Wind Design – Not Just Another SPRI Wind/ES Presentation

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ABSTRACT

Roofing systems are one of the most commonly damaged portions of the building envelope during high wind events. For this reason, additional emphasis has been placed in the International Building Code on designing low-slope commercial roofing systems to reduce damage during high wind events.

Reducing damage to roof systems during high wind events requires a full system approach, including proper design of the field, perimeter, corner, and edge metal of the roofing system. This presentation will summarize:

1. Lessons learned from post hurricane inspections conducted by the Roofing Industry Committee on Weather Issues (RICOWI).
2. SPRI standards that can be used to design the roofing system to be in compliance with the requirements of the International Building Code, including:
   - SPRI WD-1 – Wind Design Standard for Low Slope Roofing Systems
   - ANSI/SPRI RP-4 – Wind Design Standard for Ballasted Single-Ply Roofing Systems
   - ANSI/SPRI ES-1 – American National Standard Wind Design Standard for Edge Systems Used with Low Slope Roofing Systems

SPEAKERS

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INTRODUCTION

Combined insurance losses from Hurricanes Katrina and Rita exceeding $60 billion, by far the most expensive natural disasters on record for the U.S. (Greenberg Traurig Alert, October 2005). Factory Mutual Global reports that roofing claims related to wind damage to commercial roofing systems account for $210 million/year in insurance losses, 10% of the total losses. (FM Global, "Protecting Roofing Systems Against Windstorm Damage.") Proper design and installation of roofing systems will help mitigate these losses and the associated losses from business disruption.

The International Building Code (IBC) contains requirements for roofing systems that must be met to resist wind uplift forces. Investigations conducted after high wind events have determined that in many instances, the roof system was not installed in accordance with the applicable code, whether due to deficient design or installation. Problems were also noted with a lack of maintenance. If the requirements of the code had been met, losses due to high wind events could have been dramatically reduced.

This paper discusses standards and recommendations developed by SPRI, the trade association representing the single-ply roofing industry, that meet the requirements of the International Building Code for wind resistance of roofs.

BALLASTED SINGLE-PLY ROOF SYSTEMS

Ballasted single-ply roofing systems have been in use since the 1970s. Designing these systems to resist wind load forces was one of the initial concerns with ballasted systems. To address this concern, the roofing industry conducted wind tunnel and full-scale mockup testing of ballasted systems. In addition to the testing, field observations were performed by manufacturers and consultants to develop additional data on the wind performance of these systems. Based on this information, a *Standard Design Guide* was developed.

Much of the information that was used as the basis for the development of the *Standard Design Guide* was presented at the Second International Symposium on Roofing Technology held in 1985.

The following papers were presented at that symposium regarding ballasted roof systems. The information from this work is the basis for much of the information presented in this paper:

- "Wind Design Guide for Ballasted Roofing Systems," Richard J. Gillenwater
- "Wind Tunnel Tests on Loose-Laid Roofing Systems for Flat Roofs," R.J. Kind
- "Stone Ballast Design Criteria on Loose-Laid Single-Ply Ballasted Roofs for Wind Speed, Size and Weight," Thomas E. Phalen Jr.
- "A Study of the Behavior of Loose-Laid Ballasted Single-Ply Roofing Systems Subjected to Violent Winds," Kenneth G. Schneider Jr.

The IBC requires that ballasted single-ply roof systems be installed in accordance with ANSI/SPRI Standard RP-4, "Wind Design Standard For Ballasted Single-ply Roofing Systems." ANSI/SPRI RP-4 was first included in the regional building codes (BOCA, SBCCI, IBCO) starting in 1986. It is imperative that stone-ballasted roof systems be designed in accordance with this standard design guide to assure that stone blow-off will not occur. Ballasted single-ply roof systems have performed very well during high wind events when designed in accordance with the ANSI/SPRI standard, and even in some instances when they have not.

As an example, *Figure 1* shows a stone-ballasted EPDM roof in Mississippi City, Mississippi, after Hurricane Katrina that did not appear to meet the requirements of ANSI/SPRI RP-4. The estimated wind speeds at this location were 120 to 130 mph. As can be seen, the roof system performed very well, with just a few areas of localized stone scouring as shown in *Figure 2*. This is due to high wind loads in this area from wind flowing around roof-top equipment. In this case, the wind came from the backside of the equipment and caused wind scouring on the opposite or near side in this photo. Methods of addressing stone scour are addressed in the

Figure 1 – Typical roof area at this location (photo courtesy of RICOWI Inc.).

Figure 2 – Example of stone scour that can occur in areas of localized high wind loads (photo courtesy of RICOWI Inc.).

. The investigators on this roof did not find ballast stone that had blown off the roof.

Even though in this example stone blow-off was not observed, SPRI's position is that all ballasted roof systems should be installed in strict adherence to the code-mandated ANSI/SPRI RP-4 standard. Not doing so can lead to stone blow-off, providing debris that has been observed to cause collateral damage to surrounding buildings and vehicles (see FEMA 549).

Section 1504.4 of the 2007 Supplement to the International Building Code (the most current version of the code) states, "Ballasted low-slope (roof slope <2:12) single-ply roof system coverings installed in accordance with Section 1507.12 and 1507.13 shall be designed in accordance with Section 1504.8 and ANSI/SPRI RP-4. This Section provides a direct reference to the ANSI/SPRI Standard in the International Building Code."

Section 1504.8 describes requirements for aggregate surfacing materials, while the ANSI/SPRI standard describes ballasting requirements for large stones.

The standard contains five sections that will be discussed in detail in the portion of this report that details how to use the standard:

General design considerations

This section contains definitions and information that applies to designing the roof system to resist wind loads for any type of system.

System requirements

This section contains requirements for single-ply membranes to be used in ballasted systems, along with requirements for the various types of ballast that can be used.

Design options

This section describes the methods for installing Systems 1, 2, and 3 as called out in the design tables. The design provisions become more resistant to wind loads as the number increases. This section also describes how Protected Membrane Roof systems should be ballasted.

Design provisions

This section describes how to handle special considerations for example large openings in the wall and eaves and overhangs.

Design tables

This section contains tables that allow the user to determine which system design will be required, based on the design wind speed, building height, parapet height, and exposure category.

It is important to note that this is a very conservative standard. The following conservative approaches were taken in developing the requirements included in this standard:

- The ballast design tables have been developed so that the ballast will not blow off the roof at the design wind speed. There has been some concern expressed with the gradation that occurs within a specified stone type in ASTM D448, Standard Classification for Sizes of Aggregate for Road and Bridge Construction, which is the standard referenced for ballast stone size in the RP-4 standard. For example, ASTM D448 Type 4 stone is nominal 1-1/2 inches in diameter; however, it can range from greater than 3/8 inch to less than 2 inches in diameter. It has been the experience of SPRI manufacturers that have investigated the performance of these systems that the smaller stones migrate to the bottom and are not available to become windborne debris.

- This standard is based on having no deliberately installed air retarders for all systems with 10 lbs/sq ft or more of ballast weight. This was done because it is recognized that 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. Therefore, the worse-case scenario was considered in the design of this standard.
- For lighter weight systems, air retarders are required, but this standard assumes the air retarder is imperfect. The standard in cludes a discussion on where air retarders may be required.

A few examples of restrictions placed on the use of ballasted roof systems included in the ANSI/SPRI standard are:

- When the maximum build ing height exceeds 150 feet, the roof design shall be based on an expert's design method and approved by the authority having jurisdiction.
- When the maximum wind speed exceeds 140 miles per hour, the roof design shall be based on an expert's design method and approved by the authority having jurisdiction.
- In areas designated as windborne debris regions, ballast designs using stone ballast shall use a minimum nominal stone diameter of 2-1/2 inches.
- In hurricane-prone regions, buildings exceeding 60 feet in height shall not use stone ballast in the corners and perimeters unless the parapet height exceeds 36 inches.

In the above restrictions, the use of expert design is required if the building height is above 150 feet or if the design wind speed is above 140 mph. In doing the expert design analysis, the key factor is determining the anticipated wind speed at the roof surface. This will be significantly impacted by the parapet height. Once this is determined, an excellent reference is NRC *Report Number 15544, Design of Rooftops Against Gravel Blow-Off.* This report provides an analysis of wind tunnel testing that was conducted to evaluate the critical speeds at which stone ballast would begin to move. Data from this report can be compared to the rooftop wind speed and be used as the basis of a rational design.

HOW TO USE THE ANSI/SPRI RP-4 STANDARD

When considering the use of a ballasted single-ply roof system, the designer must first verify that the roof structure and deck will support the ballast load in combination with all other design loads. A licensed architect or an engineer should make this determination.

Once the structure has been determined to be adequate, the following variables must be determined in order to identify the proper way to ballast the system.

Wind Speed

The wind speed used in the standard is the Basic Wind Speed as provided in the ANSI/ASCE 7-2005 standard or the local authority having jurisdiction when local values exceed ASCE 7-2005. This is the 3-second gust speed at 33 ft (10 m) above the ground in Exposure C. The intensifying effects of abrupt or unique topographical features need to be accounted for in the design (See ASCE-7). Both the Commentary of the standard and sections within the standard address how this should be accomplished.

Building Height

The building height is measured from ground level to the roof system surface at the roof edge. If multiple roof levels are present, each one must be designed separately.

Edge Condition

If a gravel stop is used at the building perimeter, the top edge of the flashing must be at least 2 in above the top surface of the membrane and higher than the top of the ballast.

If the edge of the roof uses a parapet, the height of the parapet is the distance from the top of the roof system membrane to the top of the parapet for conventional ballasted systems (roof deck, loose-laid insulation, loose-laid membrane, ballast). For Protected Membrane Systems (roof deck, loose-laid or adhered membrane, loose-laid insulation, fabric, and ballast), the parapet height is the distance from the top of the insulation to the top of the parapet.

If the edge of the roof consists of a parapet of variable height, special conditions may influence the measurement of parapet height. The standard defines how to calculate parapet height in these situations.

Building exposure

The terrain surrounding the building will influence the degree of exposure of the building to the wind. The building is classified as either protected or unprotected.

Protected exposures

Surface Roughness 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 2,600 ft (800 m) or 20 times the height of the building, whichever is greater.

Unprotected exposures

Surface Roughness C: Open terrain with scattered obstructions having heights generally less than 30 ft (9.1 m). This category includes flat open country, grasslands and all water surfaces in hurricane-prone regions. Exposure C shall apply for all cases where exposures B or D do not apply.

Surface Roughness D: Flat, unobstructed areas and water surfaces outside hurricane-prone regions. This category includes smooth mud flats, salt flats, and unbroken ice. Use of this exposure category shall be limited to those areas for which terrain representative of Exposure D prevails in the upwind direction for a distance of at least 5,000 ft (1524 m) or 20 times the height of the building, whichever is greater.

In most instances, the unprotected exposure will be used.

DETERMINING BALLAST DESIGN

You now have the basic information necessary to determine the required ballast design. *Table*

BLDG.	SYSTEM 1		SYSTEM 2		SYSTEM 3	
Ht. Ft	Exp.C	Exp. B	Exp. C	Exp. B	Exp. C	Exp. 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

Table 1–A – From 2-in high gravel stop to less than 6-in high parapet maximum allowable wind speed (mph).

BLDG.	SYSTEM 1		SYSTEM 2		SYSTEM 3	
Ht. Ft	Exp.C	Exp. B	Exp. C	Exp. B	Exp. C	Exp. 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

TABLE 1-C – For parapet heights from 12 to less than 18 inches maximum wind speed (mph).

BLDG.	SYSTEM 1		SYSTEM 2		SYSTEM 3	
Ht. Ft	Exp.C	Exp. B	Exp. C	Exp. B	Exp. C	Exp. 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

TABLE 1-F – For parapet heights from 36 to less than 72 inches maximum wind speed (mph).

1 provides an example of a ballast design table.

The Design Tables cover ballast designs for various parapet heights. This example contains designs for some of the heights. The standard actually contains designs for the following parapet heights:

Part A: From 2-in gravel stop to less than 6-in-high parapet

Part B: From 6-in gravel stop to less than 12-in-high parapet

Part C: From 22-in gravel stop to less than 18-in-high parapet

Part D: From 18-in gravel stop to less than 24-in-high parapet

Part E: 24-in gravel stop to less than 36-in-high parapet

Part F: 36-in gravel stop to less than 72-in-high parapet

Part G: 72-in gravel stop and above

The Design Tables also references System 1, System 2, and System 3. These are references to different ballasting schemes. The resistance to wind loads increases as the System number increases. The designs are as follows:

System 1

System 1 requires that the roof covering be ballasted with 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 1,000 pounds per 100 square feet; standard concrete pavers (minimum 18 psf); or interlocking, beveled, doweled, or contoured fit lightweight concrete pavers (minimum 10 psf).

System 2

System 2 requires that the field of the roof be ballasted in the same manner as was used in System 1 and the perimeters and corners are ballasted with 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 1,300 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.

The perimeter 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.

The corner is defined as the space between intersecting walls forming an angle greater than 45 degrees but less than 135 degrees. 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.

Unlike ASCE-7, which allows either 40% of the building height or 10% of the building width, whichever is less, to determine the perimeter and corner areas, RP-4 requires the use of 40% of the building height. For tall buildings, this results in very large perimeter and corner areas.

System 3

System 3 is the most stringent design and is required in areas where the design wind speed exceeds 120 mph. For this design, the field of the roof is ballasted in the same manner as the perimeters and corners are in the System 2 design. The corner and perimeter areas must use either a mechanically attached or adhered system that is designed to withstand the uplift force in accordance with ANSI/ASCE 7-2005 or the local building code. No loose stone can be used in these areas. If a protective covering is required, then a fully adhered membrane system must be used and covered with minimum 22 psf pavers or other material approved by the authority having jurisdiction.

At the junction of the loose-laid roof membrane with the adhered or mechanically attached membrane areas, a mechanical termination providing a minimum 100 pounds per linear foot holding power must be provided.

Practical example of determining the ballast requirements

Example building:

Building height - 60 ft

Edge condition - gravel stop

Design Wind Speed - 90 mph

Exposure - unprotected (C)

To determine the ballast requirements for this building, look in *Table 1*, Part A, from 2-inch high gravel stops to less than 6-inch high parapets. Find the appropriate building height in Column 1. Look across the row until the required design wind speed is located. Once it is located, make sure it matches the appropriate exposure category. In this case, Ballast System 1 cannot be used; you must use Ballast System 2. The maximum building height for these conditions that would allow for the use of Ballast System 1 is 45 ft.

The importance of parapet height can also be seen. Ballast System 1 could not be used on this building unless there were a parapet that was at least 36 inches high (*Table 1, Part F*).

The importance of correctly identifying the exposure category can also be observed. In *Table 1, Part C*, Ballast System 1 could be used if the parapet height was increased to 12 inches and the exposure category was changed to protected (B). If the exposure category remained as unprotected, System 1 could not be used.

Conditions that impact ballasting requirements

There are a number of conditions that will influence the required ballast loading. These conditions and the action that should be taken are summarized in *Table 2*.

The RP-4 standard is available free of charge from the SPRI website, www.spri.org.

MECHANICALLY ATTACHED AND ADHERED SINGLE-PLY ROOF SYSTEMS

Both mechanically attached and adhered single-ply roofing assemblies have performed well in high-wind events (see *Figures 3* and *4*).

Figure 3 shows a mechanically attached roof after exposure to Hurricane Katrina. The building is located in Bay St. Louis, Mississippi, and was exposed to wind speeds of 120 to 130 mph. *Figure 4* shows an adhered single-ply roof assembly after exposure to Hurricane Ivan. The building is located in Escambia County, Florida, and was exposed to wind speeds of 110 to 120 mph.

RICOWI, Inc. has conducted field investigations on three hurricanes: Charley, Ivan, and Katrina. Reports from these investigations are available on the RICOWI Web site, www.ricowi.com. These investigations have found that adhered and mechanically attached single-ply membrane systems can be installed to perform well in high wind events. However, in some instances, unsatisfactory performance was observed. In these situations, the unsatisfactory performance was related to deficiencies in either the design or installation of the system; either could have been the cause. In addition to design or installation issues, puncturing of the membrane was noted as a problem in high-wind events. The punctures were caused by flying debris, or in some instances, rooftop equipment coming loose and rolling across the surface of the roof.

Section 1504.3 of the 2007 supplement to the International Building Code requires that roofs be designed to resist wind loads as determined by Chapter 6 of ASCE-7. Once the appropriate wind loads have been determined, Section 1504.3.1 of the code requires that an assembly tested to resist the determined load be used. Test results from a code-approved testing laboratory and tested in accordance with ap-

Condition[1]	Action
Large openings in a wall	Roof area above the opening must be designed as a corner area of the respective System 2 or System 3 designs. For System 1 designs, use the corner area specifications of a System 2 design.
Positive pressure in building between 0.5 and 1 inch of water	Increase the roof-top wind speed by 20 mph from the basic wind speed from the wind map.
Rooftop projections (See *Figure 2* to see potential issues with rooftop projections.	The roof area that extends four feet out from the base of such projections shall have the same design as the corner area of the roof.
Overhangs, eaves, and canopies – pervious decks	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. System 3 is still designed to System 3.
Overhangs, eaves and canopies – impervious decks	Eaves and overhangs are designed as a perimeter of the applicable design. Canopies are designed as a corner section of the applicable design.
Exposure D	Increase the roof-top wind speed by 20 mph from the basic wind speed from the wind map.
Importance factor[2]	For buildings fitting category III or IV (high importance), increase the roof-top wind speed by 20 mph from the basic wind speed from the wind map.

1. – The RP-4 Standard provides definitions for each of these conditions.
2. – Importance Factor

Category I: Buildings that represent a low hazard to human life.
Category II: Buildings not covered by categories I, III or IV.
Category III: Buildings that represent a substantial hazard to human life.
Category IV: Buildings that are considered essential facilities.

Figure 3 – Mechanically fastened thermoplastic single-ply membrane after Hurricane Katrina. (Photo courtesy of RICOWI Inc.)

proved methods may be used to demonstrate compliance with the code. Approved methods are FM 4450, FM 4470, UL 580 or FM 1897.

Some states have developed requirements that must be met when designing roof assemblies. For example, the Florida has a code that has been specifically developed for high-velocity hurricane zones.

SPRI has recently developed a national consensus standard, ANSI/SPRI WD-1, "Wind Design Standard Practice for Roofing Assemblies." This wind design standard allows the user to determine wind loads through a series of easy-to-read tables that have been calculated using Chapter 6 of ASCE-7, thus meeting the requirements of the International Building Code. This standard practice also provides installation guidelines to enhance the attachment of the roofing system at the perimeters and corners where wind loads are higher. The prescriptive enhancements vary based on the attachments method used for the first layer. If the first layer is mechanically attached, then the standard provides a method to calculate the increase in fasteners required to resist the design corner and perimeter loads. If the first layer is adhered, then the adhesive bead spacing is decreased. The enhancements are based on the known holding power of the mechanical fastener or adhesive.

SPRI has proposed a code change for the 2007/2008 IBC Code cycle to include this new standard in the IBC.

HOW TO USE ANSI/SPRI STANDARD WD-1

ANSI/SPRI WD-1 consists of three primary sections.

General Design Considerations and Definitions

The information in this section is consistent with the same type of information provided in ANSI/SPRI RP-4 and was covered earlier in this report and will not be repeated here.

Two-part Methodology

First Part - Calculate the wind uplift design loads for the field, perimeter, and corner areas of a building.

This is accomplished by either using the Quick Reference tables provided in this Standard Practice or by calculating these values following the requirements of the current version of the ASCE 7 Standard, Minimum Design Loads for Buildings and Other Structures. The Quick Reference Tables are based on ASCE 7-05 and can only be used if a particular building meets the criteria identified in the standard.

Second Part – Select an appropriate roofing system assembly by comparing the tested wind uplift resistance capacity to the calculated design loads. It is strongly recommended that a safety factor be applied to the tested wind uplift resistance before comparison to the design pressures. A 2 to 1 safety factor is commonly used. The standard refers to the "factored load." The factored load is:

Factored Tested Load Capacity = tested uplift capacity (Lt) / safety factor, psf

Wind loads are higher at the perimeter and corner areas of the roofing assembly. For this reason, enhanced attachment is necessary in these areas. The standard provides a method to extrapolate

Figure 4 – Adhered single-ply membrane after Hurricane Ivan. (Photo courtesy of RICOWI Inc.)

the field of roof rating to the perimeter and corner regions, assuming certain conditions are met. These conditions and methods for various types of attachment are:

ADHERED SYSTEM ASSEMBLIES

The adhered roofing system assembly extrapolation method is only applicable when all of the following criteria are met:

1. The adhered roofing system assembly utilizes either mechanical fasteners or ribbons/beads of an adhesive for insulation attachment, and
2. The tested wind uplift load capacity of the proposed adhered roofing system assembly was determined utilizing a test chamber of sufficient size to allow side-by-side positioning of a minimum of three full-size insulation/cover board/substrate boards/panels on the test frame, and
3. The calculated field design load does not exceed 53 psf.

Extrapolation for adhered roofing system assemblies is not possible when the insulation layer(s) is (are) attached using a 100% coverage rate of an adhesive.

Mechanically Attached Insulation

For insulation attached with mechanical fasteners, determine the increased number of fasteners per insulation board (F_n) needed to meet the calculated design load(s) using the following equation: $F_n = (F_t \times L_d) / L_t$

Where:

F_n is the number of fasteners per board needed to meet the design load.

F_t is the number of fasteners per board used to achieve the tested load capacity.

L_d is the calculated design load for the perimeter or corner area of a roof, psf.

L_t is the factored tested load capacity, psf.

Ribbon/Bead Adhesive-Attached Insulation

For insulation attached with ribbons/beads of adhesive, determine the reduced ribbon/bead spacing (R_n) needed to meet the calculated design load(s) using the following equation:

$$R_n = R_t / (L_d / L_t)$$

Where:

R_n is the ribbon/bead spacing needed to meet the design load, inches.

R_t is the ribbon/bead spacing used to achieve the tested load capacity, inches.

L_d is the calculated design load for the perimeter or corner area of a roof, psf.

L_t is the factored tested load capacity, psf.

Note: When ribbon/bead-attached insulation is applied directly to a fluted steel deck, the ribbon/bead spacing will be dictated by the center-to-center spacing of the top (high) flutes of the steel deck. The extrapolated ribbon/bead spacing must be rounded down (when necessary) to coincide with a top (high) flute. If the extrapolated ribbon/bead spacing is less than the center-to-center spacing of the top (high) flutes of a steel deck, ribbon/bead attachment of the insulation in that area is not acceptable.

The F_n and R_n equations can only be used to increase the number of fasteners or decrease the spacing of ribbons/beads of adhesive needed in the corner and perimeter areas. These equations cannot be used to extrapolate backwards and reduce the number of fasteners or increase the spacing of ribbons/beads of adhesive used in the field of the roof.

EXTRAPOLATION METHOD – MECHANICALLY FASTENED SYSTEM ASSEMBLIES

The mechanically fastened roofing system assembly extrapolation method is only applicable when the following criteria are met:

1. The tested wind uplift load capacity of the proposed linearly-attached (rows), mechanically fastened roofing system assembly was determined utilizing a test chamber of sufficient size to allow positioning of a minimum of three attachment rows on the test frame. The minimum frame width shall be 8 feet.
2. The tested wind uplift load capacity of the proposed spot-attached, mechanically fastened roofing system assembly was determined utilizing a test chamber of sufficient size to allow positioning of a minimum of nine attachment locations on the test frame. The minimum frame width shall be 8 feet.

For mechanically fastened system assemblies, first determine the influence area per fastener for the tested assembly (IA_t) by multiplying the row spacing by the fastener spacing (along the row). For spot-attached systems, multiply the distance between the attachment locations in each direction (2 ft x 2 ft, 2 ft x 3 ft, etc.). This gives the number of square feet of membrane held in place by one fastener. Next, calculate the influence area needed to meet the design load using the following equation:

$$IA_n = (L_t \times IA_t) / L_d$$

Where:

IA_n is the area of membrane needed to be held in place by one fastener to meet the design load, ft^2.

IA_t is the area of membrane held in place by one fastener for the tested assembly, ft^2.

L_d is the calculated design load for the perimeter or corner area of a roof, psf.

L_t is the factored tested load capacity, psf.

The fastener row spacing or the spot attachment grid spacing of the assembly being evaluated must be reduced so the ft^2 of membrane held in place by each fastener does not exceed IA_n. Use the same fastener spacing (along the row) as was tested.

For mechanically fastened system assemblies with linear (row) attachment, only the spacing between fastener rows can be reduced to meet IA_n. This extrapolation method cannot be used to reduce the spacing between fasteners along the row (12 inches to 6 inches, for example) in place of reducing the spacing between fastener rows. This extrapolation method also cannot be used to extrapolate backwards and increase the spacing between fasteners along the row (12 inches to 18 inches, for example) or increase the spacing between fastener rows (8 feet to 10 feet, for example).

Quick Reference Tables

The Quick Reference Tables have been developed using the ASCE 7-05 Standard (Minimum Design Loads For Buildings And Other Structures). These tables are applicable to buildings in exposure categories B, C and D when all of the following criteria are met:

- The building is not situated on a hill, ridge, or escarpment.
- The building is Category II.1.
- The building is enclosed.
- The roof slope does not exceed 1.5 inches per foot (7 degrees).

PRACTICAL EXAMPLE FOR USE OF THIS STANDARD

Example Building Criteria

A 40-ft high warehouse building located outside of Pittsburgh, PA, has a plan dimension of 200 ft by 400 ft. The building has metal roof deck with flutes spaced 6 inches on center. The walls have no large openings. The roof slope is 1/2 in per ft. The architect/designer has selected a 2.0 safety factor to be used for this project.

Task

Design a system that uses an adhered membrane over insulation with mechanical fasteners.

First Part: Calculate the wind uplift design loads for the field, perimeter, and corner areas of the building that will be used for all three examples.

Step 1: Determine If the Quick Reference Tables Contained in This Document Can be Used:

- Building is Category II (or Table 1-1 of ASCE 7-05)
- Building is not situated on a hill.
- Building is enclosed (from Section 6.2 of ASCE 7-05).
- Building is in 90 mph wind zone (from figure 6-1 of ASCE 7-05).
- Roof slope is <= 70 (1.5 in/ft).

All the conditions are met so the Quick Reference Tables can be used. If this were not the case, the design loads would need to be calculated in accordance with the current ASCE 7 Standard. The equations used to calculate the design loads are referenced contained in the Standard.

Step 2: Determine Design Loads Using the Quick Reference Tables

Refer to *Table 3*.

Field Design Load = -25.5

Perimeter Design Load = -42.8

Corner Design Load = -64.4

The negative sign merely indicates that the uplift load is outward (away from the building). The negative sign will be ignored for calculation purposes.

Second Part: Select an appropriate roofing system assembly by comparing the tested wind uplift resistance capacity of that assembly to the design loads.

System 1 - Adhered Roofing System Assembly Selection Example for Mechanically Fastened Insulation

The adhered membrane roofing system assembly being considered for this building was tested on a 12 ft x 24 ft test chamber to a maximum wind uplift resistance capacity of 90 psf (L_t) using 16 fasteners (F_t) per board. Apply the 2.0 safety factor to the 90 psf tested value to determine the

1 – When a building is classified as Category I, the Quick Reference Tables are usable if the field, perimeter, and corner design loads are multiplied by 0.85. Likewise, when a building is classified as Category III or IV, the Quick Reference Tables are usable if the field, perimeter, and corner design loads are multiplied by 1.15.

Factored Tested Load Capacity:

Factored Tested Load Capacity = **L_t / 2.0 = 90 psf / 2.0 = 45 psf**

The factored tested load capacity (45 psf) exceeds the design loads for both the field (25.5 psf) and perimeter (42.8 psf) areas of the roof but not the corner area (64.4 psf). Consequently, the as-tested assembly is acceptable for use in the field and perimeter areas. To determine if extrapolation is acceptable for the corner areas, check the extrapolation requirements of the Extrapolation Method – Adhered System Assemblies. Since all the extrapolation method requirements are satisfied, extrapolation is acceptable.

To determine the number of fasteners (F_n) needed per insulation board for the corner areas of the roof, use the equation:

$$F_n = (F_t \times L_d) / L_t.$$

Where:

F_n is the number of fasteners per board needed to meet the corner design load.

F_t is the number of fasteners per board used to achieve the tested load capacity.

L_d is the calculated design load for the corner area of the roof, psf.

L_t is the factored testee load capacity.

Corner Area

F_n = (16 fasteners x 64.4 psf) / 45 psf = 23 fasteners per board

The final design for this assembly scenario is to use 16 fasteners per insulation board in the field and perimeter areas and 23 fasteners per board in the corner areas. The extra seven fasteners added to the corner areas shall be evenly distributed around the tested fastener layout pattern. Fastening pattern examples for insulation boards are included in Appendix B of the Standard.

Building Height, ft.	Field Design Load, psf	Perimeter Design Load, psf	Corner Design Load, psf
0 - 15	-20.8	-34.8	-52.4
20	-22.1	-37.0	-55.7
25	-23.0	-38.6	-58.1
30	-24.0	-40.2	-60.5
40	-25.5	-42.8	-64.4
50	-26.7	-44.7	-67.3
60	-27.6	-46.3	-69.7
70	-38.4	-60.3	-82.1
80	-39.7	-62.2	-84.8
90	-40.6	-63.7	-86.9
100	-41.2	-64.7	-88.2
120	-43.0	-67.5	-91.9
140	-44.6	-69.9	-95.3
160	-45.5	-71.4	-97.3
180	-46.9	-73.7	-100.4
200	-47.9	-75.1	-102.4
250	-50.1	-78.6	-107.1
300	-52.1	-81.8	-111.5
350	-53.7	-84.3	-114.9
400	-55.3	-86.8	-118.3
450	-56.7	-89.0	-121.3
500	-58.0	-91.0	-124.0

Table 3 – Building Category II, Exposure C - 90 mph peak gust wind zone.

The WD-1 Standard is available free of charge from the SPRI Web site www.spri.org.

EDGE METAL ATTACHMENT

In the RICOWI hurricane investigations, the most common source of low-slope roof system damage was failure of the edge metal system, resulting in exposure of the edge of the roofing system allowing for the membrane and insulation to be peeled off the roof. *Figures 5* and *6* are pictures of a modified bitumen roof system in Pass Christian, MS, after Hurricane Katrina. The roof was exposed to wind speeds of 120 to 130 mph. It appears that the edge metal system was lost and the membrane then peeled off the insulation.

The FEMA Mitigation Assessment Team also investigated this roof (see FEMA 549). Its report also concluded that the edge system was lost resulting in progressive roof failure. The FEMA team determined that the edge system was lost due to inadequate attachment of the wood nailer.

To address the need for more robust edge-metal attachment, and the need for a standard procedure for measuring the strength of various attachment methods, SPRI developed ES-1, "Wind Design Standard for Edge Systems Used with Low-Slope Roofing Systems." Section 1504.5 of the 2007 supplement to the International Building Code requires that the resistance of edge metal systems be tested in accordance with this standard.

At the time of this writing, ANSI/SPRI ES-1 was being routed through the ANSI canvassing process. The standard was updated to combine ES-1 and Factory Mutual Standard 4435. This will result in the following changes:

- Title changes to SPRI ES-1 and FM 4435, and, pre sumably, to ANSI/SPRI/ FM 4435 - ES-1.
- A 2.0 safety factor has been added into the design calculation.
- Tables have been added listing the Field Design Pressures for given building heights and wind speeds for each exposure factor, thus reducing the amount of calculations required.
- The RE-1 test for Depend ently Terminated Systems will now be performed to failure (previously, this was a pass/fail at 100 lb/ft). A table listing the Membrane Tension Design Load, based upon the field design pressure and the membrane fastener spacing, has been included.
- The angle of pull for the RE-1 test has changed from 45 degrees to 25 degrees.
- Nailer attachment has been included and two additional tests have been added:
  - RE-4 to test fastener pull out of substrate
  - RE-5 to test fastener pull through nailer
- Test loads shall increase in 15 psf increments (previously was 10 psf increments).

HOW TO USE ANSI/SPRI ES-1

The ES-1 standard addresses copings and horizontal roof edges but does not address gutters. It focuses primarily on design for wind resistance; however, it also addresses corrosion and fascia thicknesses that provide satisfactory flatness.

The standard consists of three test procedures:

Figure 5 – Edge metal attachment lost (photo courtesy of RICOWI Inc.).

Figure 6 – Membrane peeled off the insulation (photo courtesy of RICOWI Inc.).

RE-1: Test for Roof Edge Termination of Ballasted or Mechanically Attached Roofing Membrane Systems

This test is designed to determine the force required to allow the membrane to come free of the edge termination, or for the termination to come free of its mount. It is required for systems for which the edge termination is expected to secure the membrane. *Figure 7* shows the set-up of the test apparatus.

A minimum 12-inch-wide mock-up of the edge device system is evaluated. The jaws of the test unit are clamped to the membrane and the load is applied until either the membrane comes free of the membrane termination or the termination comes free of its mount.

Performance Criteria

For ballasted systems, the edge device assembly must provide a minimum-load resistance of 100 lbs/ft.

For mechanically attached assemblies, the required minimum-load resistance is a function of the distance between the first-row membrane fasteners and the perimeter edge, or the first row of membrane fasteners parallel to the edge in the corner regions, with the requirement being whichever load is greater. The following equations are used:

$$F = (D)(P) / 2$$

$$F_{corner} = 1.5(D_{corner})(P)/2$$

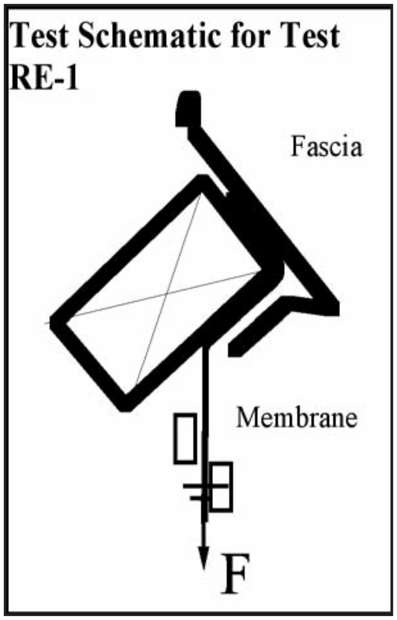

Figure 7 – RE-1 Test set-up.

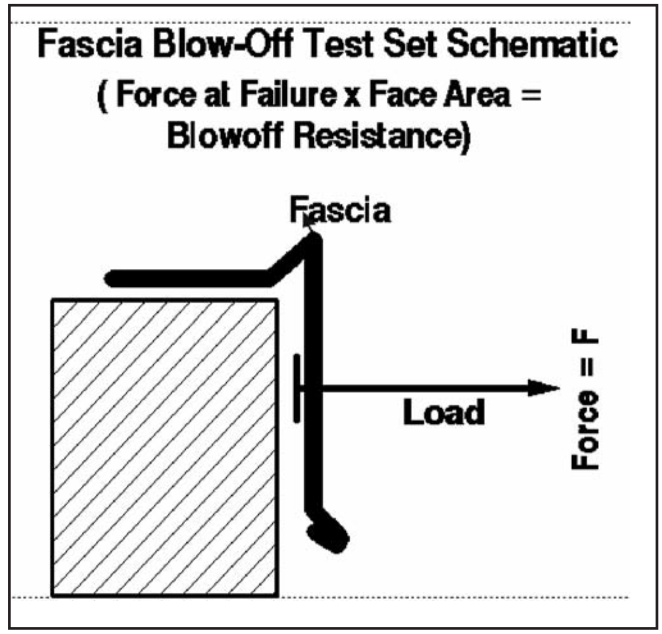

Figure 8 – RE-2 Test set-up.

Where:

F = minimum load resistance

D = distance between first row of membrane fasteners and roof edge (ft)

P = design pressure (psf)

Typically, the fastening rate is increased in the corner, so the equation for outside the corner areas would be used.

RE-2 Pull-Off for Edge Flashings Where Exposed Horizontal Component is 4 Inches or Less

This test is designed to measure the fascia blow-off resistance. The test specimen for this evaluation is full size in width and all other dimensions with a length equal to the average length designed for use on the project, with a minimum of 8 ft. If the minimum length designed for the project is less than 8 ft, then the longest design length must be used.

The load is applied incrementally at a point no greater than 12 inches to the centerline of vertical face of the edge flashing (see *Figure 8*). The load is held for a minimum of 60 seconds after stabilization and then removed until the specimen stabilizes. The next incremental load is then applied. This continues until there is a loss of attachment of any component of the roof edge system or deformation that would result in loss of weather protection of the edge.

Test results

The maximum load (outward force) is converted to pressure using the following formula:

Pressure = Outward Force/Face Height x Face Length

Where:

Pressure is measured in lbs/ft^2. Force is measured in lbs force. Face height is measured in ft.

Performance requirements

The test results must exceed the design outward wind pressures for the building.

RE-3 Pull-Off Test for Copings – Where Exposed Horizontal Flange Depth Exceeds 4 Inches

This test is designed to determine the force necessary to pull the copings off the substrate. The specimens for this test must be full size in width and all other dimensions using the same materials, details, and methods of construction and anchoring devices as used on the actual building. The specimen length is the average length designed for field use on the project and a minimum of 8 ft unless the longest length designed for the project is less than 8 ft. In this case, the longest design length should be used.

The load is applied to the top of the coping and to the face of the coping simultaneously in the ratio of (Face height x Horizontal Gcp) to (Top Width x Vertical Gcp). (Gcp is the gust coefficient described in ASCE 7.) See *Figure 9*. Loads are applied incrementally on centers no greater than 12 inches to the top of the coping and to one of the faces of the coping at the same time. Both the face and back leg are tested, using separate specimens for each evaluation. The load is held for 60 seconds and then released. The next incremental load is then applied. This process continues until there is a loss of attachment of any component of the coping system or deformation that would result in loss of weather protection at the edge.

Test results

The outward and upward maximum force at failure is recorded. These forces are converted to pressure using the following formulas:

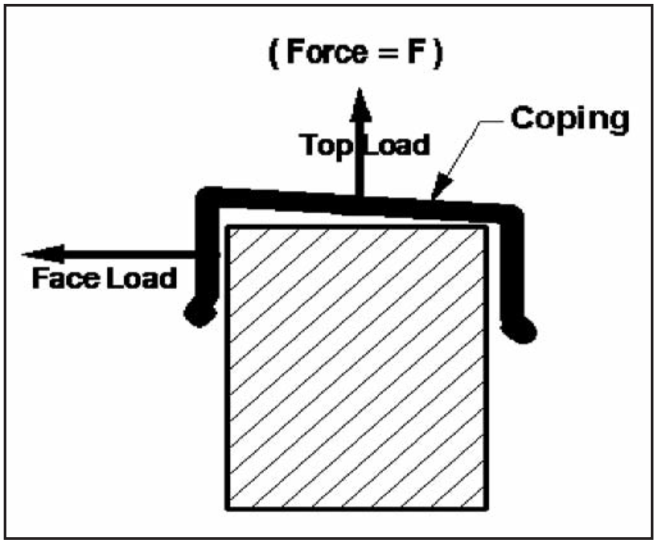

Figure 9 – RE-3 test set-up.

Outward pressure = Outward force/face height x face length

Upward pressure = Upward force/ coping width x coping length

Where:

Pressure is measured in lbs/ft^2.
Force is measured in lbs force.
Face length is the test sample length in feet.
Face height is in feet.
Face refers to back leg or front leg.

Performance requirements

The test results for the coping design must exceed the design upward and outward wind pressures on both the front and back leg tests.

ANSI/SPRI ES-1 is available free of change from the SPRI website at www.spri.org.

PEEL STOP RECOMMENDATION

As noted earlier in this paper, one of the findings from the RICOWI hurricane investigations is that a common mode of roof system damage is edge failure. In fact, Factory Mutual cites edge damage in 79 percent of 145 cases of insurance losses experienced after high-wind events.

The peel-failure phenomenon can occur in two basic ways. In the first case, the edge termination fails and becomes a sail to catch wind, allowing the wind to progressively peel the membrane from the perimeter edge inward toward the center of the roof.

In the second failure mode, the membrane remains attached at the edge but it separated from the substrate and balloons. This ballooning action creates increased peel forces around the edges of the balloon and causes the ballooned area to progressively expand. In either case, the peel action will continue until stopped by a physical feature or roof system enhancement.

The basic concept of a peel-stop design (also referred to as a storm strip, hurricane strip, or hurricane bar) is to install a termination device approximately 12 inches away from the roof edge or parapet wall around the entire roof perimeter. The device is attached to the structural deck with mechanical anchors spaced 6 inches on center (see *Figure 10*). This *Figure* shows a mechanically attached EPDM membrane that uses a type of peel-stop design. This roof is located in Bay St. Louis, MS, and even though it was exposed to wind speeds of 120 to 130 mph during Hurricane Katrina, there was no damage to the attachment of the membrane.

SPRI members recommend the inclusion of a peel-stop device in high velocity hurricane zones, or when the designer is concerned about the possibility of high wind events as a common-sense design enhancement.

CONCLUSION

Proper design of roofing systems to resist anticipated wind loads is a key component of a sustainable roofing system. Investigations conducted by RICOWI after hurricane events show that roof systems that were designed and installed in a manner that met manufacturer and building code requirements performed well in high wind events.

SPRI offers the following code-complaint test standards free of charge on its Web site, www.spri.org. These can be used by the roof design professional to design roof systems that will

Figure 10 – This perimeter fastening is designed for high wind resistance. (Photo courtesy of RICOWI Inc.)

resist significant damage in high-wind events.

- ANSI/SPRI WD-1 - Wind Design Standard for Low-Slope Roofing Systems
- ANSI/SPRI RP-4 - Wind Design Standard for Ballasted Single-Ply Roofing Systems
- ANSI/SPRI ES-1 - American National Standard Wind Design Standard for Edge Systems Used with Low-Slope Roofing Systems

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