Wind Design Standard For Ballasted Single-ply Roofing Systems

1.0 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.

2.0 GENERAL DESIGN CONSIDERATIONS AND DEFINITIONS

The following factors shall apply when designing a ballasted single-ply roof system.

2.1 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.

2.2 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.

2.3 Protected Membrane Ballasted Roof System Using A Cementitious Coating Which Has Been Attached To the Insulation as Ballast: The insulation panels with an attached cementitious material act as both insulation and ballast. The panels shall be interlocking and weigh a minimum of 4.0 psf. A water-and air-pervious fabric is not required in this construction.

2.4 Roof Structure: The building owner shall consult with a qualified and licensed professional such as an architect, architectural engineer, civil engineer, or structural engineer to verify that the structure and deck will support the ballast load in combination with all other design loads.

Slope: The roof slope design shall not exceed 2" in 12".

2.6 Wind Speed: The Basic Wind Speed is the 3-second gust speed at 33 ft (10 m) above the ground in Exposure C and associated with an annual probability of 0.02 of being equaled or exceeded (50 year mean recurrence interval). The Basic Wind Speed value to be used in the design calculations shall be taken from the ANSI/ASCE 7-98[1] document or the local authority having jurisdiction when local values exceed ASCE 7-98. The intensifying effects of valleys on wind speed as well as unique topographic features such as hills or escarpments, shall be accounted for in the design (See Commentary 2.6 and Figure 6. Minimum Design Loads for Buildings and

1 The wind speed map shown as Attachment II is an element of the ANSI/ASCE 7-98 document, "Minimum Design Loads for Buildings and Other Structures", an American National Standards Institute Standard, copyrighted in 1998 by the American Society of Civil Engineers. Copies of this standard may be purchased from the American Society of Civil Engineers at 1801 Alexander Bell Drive, Reston, VA 20191

DISCLAIMER

This standard is for use by architects, engineers, roof consultants, roofing contractors and owners of single-ply roofing systems. SPRI, AND ITS MEMBERS AND EMPLOYEES DO NOT WARRANT THAT THIS STANDARD IS PROPER AND APPLICABLE UNDER ALL CONDITIONS. Please see explanation of a "Standard" on page 22.

Other Structures, in Attachment II). A local authority having jurisdiction shall be contacted for verification of the wind data and shall, if necessary, adjust the values given in Attachment II to account for higher local wind speeds.

When the wind speed exceeds 140 miles per hour 3-second gust wind speed after all adjustments are applied, the roof design shall be based on an expert's design method and approved by the authority having jurisdiction.

Roofs shall be installed with minimum # 2 ballast (See Section 3.2.2 for definition) in regions designated by ASCE 7-98, or the authority having jurisdiction, as Wind Borne Debris Regions.

2.7 Building Height: The building height shall be measured from ground level to the roof system surface at the roof edge. If more than one roof level is involved, each shall have its own design per Sections 4.0 and 5.0. (See Commentary 2.6)

When building height exceeds 150 feet, the roof design shall be based on an expert's design method and approved by the authority having jurisdiction.

2.8 Roof Areas: Different areas of the roof surface are affected by wind in different ways. For design and installation purposes, the roof surface is divided into the following areas:

2.8.1 Corners: The space between intersecting walls forming an angle greater than 45 degrees but less than 135 degrees (See Figure 1).

2.8.2 Corner Areas: The corner area is defined as the roof section with sides equal to 40% of the building height. The minimum length of a side is 8.5 feet (See Figure 1).

2.8.3 Perimeter: The perimeter area is defined as the rectangular roof section parallel to the roof edge and connecting the corner areas with a width measurement equal to 40% of the building height, but no less than 8.5 feet (See Figure 1).

2.8.4 Field: The field of the roof is defined as that portion of the roof surface which is not included in the corner or the perimeter areas as defined above (See Figure 1).

2.9 Edge Condition:

2.9.1 Metal Edge Flashing (Gravel Stop): If 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, but not less than 2 inches above the top surface of the roof membrane (See Figure 6). Metal Edge Flashing shall be designed and installed in accordance with ANSI/SPRI ES-1

2.9.2 Parapet Height: The parapet height for conventional ballasted roof systems (See Section 2.1 for definition) is the distance from the top of the roof system membrane to the top of the parapet (See Figure 5A, and D).

For Protected Membrane Ballasted Roof Systems (See Section 2.2 & 2.3 for definition), the parapet height is the distance from the top of the insulation to the top of the parapet (See Figure 5B & 5C).

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

2.10 Building Location: The terrain surrounding a building will influence the degree of exposure of that building to the wind. The building shall be classified into one of the following exposures:[2]

[2] The definitions below are based on those of ANSI/ASCE 7-98, with modifications to suit the needs of this document.

2.10.1 Protected Exposures:
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. Use of this exposure category shall be limited to those areas for which terrain representative of Exposure B prevails in the upwind direction for a distance of at least 1,500 ft (460 m) or 10 times the height of the building or other structure, whichever is greater.

2.10.2 Unprotected Exposures: Exposure A: Large city centers with at least 50% of the buildings having a height in excess of 70 ft (21.3 m). Use of this exposure category shall be limited to those areas for which terrain representative of Exposure A prevails in the upwind direction for a distance of at least 0.5 mi. (0.8 km) or 10 times the height of the building or other structure, whichever is greater. Possible channeling effects or increased velocity pressure due to the building or structure being located in the wake of adjacent building shall be taken into account.

Exposure C: Open terrain with scattered obstructions having heights generally less than 30 feet. This category includes flat open country and grasslands and shorelines in hurricane prone areas.

Exposure D: Flat, unobstructed areas exposed to wind flowing over open water for a distance of at least 1 mi. (1.61 km). This exposure shall apply only to those buildings and other structures exposed to the wind coming from over the water. Shorelines in Exposure D include inland waterways, the Great Lakes and coastal areas of California, Oregon, Washington and Alaska, Exposure D extends inland from the shoreline a distance of 1,500 ft (460 m) or 10 times the height of the building or structure, whichever is greater. Such conditions shall be designed in accordance with Section 5.5.

2.11 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 Commentary 2.11).

2.12 Positive Pressure Building Systems: When HVAC equipment generates a positive pressure inside a building greater than 0.5 inches of water, the roof system shall be designed to resist the pressure by increasing the wind load requirements in accordance with Section 5.2.

2.13 Rooftop Projections: The roof area at the base of any rooftop projection which extends more than two feet above the top of the parapet and has one side longer than 4 ft shall be designed in accordance with Section 5.3.

2.14 Overhanging Eaves & Canopies: By their design, overhanging 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.

2.15 Impervious Decks: A roof deck that will not allow air to pass through it. Some examples are poured in-place-concrete, gypsum, and poured-in-place lightweight concrete, (See Commentary Section 2.15).

2.16 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.

2.17 Importance Factor: Importance factor accounts for the degree of hazard to human life and damage to property. For buildings fitting Category III or IV (see page 4), the roof shall be designed in accordance with Section 5.6.

Classification of Buildings and Other Structures for Wind, Snow, and Earthquake Loads

Nature of Occupancy	Category
Buildings and other structures that represent a low hazard to human life in the event of failure including, but not limited to: • Agricultural facilities • Certain temporary facilities • Minor storage facilities	I
All buildings and other structures except those listed in Categories I, III, IV	II
Buildings and other structures that represent a substantial hazard to human life in the event of failure including, but not limited to: • Buildings and other structures where more than 300 people congregate in one area • Buildings and other structures with elementary school, secondary school, or day care facilities with capacity greater than 150 • Buildings and other structures with a capacity greater than 500 for colleges or adult education facilities • Health care facilities with a capacity of 50 or more resident patients but not having surgery or emergency treatment facilities • Jails and detention facilities • Power generating stations and other public utility facilities not included in Category IV • Buildings and other structures containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released including, but not limited to: A. Petrochemical facilities B. Fuel storage facilities C. Manufacturing or storage facilities for hazardous chemicals D. Manufacturing or storage facilities for explosives	III
Buildings and other structures designated as essential facilities including, but not limited to: • Hospitals and other health care facilities having surgery or emergency treatment facilities • Fire, rescue and police stations and emergency vehicle garages • Designated earthquake, hurricane, or other emergency shelters • Communications centers and other facilities required for emergency response • Power generating stations and other public utility facilities required in an emergency • Ancillary structures (including, but not limited to communications towers, fuel storage tanks, cooling towers, electrical substation structures, fire water storage tanks or other structures housing or supporting water or other fire suppression material or equipment) required for operation of Category IV structures during an emergency • Aviation control towers, air traffic control centers and emergency aircraft hangers • Water storage facilities and pump structures required to maintain water pressure for fire suppression • Buildings and other structures having critical national defense functions	IV

From ASCE 7/98

3.0 SYSTEM REQUIREMENTS

All single-ply ballasted roof systems shall comply with the following:

3.1 Membrane Requirements: The membrane specified for use in the ballasted system shall meet the recognized industry minimum material requirements listed below for the generic membrane type, and shall meet the specific requirements of its manufacturer.

EPDM	PVC
ASTM D-4637	ASTM D-4434
	Hypalon/CPE/PIB
	ASTM D-5019

3.2 Single-Ply Membrane Perimeter Attachment: The perimeter attachment used to terminate a roofing system shall be designed for a minimum load of 100 pounds per linear foot. This termination system shall be located at the roof perimeter and at the base of any angle change (See Attachment I, Figure 5 and Figure 6). The substrate into which the termination system is anchored shall be capable of withstanding a minimum of 100 pounds per linear foot. The procedure outlined in Attachment I shall be used to measure pull-out strength.

3.3 Ballast Requirements: Ballast shall be in accordance with the manufacturer's specification and not less than the following:

3.3.1 #4 Ballast: Nominal 1-1/2 inch smooth river bottom stone of ballast gradation size #4, or alternatively, #3, #24, #2, or #1 as specified in ASTM D-448, "Standard Sizes of Coarse Aggregate" spread at a minimum rate of 1000 pounds per 100 square feet; standard concrete pavers (minimum 18 psf); or interlocking, beveled, doweled, or contoured fit lightweight concrete pavers (minimum 10 psf).

3.3.2 #2 Ballast: Nominal 2-1/2 inch smooth river bottom stone of ballast gradation size #2 or alternatively #1, as specified in ASTM D 448, "Standard Sizes of Coarse Aggregate" spread at a minimum rate of 1300 pounds per 100 square feet; concrete pavers (minimum 22 psf); or approved interlocking, beveled, doweled or contoured fit, lightweight concrete pavers (minimum 10 psf) when documented or demonstrated as equivalent.

3.3.3 Crushed stone, when the gradation requirements for 3.3.1 and 3.3.2 above are met. A protection layer meeting the membrane manufacturers specifications shall be installed between the membrane and the crushed stone.

4.0 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 (See Commentary Section 4.0). The designs listed in Sections 4.1 and 4.2 are the minimum specifications.

4.1 Conventional Single-Ply Systems: See Section 2.1 for definition.

4.1.1 System 1: The installed membrane shall be ballasted with #4 ballast (See Section 3.3.1).

4.1.2 System 2: The installed membrane shall be ballasted as follows:

4.1.2.1 Corner Area (See Section 2.8.2 for definition of corner area): The installed membrane in the corner area shall be ballasted with #2 ballast (See Section 3.3.2 and Figure 1).

4.1.2.2 Perimeter (See Section 2.8.3 for definition of perimeter area): The installed membrane in the perimeter area shall be ballasted with #2 ballast (See Section 3.3.2 and Figure 1).

4.1.2.3 Field (See Section 2.8.4 for definition of field): In the field of the roof, the installed membrane shall be ballasted with #4 ballast (See Section 3.3.1).#2 ballast shall be the minimum size-weight ballast used in wind borne debris areas.

4.1.3 System 3: Install the system as follows:

4.1.3.1 Corner Area (See Section 2.8.2 for definition of corner area): In each corner area, an adhered or mechanically attached roof system designed to withstand the uplift force in accordance with ANSI/ASCE 7-98 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 and Commentary Section 4.1.3).

When a protective covering is required, a fully adhered membrane system shall be used. Over the fully adhered membrane, install minimum 22 psf pavers or other material approved by the authority having jurisdiction. Mechanically fastened membrane systems shall not be used when a protective covering is required. (see Commentary 4.1.3.2)

4.1.3.2 Perimeter: (See Section 2.8.3 for definition of perimeter area): In the perimeter area, an adhered or mechanically attached roof system designed to withstand the uplift force in accordance with ASCE 7-98 or the local building code, shall be installed, in accordance with the provisions for the perimeter location with no loose aggregate placed on the membrane.

When a protective covering is required, a fully adhered membrane system shall be used. Over the fully adhered membrane, install minimum 22 psf pavers or other material approved by the authority having jurisdiction. Mechanically fastened membrane systems shall not be used when a protective covering is required.

4.1.3.3 Field: (See Section 2.8.4 for definition of field) In the field of the roof, install #2 ballast (See Section 3.3.2).

4.1.3.4 Transition: At the junction of the loose laid roof membrane with the adhered or mechanically attached membrane areas, a mechanical termination shall be provided. The termination shall be designed for 100 pounds per linear foot holding power minimum, This force shall be measured in a direction of 45 degrees back onto the roof as tested in accordance with the procedure outlined in Attachment I. Specifically for mechanically attached membrane roofing systems, the perimeter attachment loadings shall be calculated based on the force required to hold the roof systems perimeter sheet in place for the design wind speed. The fastener spacing shall be adjusted and the edge detail shall have sufficient strength to meet and resist these loads.

4.2 Protected Membrane Roofing systems: (For definition of Protected Membrane Roofing systems, See Section 2.2).

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 specification 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, respectively.

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” parapet height (See Section 2.9.2 for determining 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 fully adhered perimeter and corner areas (mechanically attached systems shall not be used) shall be ballasted with 22 psf pavers (minimum) or other material approved by the authority having jurisdiction.

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

For definition of Protected Membrane Ballasted Roof Systems using a Cementitious Coating, see Section 2.3. 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 ANSI/ASCE 7-98, 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 two feet of the perimeter, minimum 22 psf 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 areas (See Section 2.8.2 and 2.8.3), 22 psf pavers (minimum) 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 an experts design method and approved by the authority having jurisdiction.

5.0 DESIGN PROVISIONS

5.1 Large Openings in a Wall: (See Section 2.11 for description):

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, the following roof location shall be designed as a corner area of the respective System 2 or System 3 designs. For System 1 designs, they shall use the corner area specifications of a System 2 design for the rectangular area.

A rectangle, located directly above the 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).

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 Tables as a System 1 design (See Table 1), 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 7-98 or the local building code. The rectangular roof area over the opening shall be designed as a corner section.

5.2 Positive Pressure in Building Interior (See Section 2.12 for description):
When positive pressure conditions between 0.5 and 1.0 inch of water are present in a building, the applicable roof system design, as identified in the Design Tables (See Table 1), shall be upgraded to a higher level of resistance to wind. Under these conditions, the roof top wind speed shall be increased by 20 mph from the basic wind speed from the wind map. (See Attachment II.) Under these conditions a building roof located in a 90 mph wind zone would be upgraded to 110 mph, etc. Installation shall follow all of the requirements for the higher design wind. When positive pressures are greater than 1.0 inch of water, the design of the roof shall be based on an experts design method and approved by the authority having jurisdiction. (See Commentary section C 2.12)

5.3 Rooftop Projections: (See Section 2.13 for description):

When rooftop projections rise two feet or more above the parapet height and have at least one side greater than four feet in length, the roof area which extends four feet out from the base of such projections shall have the same design as the corner area of the roof.

5.4 Overhangs, Eaves and Canopies: (See Section 2.14 for description):

5.4.1 Impervious Decks: (See Section 2.15 for description):

When a deck is impervious, overhang, eaves and canopy shall be defined as the following:

Eaves and overhangs: The overhang or eave shall be considered the perimeter of the applicable design (See Figure 3). Canopies: The entire canopy area shall be designed as a corner section of the applicable design.

5.4.2 Pervious Decks: (See Section 2.16 for description)

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 areas 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 Exposure D: (See Section 2.10 for description.)

For buildings located in Exposure D, the roof design as identified in the Design Tables (See Table 1) shall be upgraded to a higher level of resistance to wind. Under Exposure A & C the roof top wind speed shall be increased by 20 mph from the basic wind speed from the wind map. (See Attachment ll.) Under these conditions a building roof located in a 90 mph wind zone would be upgraded to 110 mph. Installation shall follow all of the requirements for the higher design wind.

5.6 Importance Factor:
(See Section 2.17 for description)

For buildings fitting category III or IV as per Section 2.17, the applicable roof system design as identified in the Design Tables (See Table 1) shall be upgraded to a higher level of resistance to wind. The roof top wind speed shall be increased by 20 mph from the basic wind speed from the wind map. (See Attachment ll.) Under these conditions a building roof located in a 90 mph wind zone would be upgraded to 110 mph etc. Installation shall follow all of the requirements for the higher design wind.

6.0 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, the basic wind speed shall be determined following Section 2.6 and exposure from Section 2.10.

6.2 The building height shall be determined by following Section 2.7 and the parapet height from Section 2.9.

6.3 Knowing the wind speed, building height, parapet height, Importance factor and exposure, determine the System design (1,2 or 3) using the appropriate Design Table contained in Table 1 .

6.4 Having determined the System from the Design Tables (Table 1), use Section 4.0, Design Options, to determine the ballasting requirements based on the type of roof system; Conventional or Protected Membrane.

6.5 Then Section 5.0, 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 Tables.

7.0 MAINTENANCE

When wind scour occurs to an existing ballasted roof system and the scour is less than 50 square feet, the ballast shall be replaced. For scour areas greater than 50 square feet, the ballast shall be upgraded a minimum of one system design level per Section 4.0. Maintenance shall be the responsibility of the building owner.

Design Tables[3]

Table 1

A. FROM 2 INCH HIGH GRAVEL STOP TO LESS THAN 6.0 INCH HIGH PARAPET
MAXIMUM ALLOWABLE WIND SPEED (MPH)

BLDG.	SYSTEM 1		SYSTEM 2		SYSTEM 3	
HT. FT.	EXPOSURE A+C*	EXPOSURE B*	EXPOSURE A+C	EXPOSURE B	EXPOSURE A+C	EXPOSURE B
0-15	100	105	115	115	130	140
> 15-30	100	105	110	115	130	140
> 30-45	90	100	100	115	130	140
> 45-60	NO	NO	95	115	120	140
> 60-75	NO	NO	90	110	120	120
> 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 WIND SPEED (MPH)

BLDG.	SYSTEM 1		SYSTEM 2		SYSTEM 3	
HT. FT.	EXPOSURE A+C	EXPOSURE B	EXPOSURE A+C	EXPOSURE B	EXPOSURE A+C	EXPOSURE B
0-15	100	105	115	115	130	140
> 15-30	100	105	110	115	130	140
30-45	90	100	100	115	130	140
> 45-60	NO	NO	95	115	120	140
> 60-75	NO	NO	90	110	120	130
> 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

C. FOR PARAPET HEIGHTS FROM 12.0 TO LESS THAN 18.0 INCHES
MAXIMUM WIND SPEED (MPH)

BLDG.	SYSTEM 1		SYSTEM 2		SYSTEM 3	
HT. FT	EXPOSURE A+C	EXPOSURE B	EXPOSURE A+C	EXPOSURE B	EXPOSURE A+C	EXPOSURE B
0-15	100	105	115	115	140	140
> 15-30	100	105	110	115	140	140
> 30-45	90	105	105	115	140	140
> 45-60	NO	90	95	115	130	140
> 60-75	NO	90	90	110	120	130
> 75-90	NO	NO	90	110	110	120
> 90-105	NO	NO	90	100	110	110
> 105-120	NO	NO	85	100	100	110
> 120-135	NO	NO	NO	100	100	110
> 135-150	NO	NO	NO	95	100	110

EXPOSURE A = LARGE CITIES
EXPOSURE B = SUBURBS AND SMALL CITIES
EXPOSURE C = OPEN TERRAIN

[3] Wind speed reference see Section 2.6
Wind speeds in above tables are “3 second gust” measured at 10 meters (33 feet).

Design Tables[3]

D. PARAPET HEIGHTS FROM 18.0 TO LESS THAN 24.0 INCHES
MAXIMUM WIND SPEED (MPH)

	BLDG.	SYSTEM 1		SYSTEM 2		SYSTEM 3	
	HT. FT.	EXPOSURE A+C*	EXPOSURE B*	EXPOSURE A+C	EXPOSURE B	EXPOSURE A+C	EXPOSURE B
	0-15	110	110	120	120	140	140
>	15-30	110	110	110	120	140	140
>	30-45	95	110	110	120	140	140
>	45-60	85	110	95	120	140	140
>	60-75	NO	90	90	110	140	140
>	75-90	NO	90	90	110	120	130
>	90-105	NO	NO	90	100	110	120
>	105-120	NO	NO	90	100	110	110
>	120-135	NO	NO	90	100	110	110
>	135-150	NO	NO	NO	100	100	110

E. FOR PARAPET HEIGHTS FROM 24.0 TO LESS THAN 36.0 INCHES
MAXIMUM WIND SPEED (MPH)

	BLDG.	SYSTEM 1		SYSTEM 2		SYSTEM 3	
	HT. FT.	EXPOSURE A+C	EXPOSURE B	EXPOSURE A+C	EXPOSURE B	EXPOSURE A+C	EXPOSURE B
	0-15	110	110	120	120	140	140
>	15-30	110	110	120	120	140	140
>	30-45	95	110	110	120	140	140
>	45-60	85	110	100	120	140	140
>	60-75	NO	90	90	120	130	140
>	75-90	NO	90	90	110	130	140
>	90-105	NO	NO	90	100	120	140
>	105-120	NO	NO	90	100	120	140
>	120-135	NO	NO	90	100	120	140
>	135-150	NO	NO	90	100	110	130

F. FOR PARAPET HEIGHTS FROM 36.0 TO LESS THAN 72 INCHES
MAXIMUM WIND SPEED (MPH)

	BLDG.	SYSTEM 1		SYSTEM 2		SYSTEM 3	
	HT. FT.	EXPOSURE A+C	EXPOSURE B	EXPOSURE A+C	EXPOSURE B	EXPOSURE A+C	EXPOSURE B
	0-15	110	110	120	120	140	140
>	15-30	110	110	120	120	140	140
>	30-45	100	110	120	120	140	140
>	45-60	95	110	105	120	140	140
>	60-75	90	100	100	120	140	140
>	75-90	90	100	100	120	140	140
>	90-105	90	90	100	110	130	140
>	105-120	85	90	100	110	130	140
>	120-135	85	90	100	110	130	140
>	135-150	NO	85	100	110	130	140

EXPOSURE A = LARGE CITIES
EXPOSURE B = SUBURBS AND SMALL CITIES
EXPOSURE C = OPEN TERRAIN

[3] Wind speed reference see Section 2.6
Wind speeds in above tables are “3 second gust” measured at 10 meters (33 feet).

Design Tables[3]

G. FOR PARAPET HEIGHTS FROM 72 INCHES AND ABOVE
MAXIMUM WIND SPEED (MPH)

BLDG.	SYSTEM 1		SYSTEM 2		SYSTEM 3	
HT. FT.	EXPOSURE A+C*	EXPOSURE B*	EXPOSURE A+C	EXPOSURE B	EXPOSURE A+C	EXPOSURE B
0-15	110	110	120	120	140	140
> 15-30	110	110	120	120	140	140
> 30-45	110	110	120	120	140	140
> 45-60	100	110	120	120	140	140
> 60-75	95	110	115	120	140	140
> 75-90	90	100	110	120	140	140
> 90-105	90	100	110	120	140	140
> 105-120	90	100	110	120	130	140
> 120-135	90	100	110	120	130	140
> 135-150	85	100	110	110	130	140

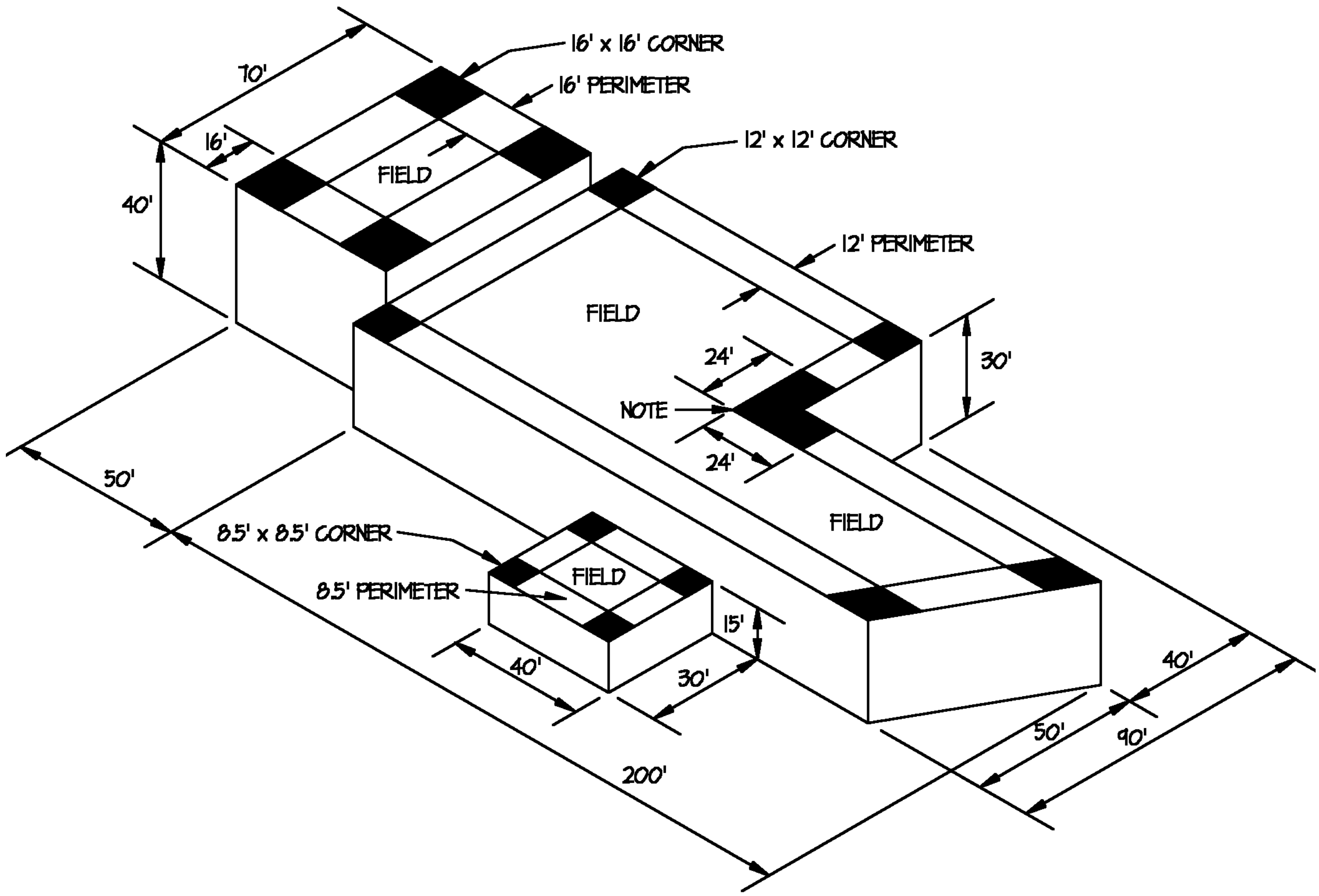
* EXPOSURE A = LARGE CITIES
EXPOSURE B = SUBURBS AND SMALL CITIES
EXPOSURE C = OPEN TERRAIN

[3] Wind speed reference see Section 2.6
Wind speeds in above tables are “3 second gust” measured at 10 meters (33 feet).

N0TE: Any building not fitting the above Design Tables shall be treated as a Special Design Consideration requiring review by a competent roof design specialist and approval by the authority having jurisdiction.

ROOF LAYOUT

SYSTEMS 2 & 3



NOTE:
REENTRANT CORNERS ARE LARGER THAN OTHER CORNERS.

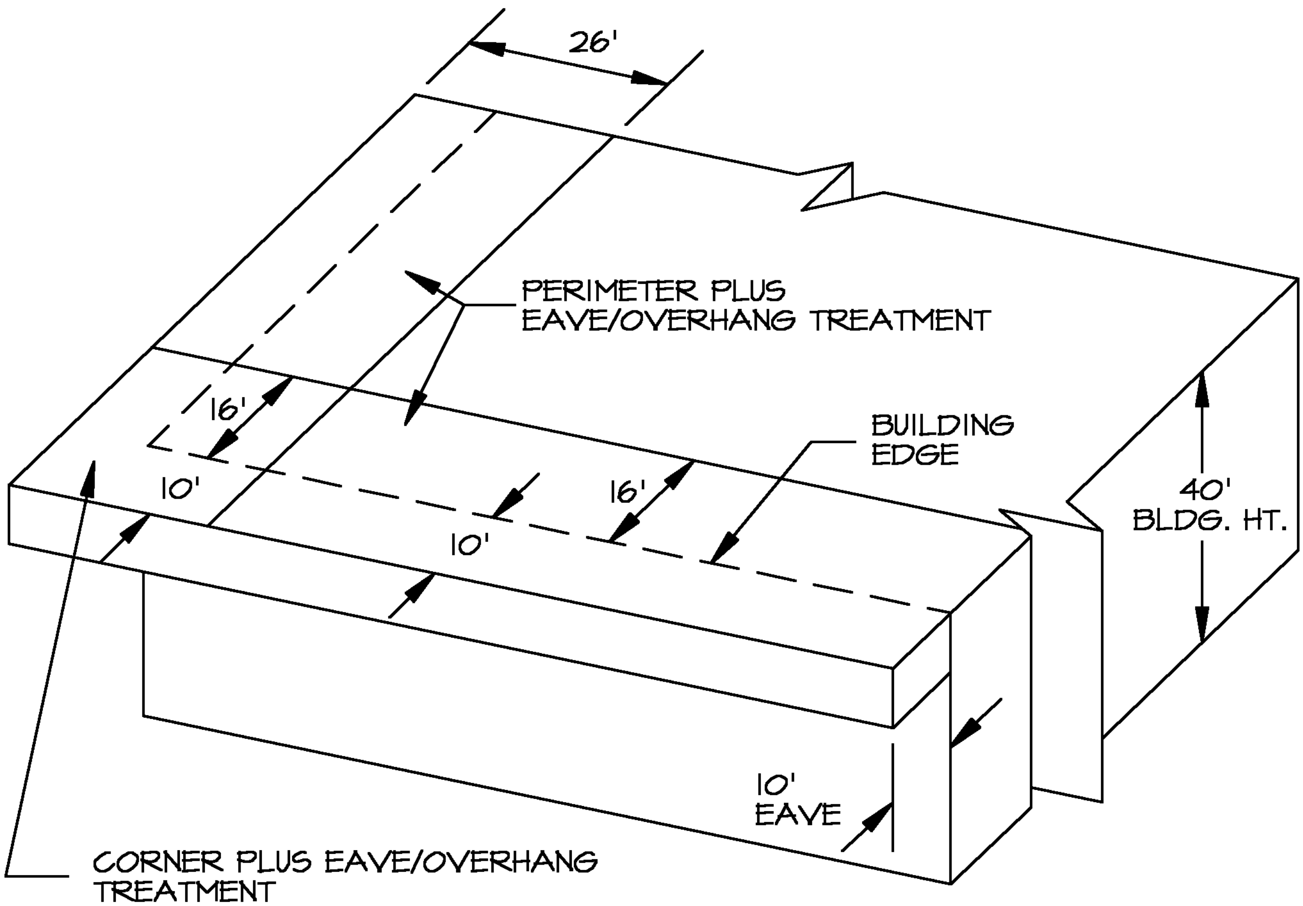
	LOW ROOF	MAIN ROOF	HIGH ROOF
ROOF HEIGHT (FT.)	15	30	40
40% OF BUILDING HEIGHT	6.0 FT.	12 FT.	16 FT.
CORNER LENGTH	8.5 FT. (a)	12 FT.	16 FT.
PERIMETER WIDTH	8.5 FT. (a)	12 FT.	16 FT.

(a) 8.5' MINIMUM CONTROLS

Figure 1

CANOPIES AND OVERHANGING EAVES PERVIOUS DECKS

FOR SYSTEMS 1,2 & 3



EAVE = 10 FT.

CORNER AREA = .4 x THE BUILDING HEIGHT PLUS THE OVERHANG AREA (OR 8.5 FT. MINIMUM) 26 FT. FOR THIS EXAMPLE.

PERIMETER AREA = .4 x THE BUILDING HEIGHT PLUS THE OVERHANG AREA (OR 8.5 FT. MINIMUM) 26 FT. FOR THIS EXAMPLE.

Figure 4

LARGE OPENINGS IN A WALL

WHEN THE SUM OF VARIOUS OPENINGS AREA (w x h)
IS GREATER THAN 10% OF THE WALL AREA

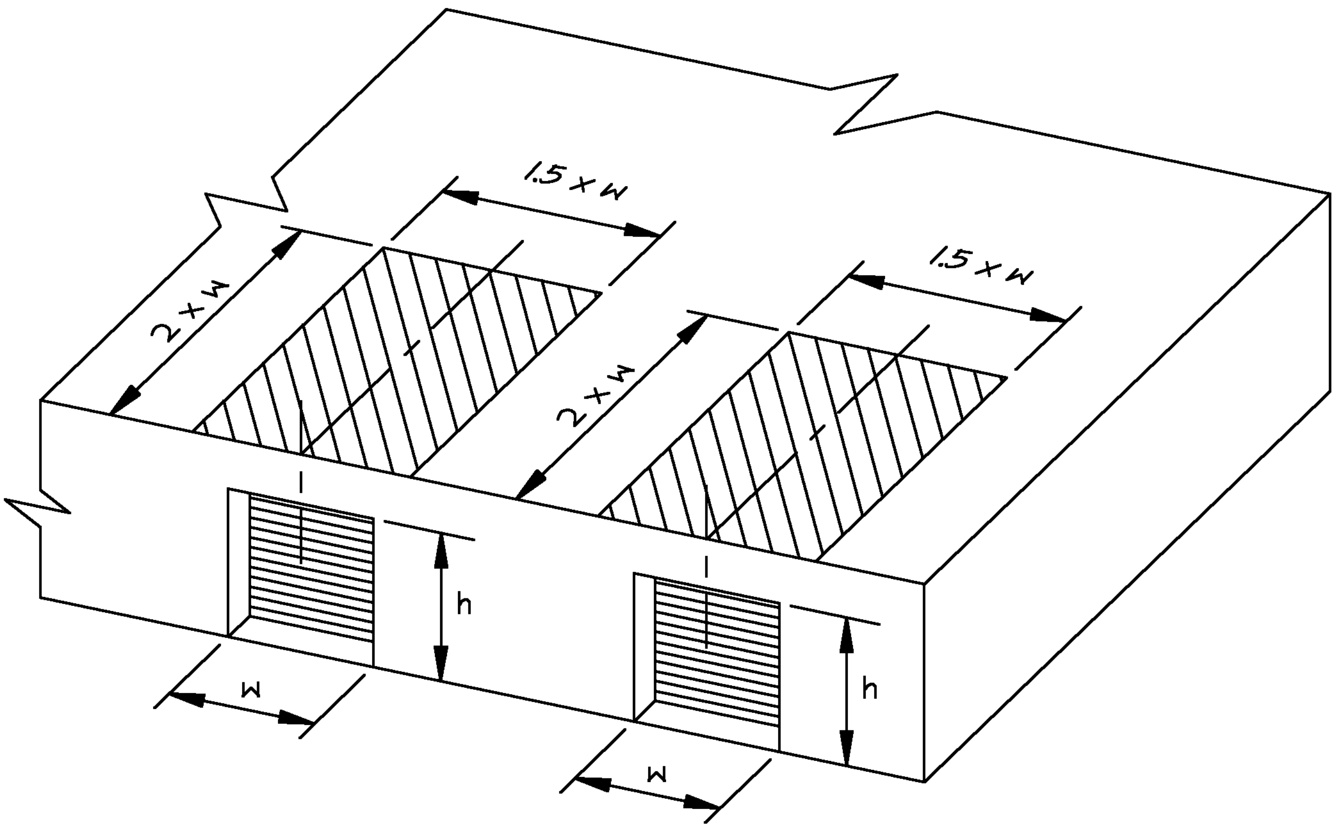
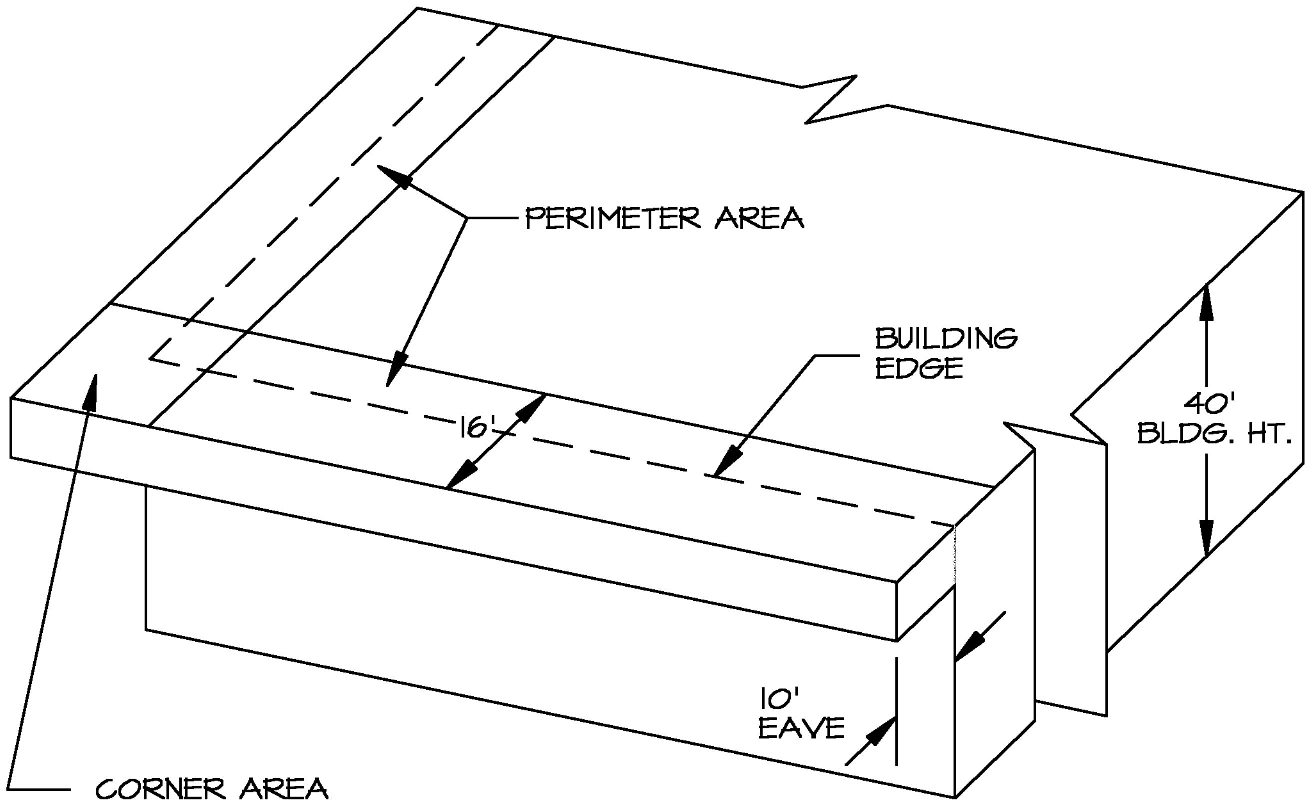


Figure 2

CANOPIES AND OVERHANGING EAVES IMPERVIOUS DECKS

FOR SYSTEMS 2 & 3

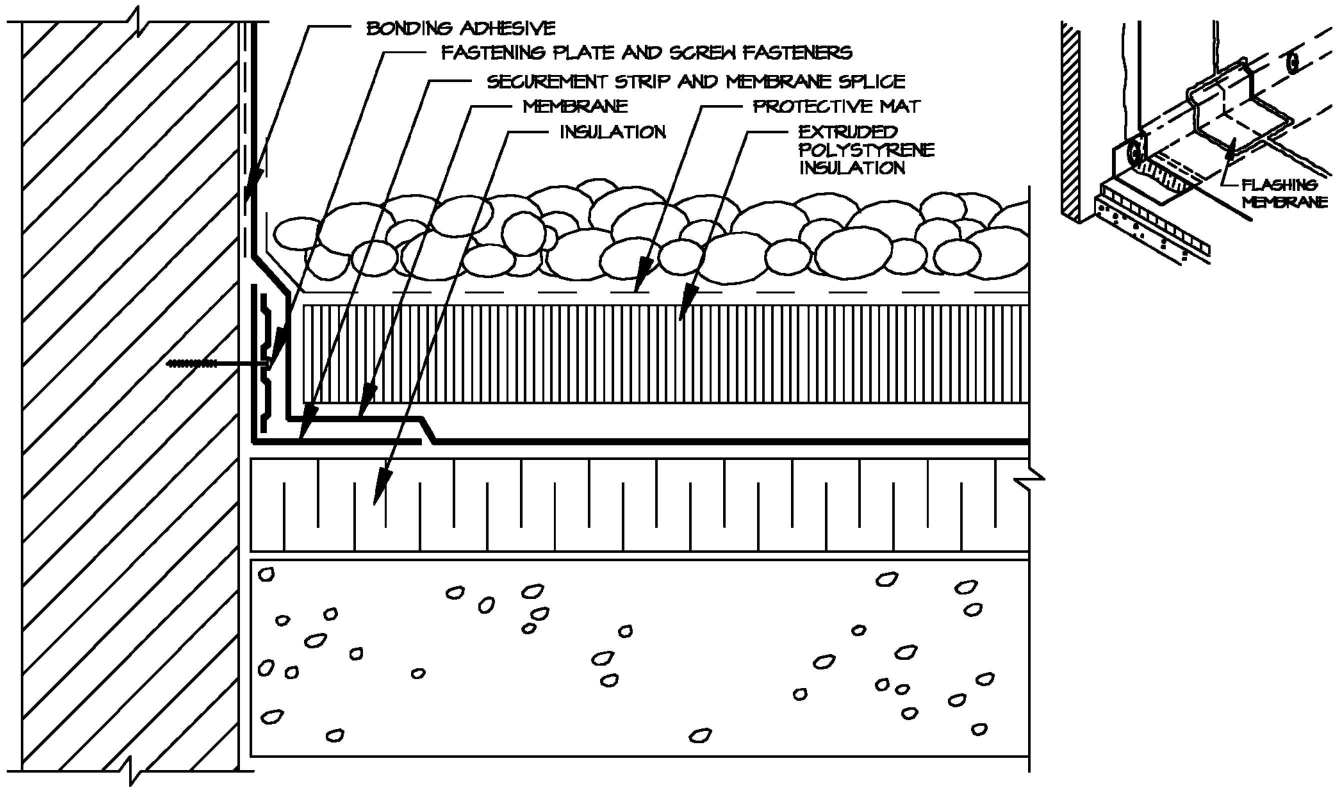


EAVE = 10 FT.

CORNER AREA = .4 x THE BUILDING HEIGHT
(OR 8.5 FT. MINIMUM)
16 FT. FOR THIS EXAMPLE.

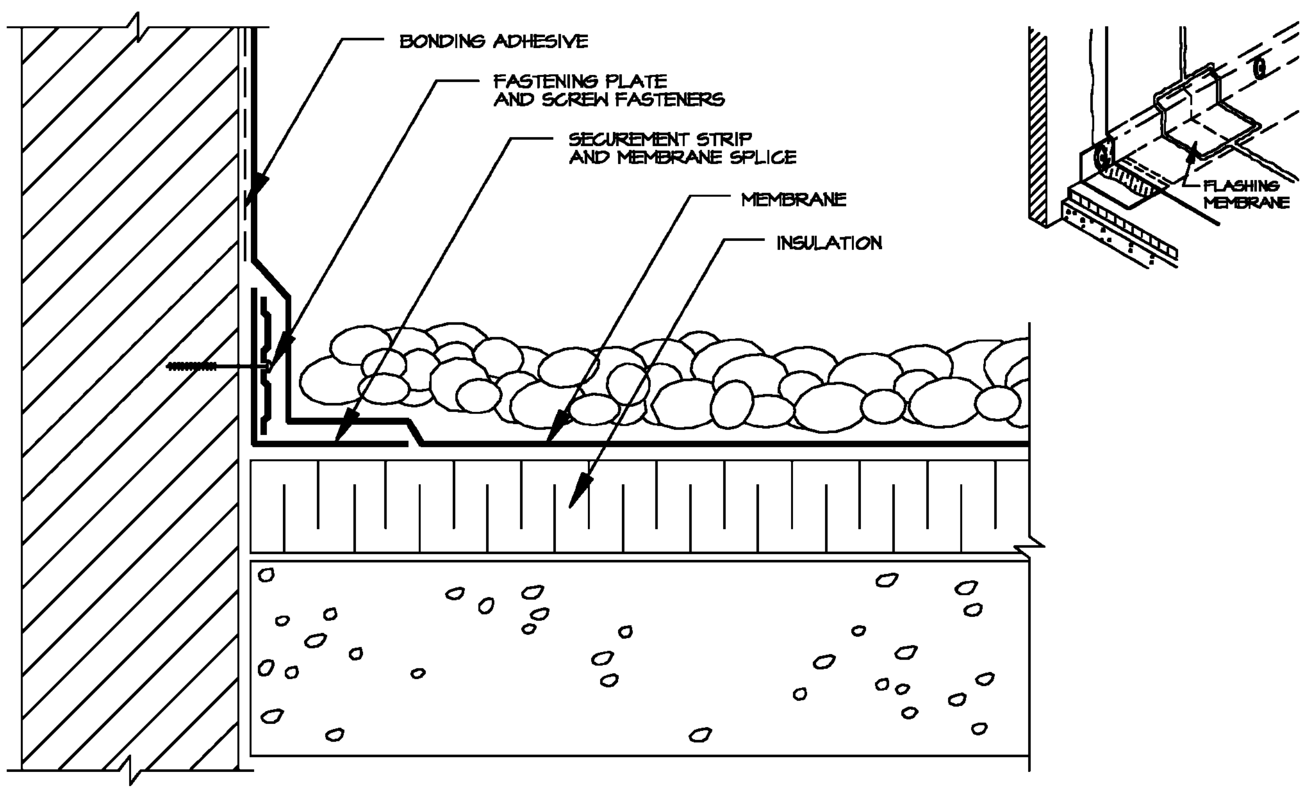
PERIMETER AREA = .4 x THE BUILDING HEIGHT
(OR 8.5 FT. MINIMUM)
16 FT. FOR THIS EXAMPLE.

Figure 3



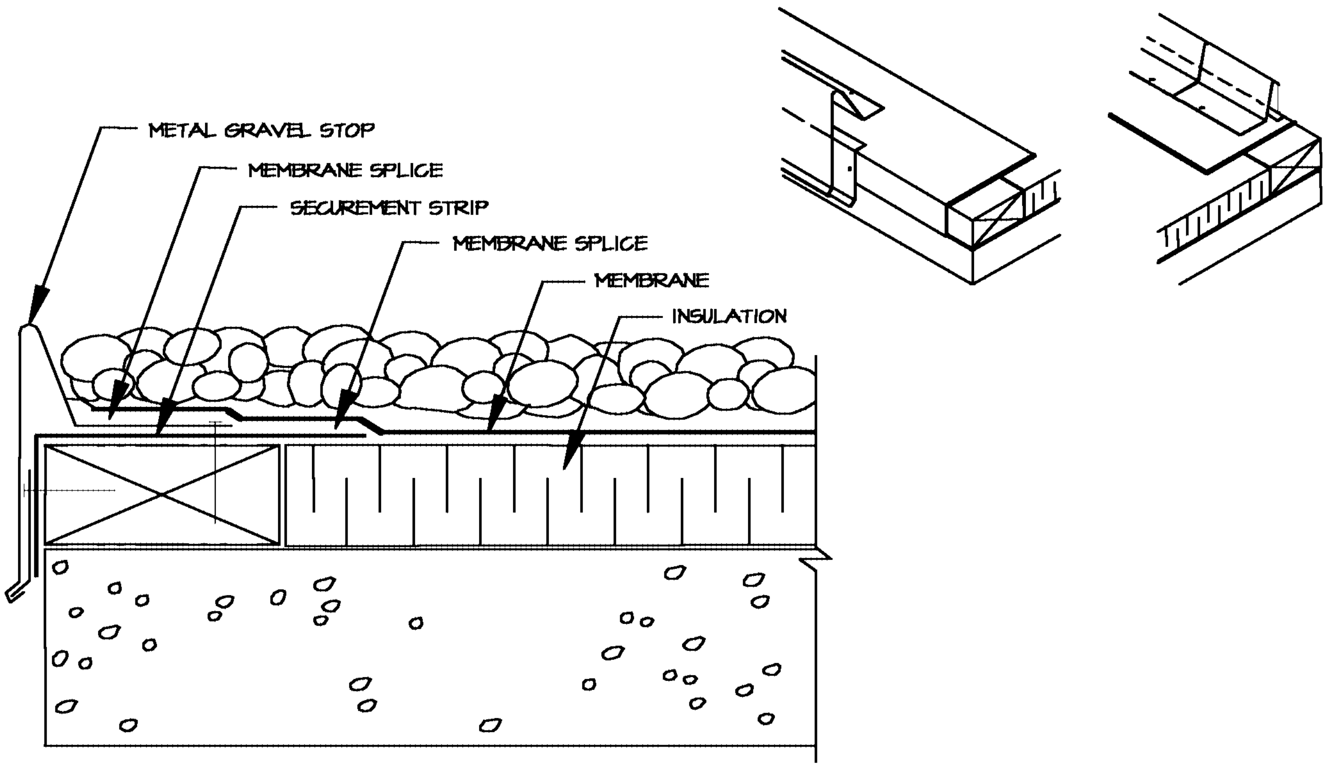
PARAPET

Figure 5C



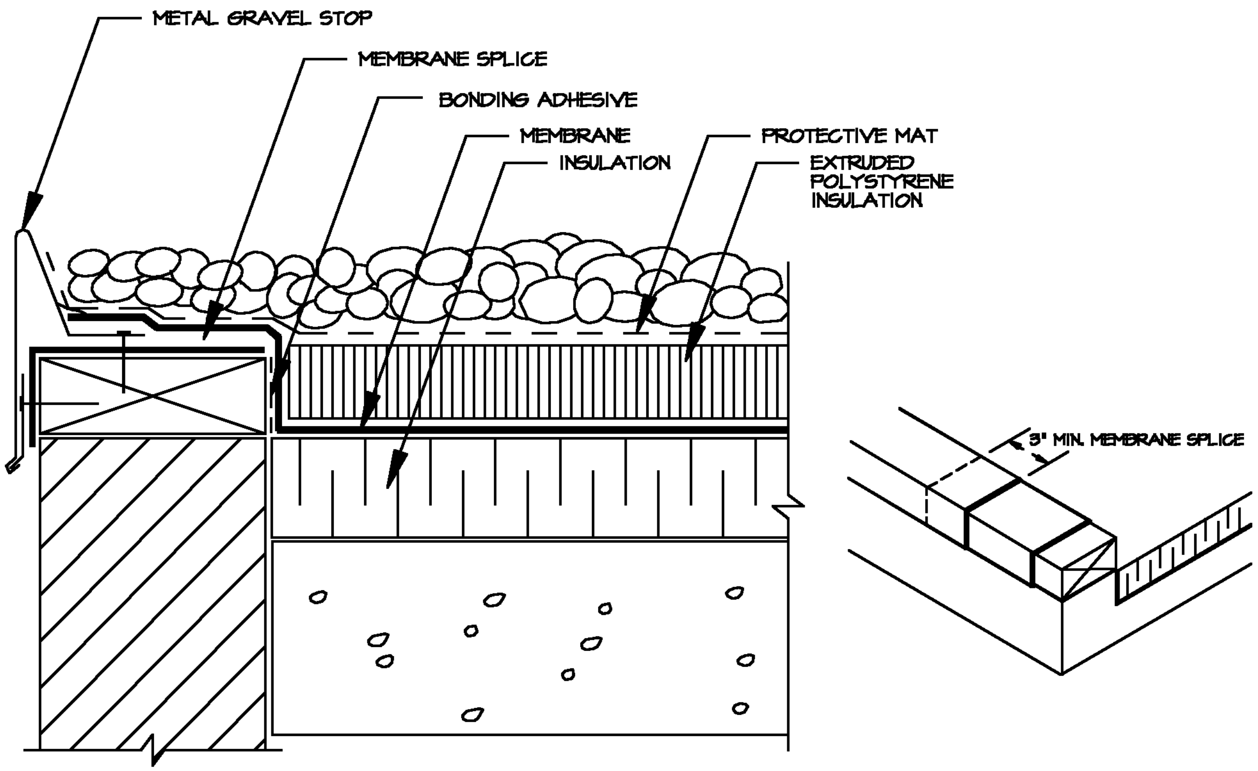
PARAPET

Figure 5D



GRAVEL STOP TERMINATION

Figure 6A



GRAVEL STOP TERMINATION

Figure 6B

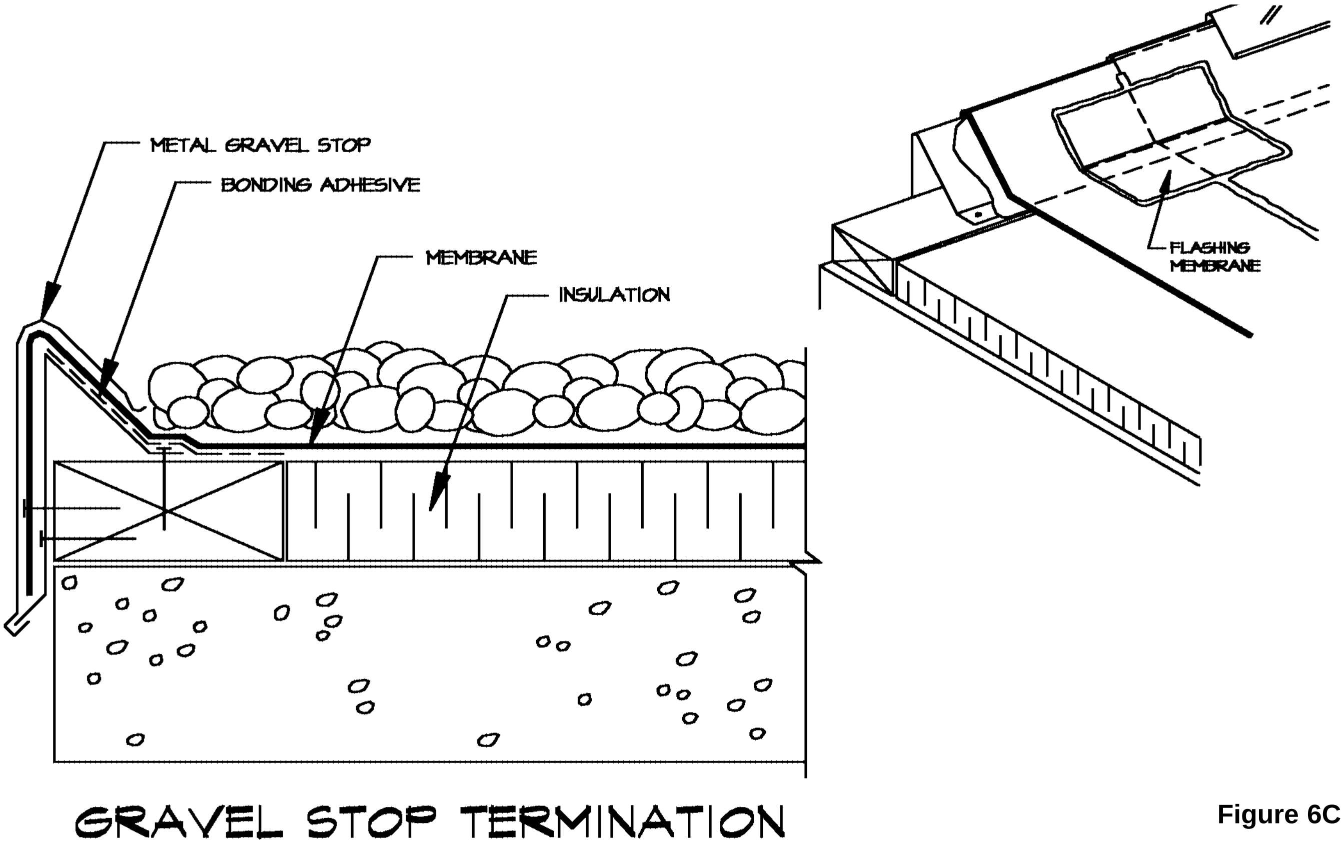


Figure 6C

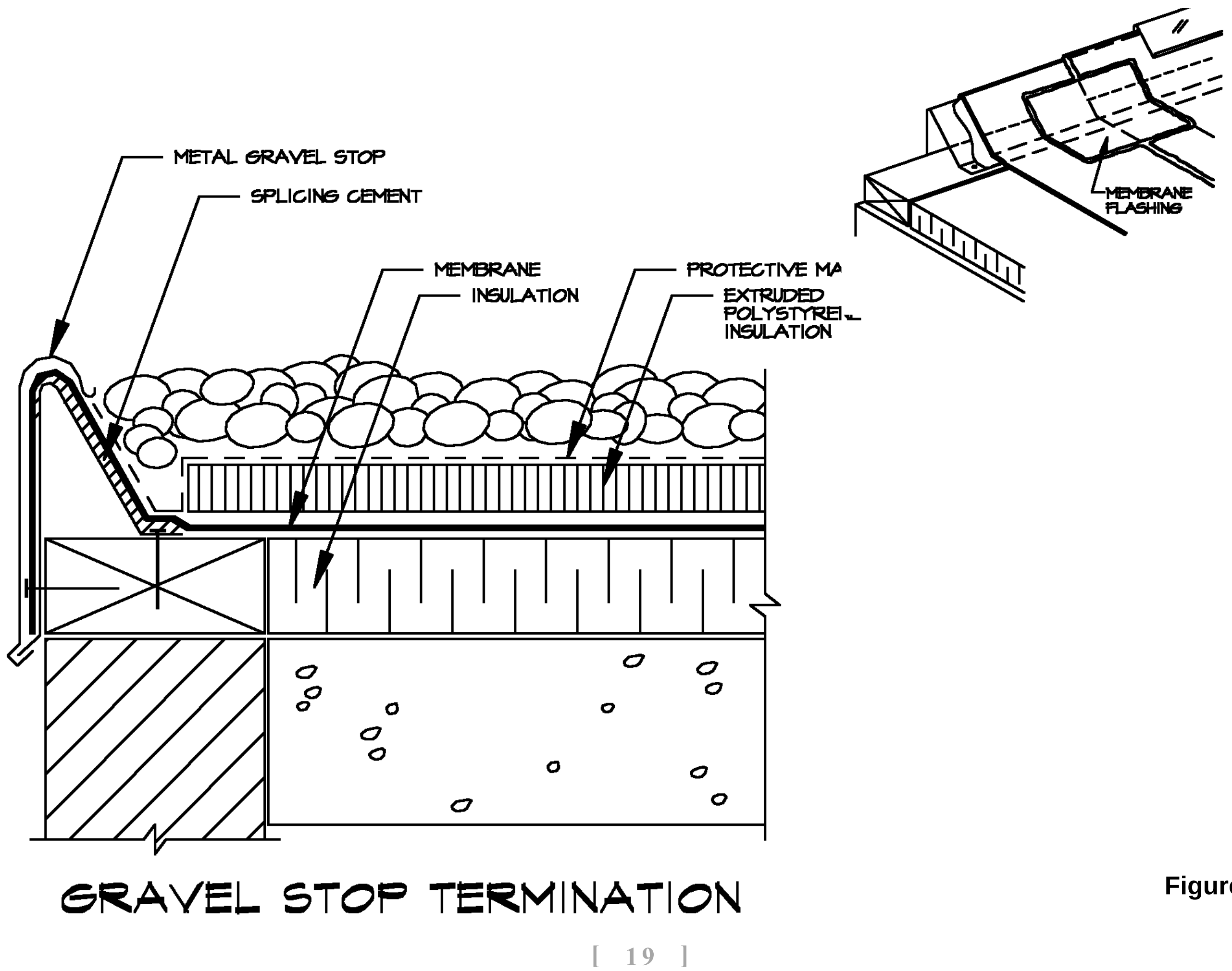
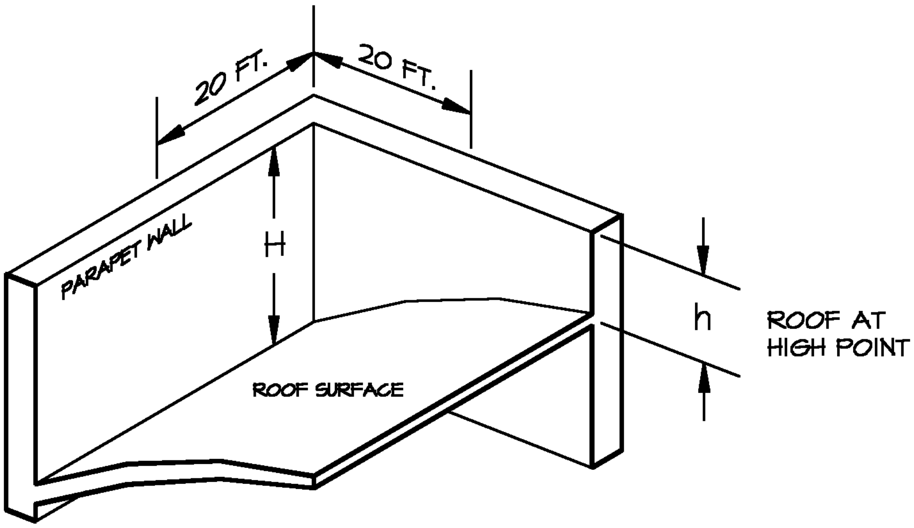
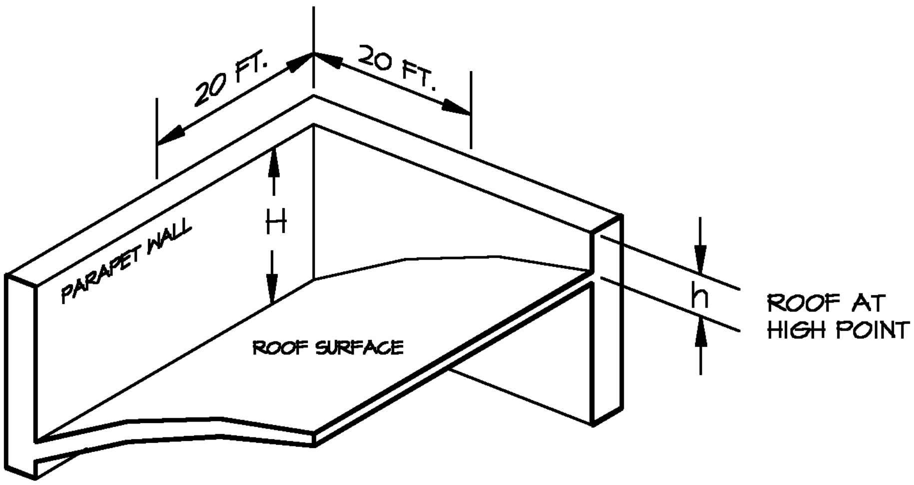


Figure 6D

PARAPET HEIGHT
DESIGN CONSIDERATIONS



IF PARAPET h IS GREATER THAN OR EQUAL TO 70% OF CORNER HEIGHT H, THEN USE H FOR DESIGN



IF PARAPET h IS LESS THAN OR EQUAL TO 70% OF CORNER HEIGHT H, THEN USE h FOR DESIGN

ANSI/FM/SPRI RP-4 - 1996

Figure 7

SPRI Test Method RE-1
Test for Roof Edge Termination of
BALLASTED OR MECHANICALLY ATTACHED ROOFING MEMBRANE SYSTEMS

(See Commentary: SPRI Test Method RE-1)

For ballasted roofs, the termination shall withstand a minimum force, F, of 100 lbs/ft (134 kg/m).

F = 100 for ballasted roofs

For mechanically attached systems, except in corner regions, the termination shall withstand a force equal to the distance of the first row of fasteners to the edge, D, multiplied by the design pressure, $\mathbf{q_z}$, of Table 4.

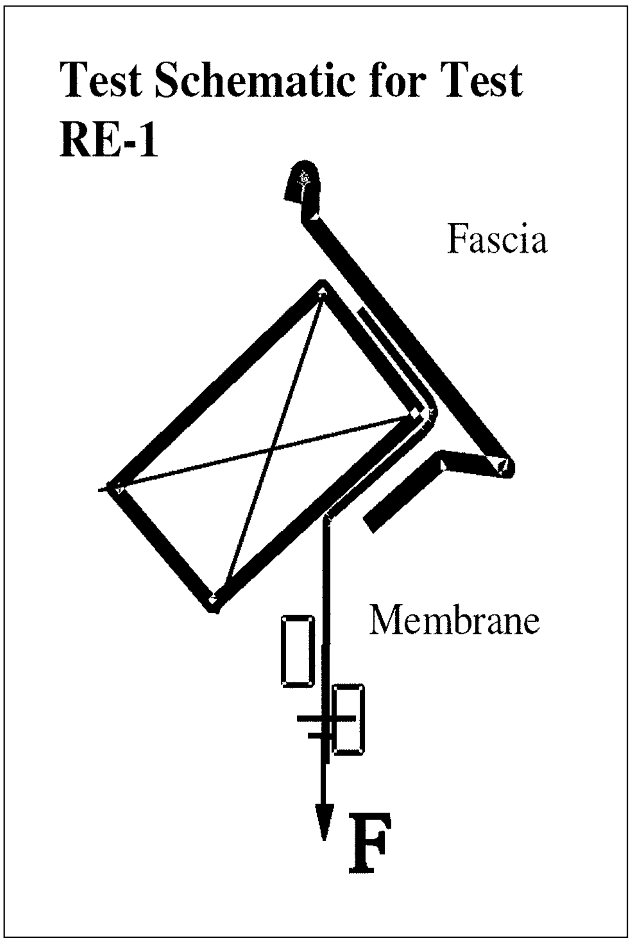
F = $q_z \times D$ for mechanically attached roofs except at corner regions

In corner regions, the force shall be 1.5 times the product of $\mathbf{q_z}$ and **D**.

F = 1,5 x q_z x D for mechanically attached roofs corner regions

Where the fastener spacing is closer in corner regions than at the general perimeter, the perimeter and corner region force, **F**, shall be calculated for both conditions. The larger value of **F** shall be used for testing the termination holding power.

Termination holding resistance shall be tested using the following method. Fully adhered systems or systems using an alternative method of terminating the roof at the edge shall not require this test.



Method: A minimum 12-inch (300 mm) wide mock-up of the termination system shall be constructed and mounted on the base of a tensile testing device so the membrane is pulled at a 45° angle to the roof deck to simulate a billowing membrane (see Figure 3). For devices in which fasteners are part of the membrane securement, at least two such fasteners shall be included in a balanced sample.

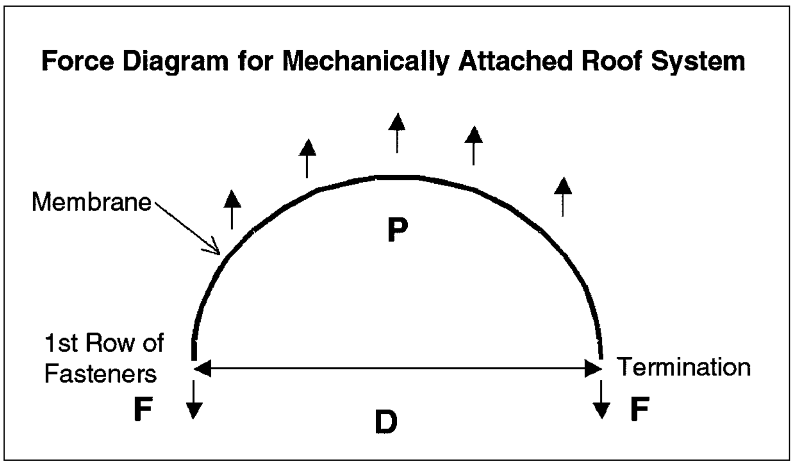
The jaws of the tester shall be connected to two bars that clamp the membrane securely between them so that the load is distributed uniformly along the width of the membrane (see Figure 3). The tester is loaded until failure occurs. Failure is defined as any event that allows the membrane to come free of the edge termination or the termination to come free of its mount. The roof edge termination strength is deemed satisfactory if the test force at failure on a 12-inch (300 mm) wide sample meets or exceeds the force, **F**, as specified above.

Attachment I

COMMENTARY to WIND DESIGN STANDARD for EDGE SYSTEMS USED with LOW SLOPE ROOFING

TEST METHOD RE-1

The method with which the edge of the roofing membrane is terminated (edge flashing, nailer, or other) is the last anchor point to hold the membrane in place during a high wind. When this happens, the roof system will put a load on the termination. For a ballasted roof, the termination must withstand a minimum force of 100 lbs/ft (134 kg/m) when tested using the method. This value has been adopted from the ANSI RP-4 Standard.



The total upward force indicated in the diagram is P, the design pressure times the distance to the first row of fasteners. The fasteners and the termination share the total force, so the restraining force, F, at either the fastening row or the termination is one half the force exerted by the membrane:

F = *P* x *D ÷ 2*

Design pressure, P, is the product of the velocity pressure, $\mathbf{q_z}$ and the Pressure Coefficient-Gust Factor Product, $\mathbf{GC_p}$. According to ASCE 7-98, $\mathbf{GC_p}$ is 2.0 at the perimeter and 3.0 in corner regions.

Therefore:

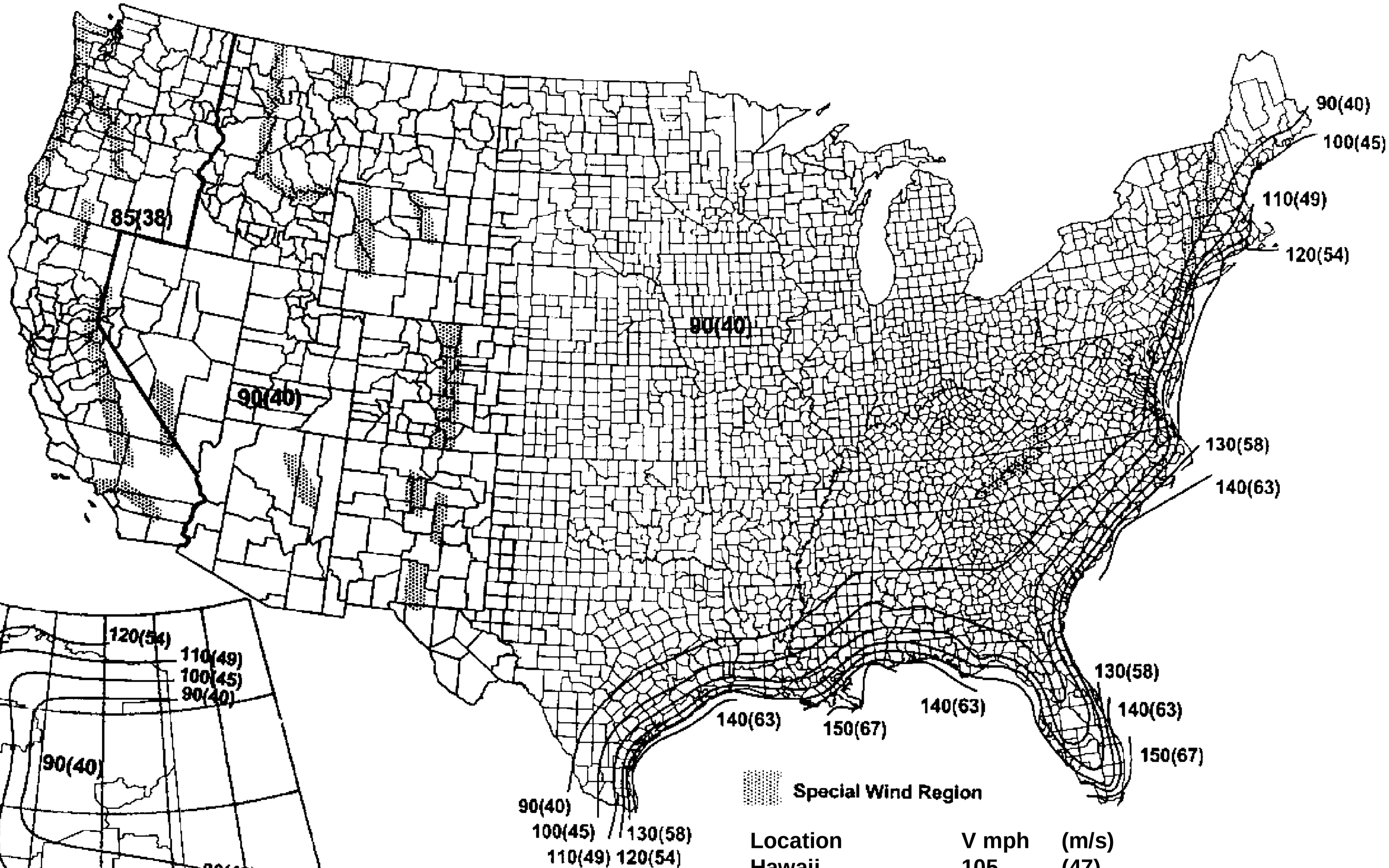
$\mathbf{F} = P \times D/2 = q_z \times GC_p \times D \div 2$

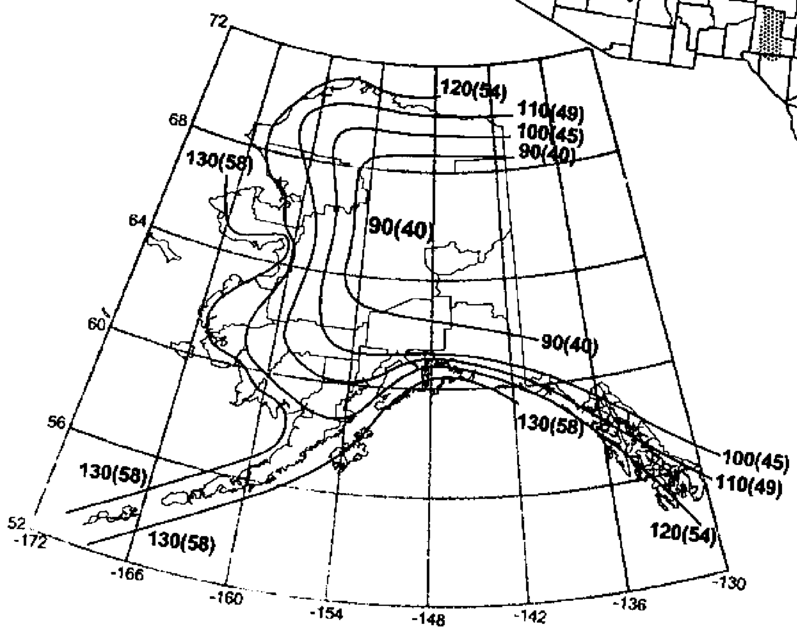
For $GC_p = 2.0$, $\mathbf{F} = q_z \times 2.0 \times D \div 2 = q_z \times D$

For $GC_p = 3.0$, $\mathbf{F} = q_z \times 3.0 \times D \div 2 = 1.5 \times q_z \times D$

Note that extra membrane fastening in corner regions, could reduce **D** enough to eliminate the need for extra reinforcement in the edge detail to comply with RE-1.

Fully adhered systems or systems using an alternative method of terminating the roof at the edge do not depend upon the edge detail for security and therefore are assumed to have no stress on the edge system under consideration.





Location	V mph	(m/s)
Hawaii	105	(47)
Puerto Rico	145	(65)
Guam	170	(76)
Virgin Islands	145	(65)
American Samoa	125	(56)

Notes:

1. **Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10m) above ground for Exposure C category.**
2. **Linear interpolationbetween wind contours is permitted.**
3. **Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.**
4. **mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.**

Attachment II

COMMENTARY TO ANSI/SPRI RP-4

This Commentary consists of explanatory and supplementary material designed to assist designers and local building code committees and regulatory authorities in applying the requirements of the preceding standard.

The Commentary is intended to create an understanding of the requirements through brief explanations of the reasoning employed in arriving at them.

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.

C1.0 INTRODUCTION

While the standard is intended as a reference for designers and roofing contractors, the design responsibility rests with the "designer of record."

C2.0 GENERAL DESIGN CONSIDERATIONS:

C2.1 Ballasted systems: 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 aggregate or other ballast may not always be adequate to resist uplift loads that result from some internal or other under membrane pressures. There shall 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 lbs./sq. ft or more of ballast weight. For lighter weight systems, air retarders are required, but this standard assumes the air retarder is imperfect. See sections 2.15, 2.16, 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.

C2.6 Wind Speed:
The wind speed used in this document is from ASCE 7-98. If the current code in the area of the building being constructed is not ASCE 7-98, but an older ASCE wind map, the commonly used conversion is; fastest mile plus 20 mph is approximately equal to the 3 second gust speed. If more detail is needed consult ASCE 7-98.

Ballasted roofs are not recommended where the basic wind speed is greater than 140mph. However they can be designed using reference 1, consultation with a wind design engineer, or wind tunnel studies of the specific building and system.

- Special Wind Regions (mountains or valleys): Refer to Section 6.5.4.1 of the ANSI/ASCE 7-98 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 7-98 Minimum design Loads for Buildings and Other Structures; Section 6.5.7. ASCE 7-98 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 ASCE reference. (ie 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 above the surrounding terrain in Ground Roughness A & B and 15 ft above the surrounding terrain in Ground Roughness C & D, need not be considered.

- Wind Borne Debris regions: ASCE 7-98 defines these regions as areas within hurricane regions located.
1. within one mile of the coastal high water line where the basic wind speed is equal or greater than 110 mph and in Hawaii; or
2. in areas where the basic wind speed is equal to or greater than 120 mph.
This document requires the use of #2 Ballast only, in these areas, to minimize the potential for ballast blow off.

The "authority having jurisdiction" is the only source for approval of designs not covered in this document. ASCE 7-98 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)

C2.7 Ballasted roofs with heights greater than 150' can be designed using reference 1, consultation with a wind design engineer, or wind tunnel studies of the specific building and system.

C2.8.1 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 designer may choose to include angles outside this range as a corner.

C2.8.2 & 2.8.3. The corners and perimeters used in this document are greater than ASCE 7-98. This adds a significant conservative factor for taller buildings. This particularly true for tall narrow buildings where the roof would need to be 90' wide using ASCE to have a 9 foot perimeter.

C2.9.2 Parapets: 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', ballasted systems are limited to 75'. The improvement in wind resistance is a function of parapet height. See tables for response.

C2.10.2 Unprotected Exposures, Exposure A:
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. Choosing an exposed category reduces the wind speeds at which the system is safely installed. Because of the effects on ballasted roof systems performance if ballast disruption were to occur, Exposure A is classified at the same level of severity as Exposure C. ASCE 7-98 has photo's that show the various categories in the commentary C6.5.6

C2.11 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 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 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 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-7-98 for further discussion.

C2.12 Positive Building Pressure. 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 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 pounds of ballast for every 0.5 inches of water interior pressure increase. Consult the mechanical design engineer for design and/or operating conditions of HVAC equipment, which may lead to positive pressure beneath the membrane.

C2.15 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 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)

C2.16 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.

C3.0 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.

C3.1 Certain PVC membranes contain plasticizers that may be extracted from the membrane. They may require a slip sheet between the membrane and some insulations.

C3.2 This standard addresses the basic requirements for membrane termination. For more details on the design of edging and attachment of nailers, see SPRI's document "Wind Design Standard for Edge Systems Used with Low Slope Roofing Systems". ANSI/SPRI 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 or consulting the manufacturer for expert design.

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.

C3.3 Ballast Weight: 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.

C3.3.1 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 buildup of these fines. If the source of stone is including too many fines, it may be advisable to have it "double washed" to get the fines below 2 percent. The research basis for the stone ballast was model stone that approximated the gradations of ASTM D-448. 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.

C4.0 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 VC2, 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 worse 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 accor dance with ASCE 7
- In a Full Scale Test conducted by a qualified Wind Engineer.
- 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.

C4.1.3.1 The Wind Load Design Guide For Low Sloped Flexible Membrane Roofing Systems provides pre-calculated loads based on ASCE 7-98. This tool can provide shortcut data when the building meets the criteria in the guide.

C4.1.3.2 Caution should be used when installing pavers, to not damage the membrane. Some manufacturers require a separation material between the membrane and the paver.

C4.2.2 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 lbs./sq. ft or more of ballast weight. For lighter weight systems, air retarders are required, but this standard assumes the air retarder is imperfect.

C4.2.2.2 Several Options exist for increased interconnectivity and securement of the perimeters. Heavy weight ballast is a non-proprietary way of achieving this requirement.

C4.2.2.3 System 3 design can be achieved by consulting references 6,7,8, and 9 or manufacturers proprietary designs.

C5.0 DESIGN PROVISIONS

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. See ASCE-7-98 for further discussion.

C6.0 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.

C7.0 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.

C Table 1.Design Tables

The maximum wind speed in the tables represents the worst case option with safety factors for each design condition. 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. Ballasted Systems shall be limited to installations in Wind zones limited to 140 mile per hour (mph) or less, 3 second gust design wind zone.
B. #2 Ballast systems shall be limited to 120-mph 3 second gust design wind zone.
C. #4 Ballast systems shall be limited to 110-mph 3 second gust design wind zone and not used in designated wind borne debris regions.
D. When parapet heights are less than 1 foot, ballasted systems shall be limited to buildings less than 75' tall.
E. 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.
F. 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(FPl2).
G. 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'-30' is based on 30 feet building height.
   The design data is always based on the lowest parapet height in a range; i.e. 6" to 12" parapet is based on the 6" parapet.
H. There are no reductions for directionality or building size factors.(see ASCE 7-98 for definitions)

ANSI/SPRI RP-4 References:

1. Kind, R.J. and Wardlaw, R.L., Design of Rooftops Against Gravel Blow-Off, National Research Council of Canada, Report No. 15544, September 1976.
2. Kind, R.J. and Wardlaw, R.L., "The Development of a Procedure for the Design of Rooftops Against Gravel Blow-off and Scour in High Winds," Proceedings of the Symposium on Roofing Technology, 1977, pp. 112.
3. Gillenwater, R.J., "Wind Design Guide For Ballasted Roofing Systems", Proceedings of the Second International Symposium on Roofing Technology, 1985, pp. 219.
4. Kind, R.J. and Wardlaw, R.L., "Wind Tunnel Tests on Loose-Laid Roofing Systems for Flat Roofs," Proceedings of the Second International Symposium on Roofing Technology, 1985, pp. 230.
5. Schneider, K.G. Jr., "A Study of the Behavior of Loose-Laid, Ballasted Single-Ply Roofing Systems Subjected to Violent Winds," Proceedings of the Second Inter- national Symposium on Roofing Technology, 1985, pp. 243.
6. Kind, R.J., Savage, M.G., and Wardlaw, R.L., "Further Model Studies of the Wind Resistance of Two Loose-Laid Roof Systems (High-Rise Buildings), National Research Council of Canada, Report LTR-LA-269, April 1984.
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