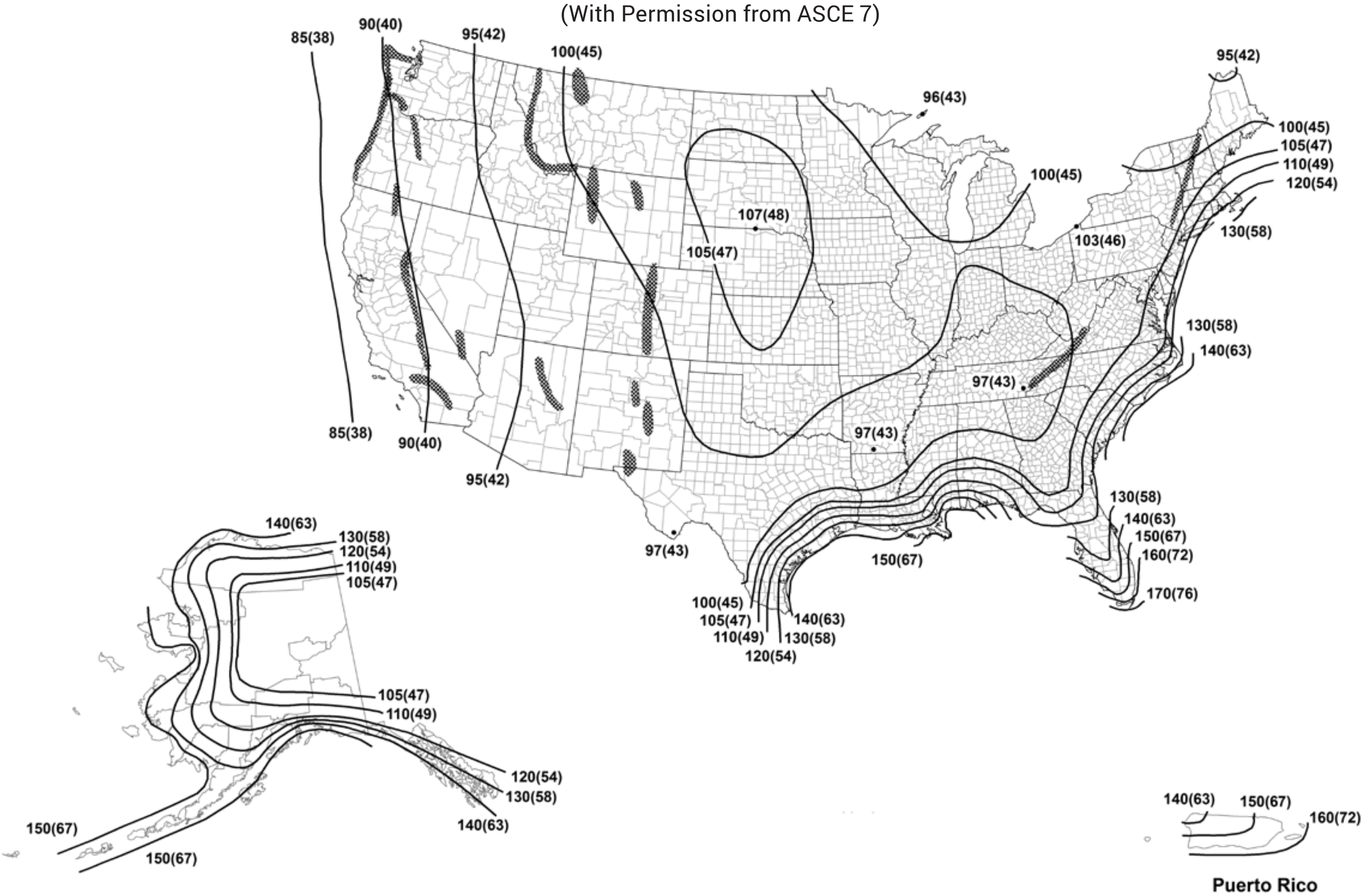
Figure 7

Parapet Height Design Considerations



Attachment I-A

Basic Wind Speeds for Risk Category I
(With Permission from ASCE 7)



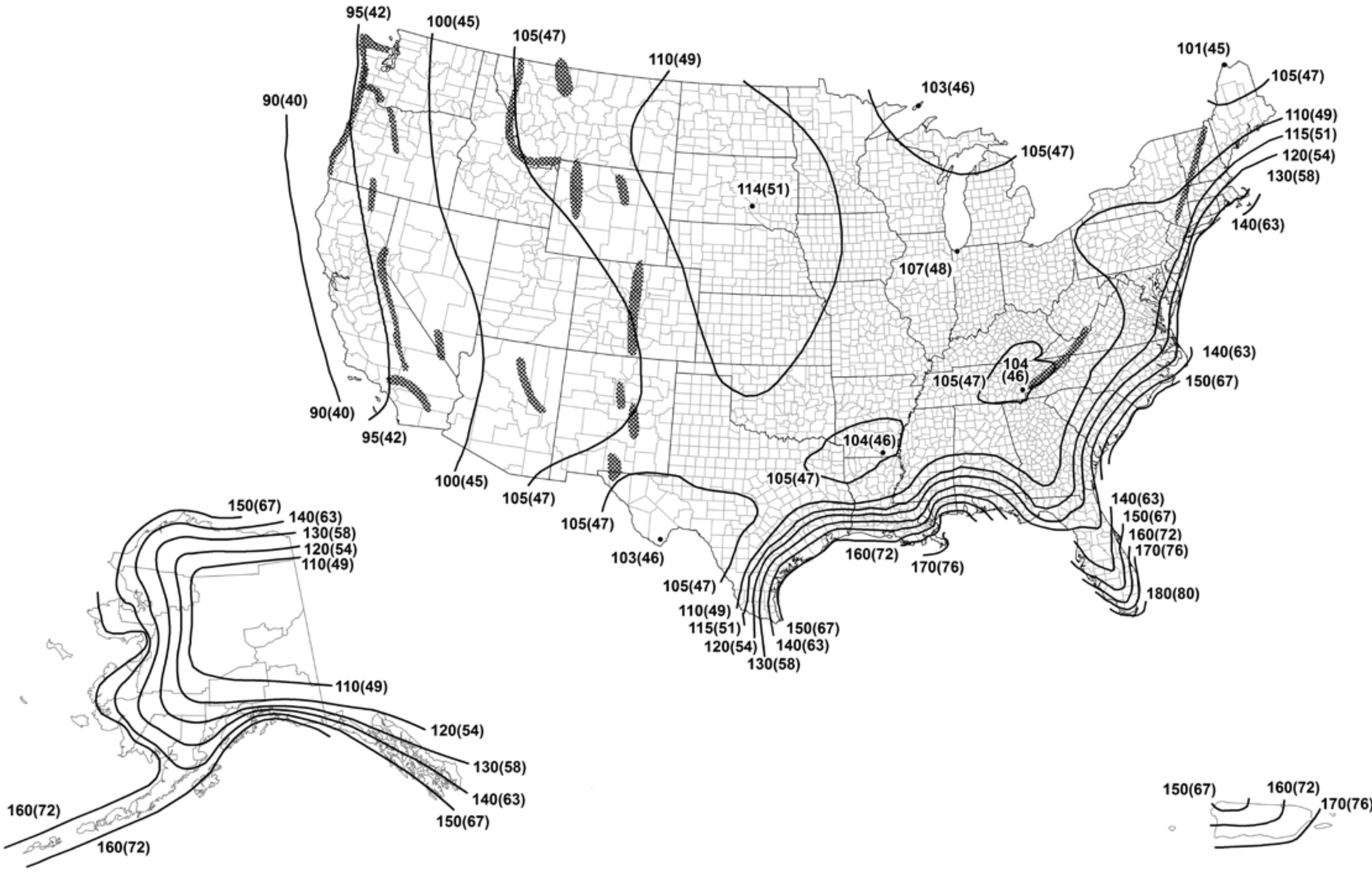
Location	V (mph)	V (m/s)
Guam	180	(80)
Virgin Islands	150	(67)
American Samoa	150	(67)
Hawaii	See Figure 26.5-2A	

Notes: Dark shading indicates a Special Wind Region.

1. Values are nominal design 3-s gust wind speeds in miles per hour (m/s) at 33 ft. (10 m) above ground for Exposure Category C.
2. Linear interpolation is permitted between contours. Point values are provided to aid with interpolation.
3. Islands, coastal areas, and land boundaries outside the last contour shall use the last wind speed contour.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 15% probability of exceedance in 50 years (Annual Exceedance Probability = 0.00333, MRI = 300 years).
6. Location-specific basic wind speeds shall be permitted to be determined using www.atcouncil.org/windspeed.

Attachment I-B

Basic Wind Speeds for Risk Category II
(With permission from ASCE 7)



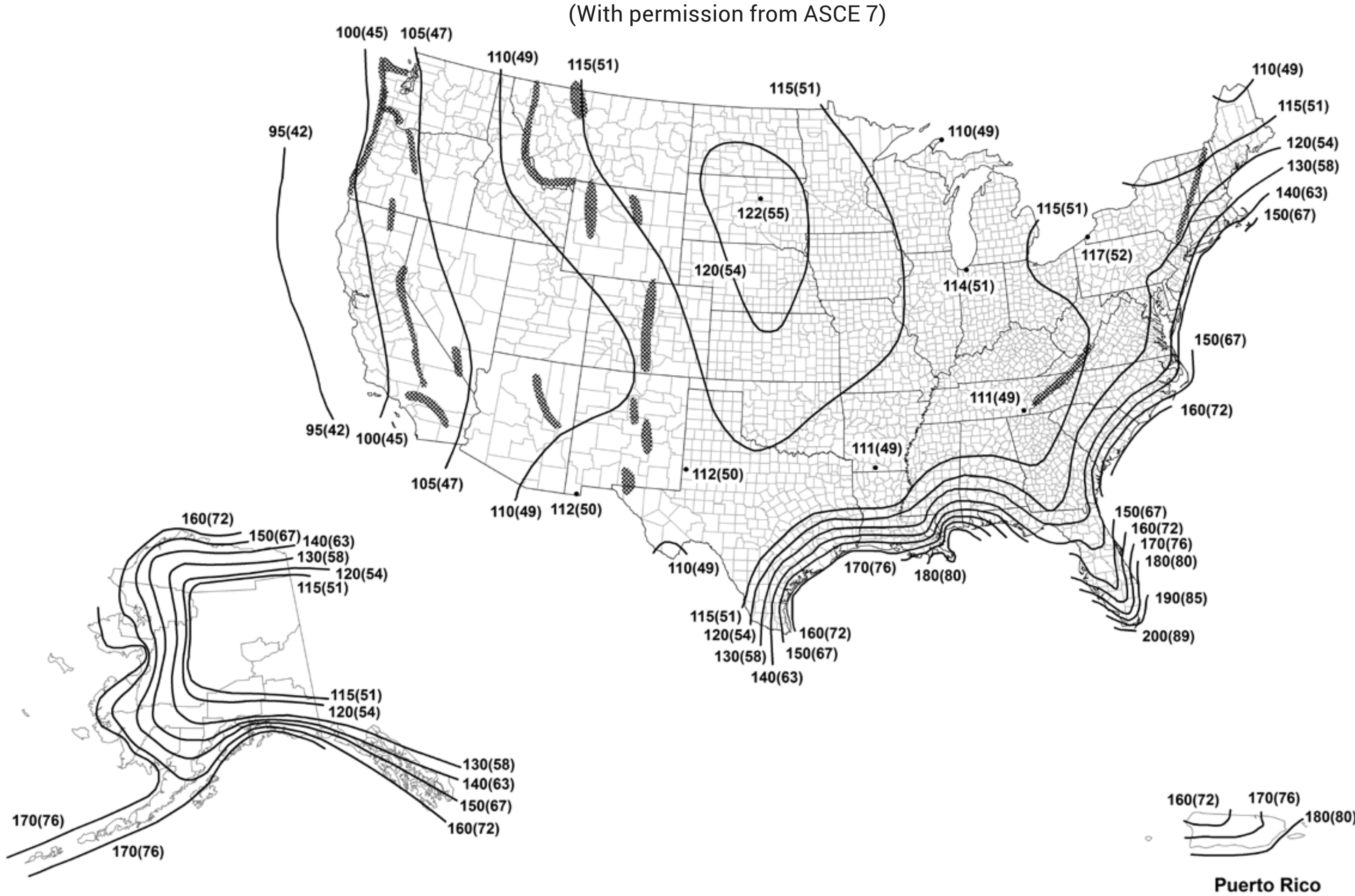
Location	V (mph)	V (m/s)
Guam	195	(87)
Virgin Islands	165	(74)
American Samoa	160	(72)
Hawaii	See Figure 26.5-2B	

Notes: Dark shading indicates a Special Wind Region.

1. Values are nominal design 3-s gust wind speeds in miles per hour (m/s) at 33 ft. (10 m) above ground for Exposure Category C.
2. Linear interpolation is permitted between contours. Point values are provided to aid with interpolation.
3. Islands, coastal areas, and land boundaries outside the last contour shall use the last wind speed contour.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 7% probability of exceedance in 50 years (Annual Exceedance Probability = 0.00143, MRI = 700 years).
6. Location-specific basic wind speeds shall be permitted to be determined using www.atcouncil.org/windspeed.

Attachment I-C

Basic Wind Speeds for Risk Category III
(With permission from ASCE 7)



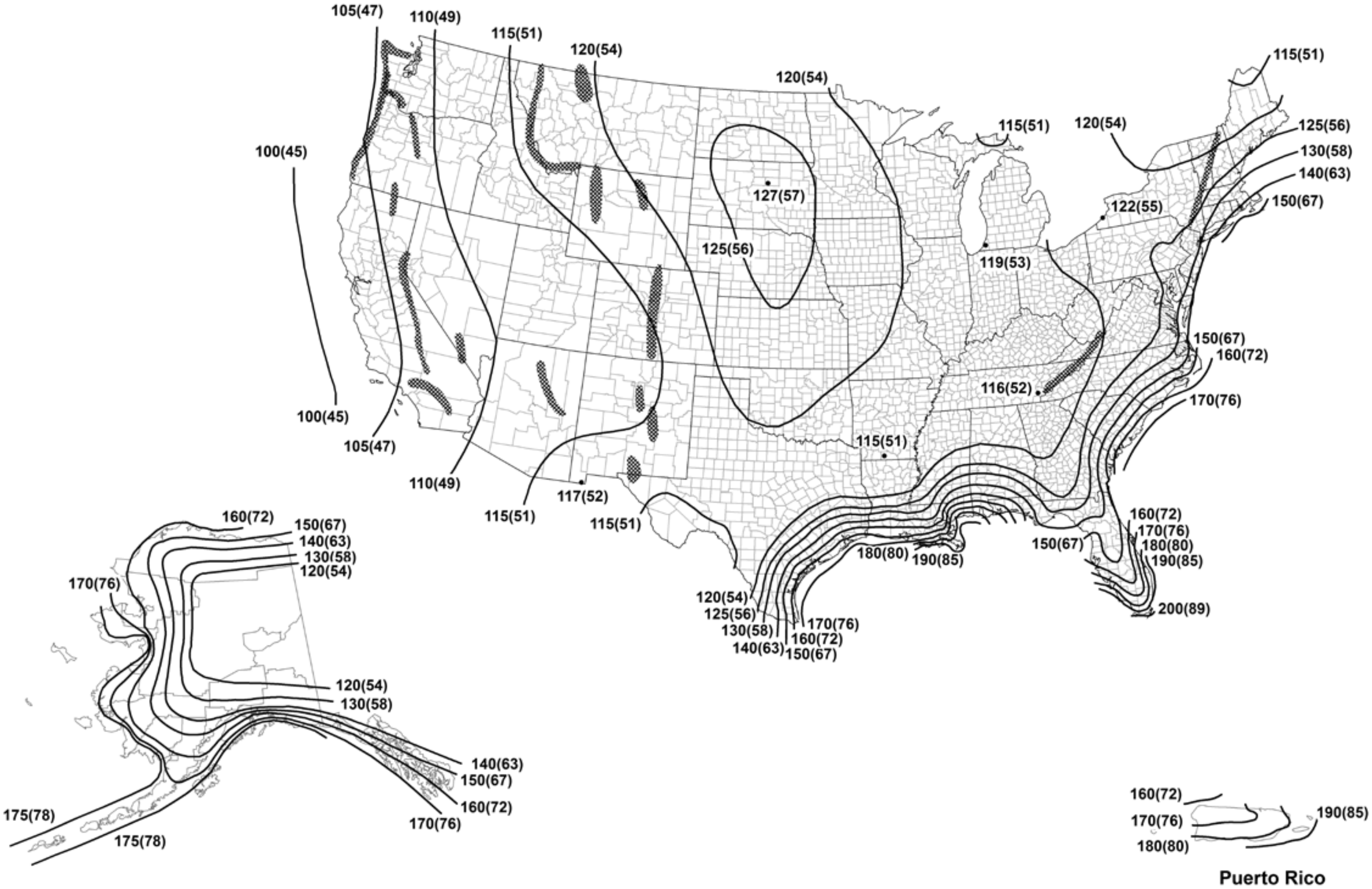
Location	V (mph)	V (m/s)
Guam	210	(94)
Virgin Islands	175	(78)
American Samoa	170	(76)
Hawaii	See Figure 26.5-2C	

Notes: Dark shading indicates a Special Wind Region.

1. Values are nominal design 3-s gust wind speeds in miles per hour (m/s) at 33 ft. (10 m) above ground for Exposure Category C.
2. Linear interpolation is permitted between contours. Point values are provided to aid with interpolation.
3. Islands, coastal areas, and land boundaries outside the last contour shall use the last wind speed contour.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 3% probability of exceedance in 50 years (Annual Exceedance Probability = 0.000588, MRI = 1,700 years).
6. Location-specific basic wind speeds shall be permitted to be determined using www.atcouncil.org/windspeed.

Attachment I-D

Basic Wind Speeds for Risk Category IV
(With permission from ASCE 7)



Location	V (mph)	V (m/s)
Guam	220	(98)
Virgin Islands	180	(80)
American Samoa	180	(80
Hawaii	See Figure 26.5-2D	

Notes: Dark shading indicates a Special Wind Region.

1. Values are nominal design 3-s gust wind speeds in miles per hour (m/s) at 33 ft. (10 m) above ground for Exposure Category C.
2. Linear interpolation is permitted between contours. Point values are provided to aid with interpolation.
3. Islands, coastal areas, and land boundaries outside the last contour shall use the last wind speed contour.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 1.6% probability of exceedance in 50 years (Annual Exceedance Probability = 0.00033, MRI = 3,000 years).

Location-specific basic wind speeds shall be permitted to be determined using www.atcouncil.org/windspeed.

Commentary to ANSI/SPRI RP-4

This Commentary is not a part of this Standard. It consists of explanatory and supplementary material designed to assist users in complying with the requirements. It is intended to create an understanding of the requirements through brief explanations of the reasoning employed in arriving at these requirements. It therefore has not been processed in accordance with ANSI Essential Requirements, and may contain material that has not been subjected to public review or a consensus process. Thus, it does not contain requirements necessary for conformance with the Standard.

The sections of this Commentary are numbered to correspond to the sections of the RP-4 standard to which they refer. Since it is not necessary to have supplementary material for every section in the standard, there are gaps in the numbering of the Commentary.

C1 Introduction

While the standard is intended as a reference for designers and roofing contractors, the design responsibility rests with the registered design professional.

C2.1 Ballast

Ballast is any object having weight that is used to hold or steady an object. In ballasted roofing systems, the most common ballast used is stone. However, materials such as concrete pavers, lightweight concrete pavers, rubber pavers, and weighted insulation panels are often used to ballast loose laid roofing systems. These ballast systems have been organized into categories based on their ability to resist the forces of the wind.

C2.5 Wind Speed

The wind speed used in this document is from ASCE 7-16

C2.6.1 Corner

Corners are not always square. They are formed by the intersection of two walls. This document is using the definition of the angle formed by the two walls as being between 45 and 135 degrees to signify a corner. The registered design professional may choose to include angles outside this range as a corner.

C2.7.2 Surface Roughness/Exposure C

A roof being designed in a city center may be either too tall to benefit from the protection of adjacent buildings, or is low enough to be affected by wind channeling between them. Wind profiles are much more complex in city centers, and therefore not necessarily subject to the more rational directionality as studied in the wind tunnels. It is suggested that exposure C be considered for all buildings in city centers. ASCE 7-10 page 546 provides descriptions of exposures B, C and D.

C2.8 Impervious Deck

The first thing that comes to mind when thinking about materials such as poured concrete and gypsum is that they are impervious to the flow of air. However, in deck constructions there are from time to time penetrations that are cut through these decks that air can pass through. There are also constructions where the expansion joint is located at the deck-wall junction or the wall construction itself (stud or cavity wall construction) can let air in under the roof system. The designer should investigate to assure the impervious construction is truly that. All penetrations (new or existing) are to be sealed to prevent the system from pressurization. Unless proper detailing is considered the system is to be treated as pervious. See Reference 7 for detailing.

C2.9 Pervious Decks

Pervious decks can result in significant uplift loads on ballasted systems. This can be particularly true if the building is pressurized, or the building is designed as a partially enclosed structure. Partially enclosed areas directly beneath a roof area which allow wind pressure to develop through open soffits, windows of pervious structures, should be considered for enhanced design as described in paragraph 5.4.2 or incorporate an air retarding system as described in Reference 7.

C3.4 Large Openings in a Wall

As an example, because of the great amount of air leakage that often occurs at large hanger doors and roll-up doors (e.g., a warehouse with multiple truck docks), the designer should utilize the provisions of Section 5.1 for design enhancements.

Glazed openings that are sited in hurricane-prone regions with a basic wind speed of 110 mph (49 m/s) or greater, or in Hawaii, are either required to be designed for missile impact or the building should be designed for higher internal pressure. Glazing below 60 ft. (18 m) is very vulnerable to breakage from missiles unless the glazing can withstand reasonable missile loads and subsequent wind loading, or the glazing is protected by suitable shutters. Glazing above 60 ft. (18 m) is also somewhat vulnerable to missile damage. The designer should take this into consideration and follow the design provision of Section 5.1. See ASCE 7-16 for further discussion.

C3.5 Positive Pressure Building Systems

Pressure in a building can become pressure beneath the membrane. When the pressure under the membrane increases it can reduce the effect of the ballast weight. Determining the system design with a 20 mph (9 m/s) increase in wind speed provides a simplified way to increase the resistance of the system to this potential increased pressure beneath the membrane. An alternate method is to add approximately 3 lb./ft.^{2} (15 kg/m^2) of ballast for every 0.5 in (13 mm) of water interior pressure increase. The building owner and or registered design professional should consult with mechanical design engineer for design and/or operating conditions of HVAC equipment, which may lead to positive pressure beneath the membrane.

C3.8 Membrane Requirements

The most current material standards available at the time this standard was developed and approved in 2013 were as follows:

EPDM ASTM D4637

PVC ASTM D4434

TPO ASTM D6878

KEE ASTM D6754

To determine if these standards are the most current, visit www.astm.org

As an historical note, previous versions of this standard referenced ASTM D5019-05 Standard Specification for Reinforced CSM (Chlorosulfonated Polyethylene) Sheet Used in Single-Ply Roof Membrane. This standard has been withdrawn.

Certain PVC membranes contain plasticizers that may be extracted from the membrane. They may require a slip-sheet between the membrane and some insulations.

C3.9.2 Parapet Height

The use of parapets will improve the wind performance of the roofing system. The designer, whenever possible, should use a parapet design that will improve the roof system's ability to resist the wind. When parapets are less than 1 ft. (0.3 m), ballasted systems are limited to 75 ft. (23 m). The improvement in wind resistance is a function of parapet height. See Table II A-F.

C3.9.4 Edge Flashing (Gravel Stop)

This standard addresses the basic requirements for membrane termination. For more details on the design of edge flashing, metal and nonmetal, and attachment of nailers see SPRI's document "Wind Design Standard for Edge Systems Used with Low Slope Roofing Systems", ANSI/SPRI/FM4435/ES-1.

Perimeter Attachment: Some wall constructions allow pressure from the interior of the building to flow up wall cavities, bypassing the deck and entering the space between the roof covering and roof deck. This can be mitigated by following Reference 7, consulting the manufacturer or a roof registered design professional.

Exterior through wall scuppers, if not sealed on the exterior, can allow air on the windward side of the parapet wall to pressurize the space under the roof covering.

C3.10 High Winds

Special Wind Regions (mountains or valleys): Refer to Section C26.5.2 of the ASCE 7-10 Commentary.

The intensifying effects of topography (hills or escarpments) are to be accounted for. Information on speed up over hills and escarpments can be found in ASCE 7-10 Section 26.8.1. ASCE 7-10 provides data for wind pressure increase but does not give specific advice for wind speed tables as are used in this document. Consult a wind engineer to determine the roof top wind speed. The increase in wind speed due to hills is the K_{zt} factor from the above ANSI/ASCE reference. (i.e. multiply the wind speed by K_{zt} and use this new wind speed as the design wind speed.) A conservative approach is to add the height of the hill to the height of the building. Hills less than 60 ft. (18 m) above the surrounding terrain in Surface roughness B and 15 ft. (4.6 m) above the surrounding terrain in Surface roughness C & D, need not be considered.

C3.11 Wind-borne Debris

The "authority having jurisdiction" is the only source for approval of designs not covered in this document. ASCE 7-16 gives guidance on how non-standard conditions should be evaluated. See Reference 1 or conduct wind tunnel studies in accordance with ASCE 7 for information to determine requirements for designs or systems not covered.

C3.12 Stone Ballast Requirements

The minimum ballast weight is based on the wind design requirements of the system. Structural design should consider that the installed system will have variation of weight. Additional structural capacity should always be considered. All stone ballast comes with some fines mixed in. ASTM standard D 448 allows up to 5 percent fines. This may lead to problems at drains, scuppers, etc. due to build-up of these fines. The design tables are based on the premise that the ballast will not blow off the roof at the design wind speed. The weight of stone or other ballast may not always be adequate to resist uplift loads that result from some internal or other under membrane pressures. The standard requires that there be no direct path from exterior of walls or interior of building to the space directly beneath the membrane. This standard is based on having no deliberately installed air retarders for all systems with 10 lb./ft.^{2} (49 kg/m^2) or more of ballast weight. For lighter weight systems, air retarders are required, but this standard assumes the air retarder is imperfect. See Section 2.8, 2.9, and 3.2 for discussion on where air retarders may be required. Reference 7 can provide guidance on elimination of direct paths for air pressurization of membranes.

If the source of stone is including too many fines, it may be advisable to have it "double washed".

The research basis for the stone *ballast* was model stone that approximated the gradations of ASTM D7655/D7655M. This included fines and the largest sizes in the simulated gradation. The average size of the stone was deemed to be the controlling factor in wind performance.

Previous versions of this standard referenced ASTM D448, "Standard Sizes of Coarse Aggregate". In 2012 a new standard was developed by ASTM for aggregate used in ballasted roof system, ASTM D7655/D7655M. This standard is now referenced for aggregate sizing requirements.

Caution should be used if existing stone ballast is collected and reused on a project. In some cases, the stone ballast will fracture overtime leaving small sharp pieces that may no longer meet the requirements of ASTM D7655 for Type #4 aggregate ballast.

C4 Design Options

The Design Options of Section 4, which also references the Design Tables in Table 1, are built on the wind tunnel work done by Kind and Wardlaw and supported by extensive field investigations (see References). The base used as the design criteria from the wind tunnel work was Critical Wind Speed V_{C2}, the gust wind speed above which scouring of stones would continue more or less indefinitely but not blow off the roof if the wind speed were maintained.

The corners and perimeter areas are where the greatest effects of the disrupted airflow over the building will occur. The worst-case scenario is the wind coming onto a corner at a 45° angle. These situations generate wind vortices along the roof edges causing low-pressure areas over the roof system as well as wind turbulence that can scour ballast and balloon the membrane. Typically, scour occurs first. To prevent ballast movement, enhanced design provisions are required in some cases for these areas.

The terminology "documented as demonstrated as equivalent with the provisions of the standard" means that a proprietary system has been evaluated through one or all of the following methods:

- Wind Tunnel Testing Conducted in accordance with ASCE 7
- In a Full-Scale Test conducted by a registered design professional.
- Field Documented Studies

The results would show performance levels that meet the locations design requirements.

Test methods typically used to evaluate roof systems for their ability to resist uplift forces are Factory Mutual 4474 and Underwriters Laboratories ANSI/UL1897. Both testing facilities publish the results for the specific roof systems tested. Contact them for additional information.

C4.1 Conventional Ballasted Single-Ply Systems

Caution should be used when installing pavers to not damage the membrane. Some manufacturers require a separation material between the membrane and the paver.

C4.1.3.2 Perimeter Zone

Several options exist for increased interconnectivity and securement of the perimeters. Heavy weight ballast is a non-proprietary way of achieving this requirement.

C4.2 Protected Membrane Roofing System

The water-and-air pervious fabric is used for two purposes: one, to prevent gravel fines from working down between the insulation joints to the membrane (which can lead to membrane damage); and two, to control insulation board rafting. Rafting is when an insulation board, that may be floating due to a heavy rainfall or a slow draining roof, moves out of place when an uneven load, such as foot traffic on the roof, is applied to the insulation board.

For information on air retarders, see References 7 and 10. Although all systems may benefit from well-installed air retarders, this standard is based on having no deliberately installed air retarders for all systems with 10 lb./ft.^{2} (49 kg/m^2) or more of ballast weight. For lighter weight systems, air retarders are required, but this standard assumes the air retarder is imperfect.

C4.2.1.2 System 3

System 3 design can be achieved by consulting References 6, 7, 8, and 9 or manufacturer's proprietary designs.

C4.2.2 Protected Membrane Ballasted Roof Systems Using a Cementitious Coating Which Has Been Attached to the Insulation as Ballast

Consult with manufacturer of membrane and cementitious *ballast* material to confirm material compatibility when no separation of materials exists.

C4.2.2.3 System 3

System 3 design can be achieved by consulting References 6, 7, 8, and 9 or manufacturers' proprietary designs.

C5.1 Large Openings in a Wall

The design provision for large openings considers glass as a solid wall. However, if the wall just under the roof system is largely glass, the designer, working on a project in an area where there is the potential for severe weather, may want to consider the glass as an opening because of the potential for glass breakage due to flying debris. Glass breakage is primarily an issue in wind-borne debris zones and other hurricane prone areas. ASCE 7 requires that glazed openings shall be protected in accordance with Section 26.10.3.2; which basically are wind-borne debris areas.

C5.6 Restrictions for Aggregate Surfaced Ballasted Roofs

Ballasted roofs with heights greater than 150 ft. (46 m) or where the basic windspeed exceeds 140 mph (63m/s) can be designed using Reference 1, consultation with a registered design professional, or wind tunnel studies of the specific building and system. Guidelines for those designing ballasted roofs for buildings over 150 ft. (46 m) are as follows. In all cases the roof has a minimum 3 ft. (0.9m) parapet. The membrane should be adhered in the perimeters and corners. Pavers or a minimum 2 in. (50mm) thick concrete pour should cover the entire roof. Although using very large stones in the field of the roofs is possible, there is very little available data on large stone performance. The paver weight suggested should exceed the paver uplift coefficient times the uplift pressure as determined in ANSI/SPRI WD-1 or the uplift pressure from specific wind tunnel tests for the roof being considered. The paver uplift coefficient can be determined from wind tunnel tests. Paver uplift coefficients can range from 0.1 to 0.8, however typical paver uplift coefficients range from 0.2 to 0.4. Interlocking or interconnected pavers may provide added wind uplift resistance.

Square-edged 2- x 2-ft. (0.6 x 0.6m) pavers are permitted on roofs with heights greater than 150 ft. (46 m) or where the ASCE 7 basic wind speed exceeds the maximum allowable wind speed given in the RP-4 Table II when designed by a registered design professional in accordance with the following procedure[1]

Step 1: Calculate the net uplift coefficient on the pavers, using the following equation:

$C_{Lnet} = R_1 \times R_2 \times C_{p\ \text{ASCE 7, exterior C\&C, Zone 3}}$

Where C_{Lnet} is the net uplift pressure coefficient. R_1 is a reduction factor based on the ratio of the gap between pavers (G) and the height of the space underneath pavers (H_s). R_2 is a reduction factor based on the ratio of the height of the parapet above the top of the pavers (h_p) and the height of the top of the parapet above grade (H). C_p is the ASCE 7 external pressure coefficient for the roof *corner zone*. Determine R_1 from Figure C5.6.1-1 or Table C5.6.1-2.

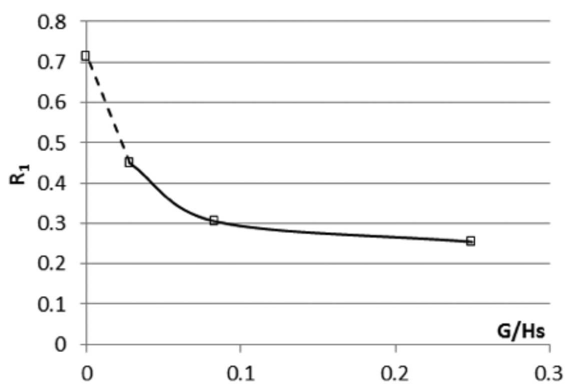


Figure C5.6.1-1: R1 reduction factor for different G/Hs ratios (based on ASCE 7-10*, Fig. 30.4-2A, Zone 3).

G/H_s ratio	R_1
Butted pavers resting on a fabric protection mat or roof membrane	0.7[2]
Pavers supported on pedestals that provide a ⅛ in.-wide gap between and a ⅝ in. space underneath pavers.	0.261

Table C5.6.1-1: R_1 reduction factor for different G/H_s ratios (based on Figure C5.6.2-1).

* If calculations are being done based on ASCE7-16, the R_1 value will need to be adjusted to suit the revised pressure coefficient for low rise buildings.

Also, R_1 values for the low-rise perimeter and field zones and for heights greater than 60 ft. will need to be considered.

[1] This procedure is based on Reference 20.

[2] This is a conservative estimate. Research is needed to refine this value.

Determine R_2 from Figure C5.6.1-2.

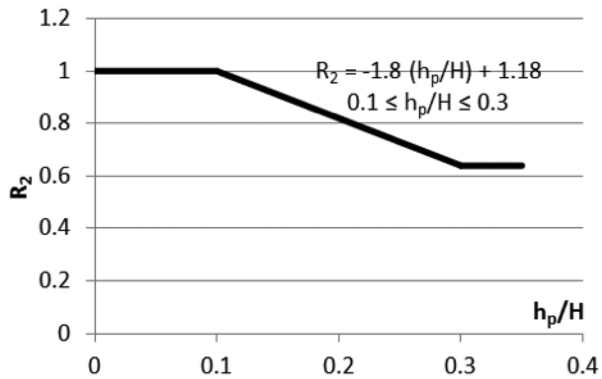


Figure C5.6.1-2: R_2 reduction factor for different h_p/H ratios.

Step 2: Determine the uplift pressure on the pavers by calculating the velocity (dynamic) pressure per ASCE 7 and multiply that value by R_1 and R_2. The roof membrane shall be adhered, or the roof assembly shall incorporate an air retarder that avoids ballooning of the roof membrane.

Step 3: Determine the overturning moment induced by the uplift pressure. For 2 × 2-ft. pavers, the overturning moment arm is conservatively estimated to occur 0.15 ft. from the center of the paver (Figure C5.6.1-3).

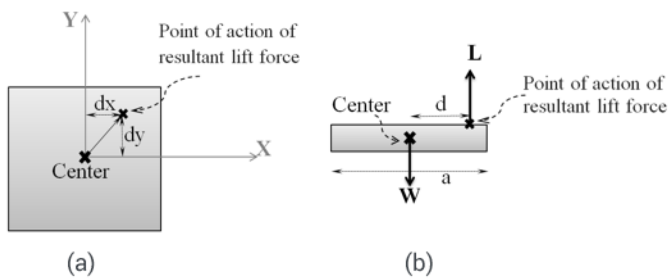


Figure C5.6.1-3: Definition of the point of action of the resultant lift force: (a) plan view; (b) side view.

Step 4: Determine the paver's resisting moment. The resisting moment shall be greater than the overturning moment. If the resisting moment is not greater than the overturning moment, increase the needed resistance by specifying a heavier paver or by connecting the pavers. See Step 5 for paver connection criteria.

Step 5: Determine the uplift resistance of connected pavers. Assume all pavers in the *corner zone* are connected. If straps are used, they shall run in both orthogonal directions, and they shall be connected to the pavers with concrete screws. Apply a reduction factor of 0.4 to the C_{Lnet} value obtained using Step 1 to calculate the C_{Lnet} value for the strapped case. To obtain the uplift on a single paver, multiply C_{Lnet} for the strapped case times the ASCE 7 velocity (dynamic) pressure times the area of the paver. Then repeat Steps 3 to 4 using this new value.

To determine whether or not connecting is needed in the field and/or perimeter zones, repeat Steps 1 to 4, using the unconnected C_{Lnet} value and the ASCE 7 field and perimeter external pressure coefficients. If connecting is not required in the field or perimeter zone, the connected zone shall extend a minimum of two pavers into the unconnected zone.

If the unstrapped overturning moment (Step 3) exceeds the unstrapped resisting moment (Step 4) by less than 15%, a single strap in each orthogonal direction is permitted. If it is 15% or greater, there shall be two straps in each orthogonal direction.[3] The center of the straps shall be approximately 3 in. from the edge of the pavers.

[3.] The 15% threshold is based on judgment. Research is needed to refine this value.

Step 6: A perimeter restraint (such as an angle attached to the parapet) shall be designed to prevent the edge of the paver at the parapet from lifting.

Example: The following example illustrates the design procedure, using ASCE 7-10. 30-ft.-tall hospital (Risk category III), 185-mph basic wind speed, Exposure b, 2 × 2-ft. pavers weighing 22 psf, on 1/8- x ⅝ in.-high pedestals, with a parapet that is 2 ft., 11 in. above the top of the pavers. RP-4 (2013) Table II.E gives a maximum allowable stress design wind speed of 140 mph (which equals a strength design wind speed of 181 mph), which is less than the ASCE 7 basic wind speed. To determine if the proposed system is acceptable:

Step 1: Calculate the net uplift coefficient on the pavers (C_{Lnet}): $R_1 \times R_2 \times C_p$.

- Determine R_1: Gap divided by space underneath (G/H_s) = ⅛ in. divided by ⅝ in. = 0.2. on the horizontal axis of Figure C5.6.1-1, 0.2 = 0.261 on vertical axis, which is R_1. For the selected pedestal, R_1 can also be obtained from Table C5.6.1-1.
- The 15% threshold is based on judgment. Research is needed to refine this value.
- Determine R_2: Height of the parapet above the top of the pavers (h_p) divided by the height of the top of the parapet above grade (H) = 2.92 ft. divided by 30 ft. = 0.095. on the horizontal axis of Figure C5.6.1, 0.095 = 1 on the vertical axis, which is R_2. Hence, this parapet offers no load reduction.
- Determine C_p: Pressure coefficient of the roof *corner zone* from Figure 30.4-2A in ASC E 7 = -2.8.

Therefore, C_{Lnet} = 0.261 × 1 × -2.8 = -0.73.

Step 2: Determine the uplift pressure on the pavers by calculating the velocity (dynamic) pressure per ASCE 7 and then multiplying that value by C_{Lnet}.

- Velocity pressure, ASCE 7 equation 30.3-1 : $0.00256 \times K_z \times K_{zt} \times K_d \times 185^2$ mph. K_z for a 30-ft. building = 0.70. K_{zt} (topography) = 1. K_d (directionality factor) = 0.85. Therefore, 0.00256 × 0.70 × 1 × 0.85 × 1852 = 52.13.
- Velocity pressure multiplied by C_{Lnet} = 52.13 x -0.73 = -38.06 psf uplift.

Step 3: Determine the paver's overturning moment induced by the uplift pressure:

- The uplift load on a single paver is -38.06 psf × 4 sq. ft. = 152 lbs..
- The point of action of the net uplift force is 0.15 ft. from the center of the paver (hence the moment arm is 1.15 ft.). The overturning moment is therefore 1.15 ft. × 152 lbs. = 175 foot-pounds.

Step 4: Determine the paver's resisting moment. The dead load of a 22 psf 2 × 2-ft. paver is 88 lbs. The point of action of the net resisting force is 1 ft. from the edge of the paver (hence the moment arm is 1 ft.). The resisting moment is 1 ft. × 88 lbs. = 88 foot-pounds. The 88 foot-pounds resisting moment is less than the 175 foot-pounds overturning moment.

Therefore, either pavers could be connected, or heavier pavers could be specified, or the height of the parapet could be increased. First, try connecting the pavers.

Step 5: Determine resistance of connected pavers. 0.4 × C_{Lnet} x velocity pressure x area of one paver (0.4 × 38.06 [from Step 2]) × 4 sq. ft. = 60.9 pounds of uplift force on a single paver. The overturning moment is 1.15 ft. × 60.9 pounds = 70 foot-pounds. The resisting moment is 88 foot-pounds (from Step 4). Hence, the resistance provided by the strapped pavers is higher than the overturning moment, and the paver array is stable.

Alternatively, try a taller parapet to reduce the uplift load on the pavers. Table II.F is for parapets up to 6 ft.; however, it gives the same maximum allowable speed as II.E. Try a 7-ft. parapet:

Repeat Step 1, using R_2 based on a 7-ft. parapet:

Determine R_2: Height of the parapet above the top of the pavers (h_p) divided by the height of the top of the parapet above grade (H) = 7 ft. divided by 30 ft. = 0.233. on the horizontal axis of Figure C5.6.1-2, 0.233 = 0.76 on the vertical axis, which is R_2. Hence, this parapet height offers load reduction.

Therefore, C_{Lnet} = 0.261 × 0.76 × -2.8 = -0.56

Repeat Step 2, determine the uplift pressure on the pavers by calculating the velocity (dynamic) pressure per ASCE 7, and then multiply that value by C_{Lnet}.

- Velocity pressure = 52.13 (from previous Step 2).
- Velocity pressure multiplied by C_{Lnet} = 52.13 × -0.56 = -29.19 psf uplift.

Repeat Step 3, determining the paver's overturning moment induced by the uplift pressure:

- The uplift load on a single paver is -29.19 psf × 4 sq. ft. = 116.76 pounds.
- The overturning moment is therefore 1.15 ft. × 116.76 pounds = 134.3 foot-pounds.

It can be seen that the overturning moment is reduced by 134.3/175 = 0.77 when using a 7-ft. parapet. However, for this case, the overturning moment is still higher than the paver's resisting moment (same as previous Step 4) = 88 foot-pounds. Therefore, stay with the 2-ft., 11-in. parapet, and strap the pavers in the corner zone (plus extend two rows into the adjacent perimeter and field zones). Also, calculate stability in the perimeter zone to determine if that zone needs to be strapped (for brevity, this calculation is not included in this example).

C6 Determination of Ballasted System Roof Design

If a building does not fit the criteria of this document, the designer should refer to Reference 1 and ASCE 7.

Wind speeds in the design tables are "3 second gust" measured at 10 meters (33 feet). To convert wind speeds in the tables to metric multiply by 0.44704 to obtain meters per second (m/s).

Determination of Ballasted System Roof Design—Exposure D

To maximize compliance with building code requirements, SPRI encourages the use of a roof design professional when designing a ballasted system located in Exposure D.

It is recommended for buildings located in Exposure D, the roof design as identified in the Design Tables (See Table II–A, B, C, D, E & F) be upgraded to a higher level of resistance to wind. Under Exposure C, it is recommended the basic wind speed be increased by 20 mph (9m/s) from the basic wind speed found on the appropriate wind map. (See Attachment I–A , B, C & D). Under these conditions a building roof located in a 90 mph (40m/s) wind zone would be upgraded to 110 mph (49m/s). Installation would then follow all of the requirements for the higher design wind speed.

C7 Maintenance

When wind scour occurs to an existing ballasted roof system and the scour is less than 50 $ft.^2$ (4.6 m^2), SPRI recommends that the ballast be replaced. In addition for scour areas greater than 50 $ft.^2$ (4.6 m^2), SPRI recommends that the ballast be upgraded a minimum of one system design level per Section 4.0 to reduce the potential of future scouring.

Ballasted Roofs should always be inspected after a wind event and at least 2 times per year to make sure *ballast* is in place. Consult SPRI/NRCA "Manual of Roof Inspection, Maintenance, and Emergency Repair for Existing Single Ply Roofing Systems" for additional information.

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Commentary to Design Tables A–F

The maximum wind speed in the tables represents the worst-case option with safety factors for each design condition. The evaluations use current ASCE7 practices for analyzing wind tunnel data In most cases additional safety factors based on over 30 years of field experience have been added to that worst-case wind.

Following are some of the conventions used to establish the tables.

A. Aggregate surfaced Ballasted Systems are limited to installations in Wind zones of 140 mile per hour (mph) or less, per the prescriptive requirements of this standard.

Design Tables A and B covers roofs with parapets less than 12-inches in height. The maximum building height in these cases is limited to 75-feet.

B. The basic wind speed limit from Kind & Wardlaw and other studies is the wind speed at which minor wind scour could occur but stones do not blow off the roof.

C. Stone size factors relate the average size of the stone to their response to wind. (see Reference 1 for detail) The factors used in this document are based on 30 years' experience and the Kind Wardlaw research. The Kind & Wardlaw wind tunnel data was found to be conservative. The design tables use a stone size factor (fs) of 1.56 for #4 ballast, and fs of 1.8 for # 2 ballast and are based on Reference 1 modified by Reference 5, and Reference 12. Parapet height and paver array factors are based on Reference 1.

D. Vd=<Vref*fs*Fpl. Vd, the maximum wind speed allowed per building is equal or less than the velocity reference (ref1) times the stone size factor (fs) times the parapet height/paver array factor (Fpl). Vd<Vc2. Vc2 is the wind speed at which stone scour can occur at worst-case conditions. The design data is always based on the greatest height in a given range; i.e. 15 ft.–30 ft. is based on 30 feet building height. The design data is always based on the lowest parapet height in a range; i.e. 6 in. to 12 in. parapet is based on the 6 in. parapet.

E. There are no reductions for directionality or building size factors. See ASCE 7 for definitions.

Adhered Roof Systems

Adhered systems are assumed to apply no stress on the edge system under consideration, unless either the metal is loosened or the membrane is in peel from the pressure differential between the exterior and interior of the system. Recent hurricane investigations have shown that both can occur.

Standards Referenced

1. American Society of Civil Engineers Standard ASCE 7-16, "Minimum Design Loads For Buildings And Other Structures".
2. ASTM International Standard ASTM D7655/D7655M Standard Classification for Size of Aggregate Used as Ballast for Membrane Roof Systems".
3. SPRI Inc. and FM Approvals Standard ANSI/SPRI/FM 4435/ES-1 2017, "Test Standard for Edge Systems Used with Low Slope Roofing Systems"
4. SPRI Inc. Standard ANSI/SPRI WD-1 2012, "Wind Design Standard Practice for Roofing Assemblies".

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15. Bienkiewicz, B. and Y. Sun, Wind-Tunnel Study of Wind Loading on Loose-Laid Roofing Systems, Journal of Wind Engineering and Industrial Aerodynamics, Vol 41-44, 1992, pp. 1817-1828
16. Bienkiewicz, B. and Y. Sun, Numerical and Experimental Studies of Wind Loading on Loose-laid Roofing Systems. U.S. National Conference on Wind Engineering, UCLA 1993
17. Manual of Roof Inspection, Maintenance, and Emergency Repair for Existing Single Ply Roofing Systems. SPRI/NRCA, Needham MA/Rosemont IL.

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