Design of Nonballasted Low-Slope Roof Assemblies for Wind Resistance—the Current Situation and Recommendations for the Future

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Abstract

This paper provides an historical perspective of wind design of roofs and an analytical basis for the development of a design standard that meets the requirements of the International Building Code and ASCE 7. It traces the development of wind design standards from the early days of Factory Mutual, the building codes, and ASCE 7, as well as providing an analysis of the current wind design standards and compliance with code. Finally, it reviews the history of the safety factors involved in wind design for roofs and provides recommended design standards based upon the code-required loads with safety provisions consistent with historical design standards.

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1. INTRODUCTION

This paper follows the authors' work on the third edition of the monograph titled *Wind Pressures on Low-Slope Roofs*,[1] published by the Roof Consultants Institute Foundation (RCIF) in March 2013. The monograph is keyed to the 2010 edition of the American Society of Civil Engineers (ASCE) standard titled *Minimum Design Loads for Buildings and Other Structures*,[2] referred to as "ASCE 7 standard."

A U.S. standard that has an international recognition, ASCE 7 provides guidance for the determination of various types of loads on buildings and nonbuilding structures. It is referenced by the International Building Code (IBC), the model code on which the building codes of almost all local jurisdictions in the U.S. are based. For the specific case of designing roof assemblies to resist wind pressures, the IBC requires that the wind pressure be determined in accordance with ASCE 7 standard, as mentioned in the following excerpts:

> 2006/2009/2012 IBC, Section 1504.3 (*Wind Resistance of Nonballasted Roofs*) states that the "roof coverings installed on roofs...shall be designed to resist the design wind load pressures for components and cladding in accordance with Section 1609." Section 1609.5.1 ("Roof Deck") states, "The roof deck shall be designed to withstand the wind pressures determined in accordance with ASCE 7. Section 16.9.5.2 ("Roof Coverings") states that "roof coverings shall comply with Section 16.9.5.1."[3,4,5]

Because building codes are legal documents, the reference in them to ASCE 7 standard gives this standard a legal status. Therefore, the roof assemblies are required to be designed for wind pressures obtained from the use of the current edition of ASCE 7 standard.

In the 2010 edition of the ASCE 7 standard (called "ASCE 7-10 standard"), substantial changes were made in wind load provisions. One of these changes relates to the specification of the basic (design) wind speed—from service-level (also called "nominal") wind speed to the strength-level (also called "ultimate") wind speed. This paper examines the impact of this change on the procedure(s) described in wind design standards for nonballasted (i.e., adhered or anchored) low-slope roofs. (The terms "nominal," "service-level," "strength-level," and "ultimate" are elaborated in Section 6 of this paper.)

2. PROCEDURE FOR THE DESIGN OF WIND-RESISTANT LOW-SLOPE ROOFS

Like all structural design, the design of a low-slope roof for wind resistance is a two-part process. The first part of the design process consists of determining the wind pressures on the roof. This determination is accomplished through calculations based on the building's location, its dimensions, envelope properties, and the roof geometry.

The second part of the design process involves the selection of an appropriate roof assembly whose uplift resistance equals or exceeds the calculated wind pressures on the roof. Safety margin is included in the design to account for the uncertainties inherent in the assessment of wind pressures and in determining the resistance of roof assemblies. The term "selection" is used (not "calculation") because under the current industry practice, wind resistance of a low-slope roof assembly cannot be calculated using standard structural analysis and design procedure similar to that used for the design of the structural elements of a building.

Instead, the roof assembly with the required wind resistance is "selected" from among several manufacturers' assemblies that have been tested for wind resistance by an independent agency. The tests are typically conducted on full-scale specimens of roof assemblies as per standard test procedures.

3. STANDARDS FOR THE DESIGN OF WIND-RESISTANT LOW-SLOPE ROOFS

The two-part design process (wind uplift calculations and the selection of roof assembly) is theoretically simple but confusing in practice. The most important factor contributing to the confusion is the absence of a design standard that has legal status by virtue of its being adopted or referenced by the building codes.

Currently, two standards for wind design of low-slope roofs exist in the United States. These are:

1. FM Global document, *Property Loss Prevention Data Sheets 1-28*[6]
2. ANSI/SPRI document, *ANSI/SPRI Wind Design Standard Practice for Roofing Assemblies*[7]

The FM Global document has a long history and has been updated several times. Its latest revision was published in 2012. The current ANSI/SPRI standard was published in 2012, preceded by its 2007/2008 version.

Note that ASCE 7 standard is not a comprehensive design standard. It is a load standard and addresses the first part of the design process by providing minimum values of loads on a building and its components and hence does not provide any guidance for the second part of the process—specification of safety factor, specification of tests used for determining the strength of the assembly, guidance for anchorage or adhesion of assembly components to the roof deck, and so on. This part is the responsibility of the material industry—in our case, the roofing industry.

By comparison, both ANSI/SPRI and FM Global documents are comprehensive design standards because they address both parts of the design process. Although

Roof height = 100 ft.; Exposure C; Enclosed building; Effective wind area = 10 sq. ft.; Roof slope ≤ 7°;
No topographical feature (K_{zt} = 1.0); Parapet height ≤ 3 ft.

Location	ASCE 7-10	ANSI/SPRI (2012)	FM Global (2012)
Dallas, TX	Risk Cat. I (-28.8 psf) Risk Cat. II (-34.5 psf) Risk Cat. III & IV (-37.6 psf)	Risk Cat. I (-33.6 psf*) Risk Cat. II (-40.4 psf) Risk Cat. III & IV (-44.0 psf*)	Min. acceptable design (-41.0 psf) Enhanced design (-59.0 psf)
New Haven, CT	Risk Cat. I (-34.5 psf) Risk Cat. II (-40.8 psf) Risk Cat. III & IV (-47.6 psf)	Risk Cat. I (-40.4 psf) Risk Cat. II (-47.9 psf*) Risk Cat. III & IV (-55.8 psf*)	Min. acceptable design (-61.0 psf) Enhanced design (-72.0 psf)

Notes:
1. Negative sign implies uplift pressure.
2. ASCE 7 values have been obtained by multiplying ultimate wind pressures (using Part 3, Chapter 30 of ASCE 7-10) by 0.6 to convert them to nominal pressures in order to provide a fair comparison with ANSI/SPRI and FM Global values, which are nominal pressures.
3. Wind speeds for ASCE 7-10 and ANSI/SPRI are 105 mph, 115 mph, and 120 mph for Risk Category I, Risk Category II, and Risk Category III-IV buildings respectively for Dallas, TX. For New Haven, CT, the corresponding wind speeds are 115 mph, 125 mph, and 135 mph.
4. Wind pressures, given in this table under the column for ASCE 7-10, can be obtained from calculations or from the tables provided in Reference 1.
5. FM Global values are based on basic wind speed of 90 mph for Dallas, TX, and 110 mph for New Haven, CT, for Minimum Acceptable Design category. The corresponding values for Enhanced Design category are 108 mph and 120 mph (Ref. 6, p. 5).
6. Values marked with an asterisk have been obtained by interpolation or extrapolation of the values given in ANSI/SPRI standard.
7. Large wind pressure values for New Haven, CT, as compared with the corresponding values in ANSI/SPRI are due to the significant reduction in basic wind speeds in hurricane-prone regions of the U.S. in ASCE 7-10, as compared with those of ASCE 7-05.8 ANSI/SPRI (2012) is based on ASCE 7-10 basic wind speeds, while FM Global (2012) values are based on ASCE 7-05 basic wind speeds. Note, however, that the lower design wind pressures based on ASCE 7-10 in hurricane-prone regions may not be obtained if the building is exposed to coastline, because ASCE 7-10 has reintroduced Exposure D for such locations in place of Exposure C in ASCE 7-05.

Table 1 – Comparison of field-of-roof wind pressures on a hypothetical low-slope roof.

the two documents share several similarities, they also contain several differences, so the design obtained from the two documents is generally quite different.

While this is one cause of confusion, a greater sense of confusion results from the fact that neither standard is referenced in the building codes. Consequently, a roof designer may be at a loss to determine whether the design based on any one of these documents is below-code, per-code, or above-code.

Wind Pressures Obtained From FM Global and ANSI/SPRI Standards

Part 1 of the design process in both FM Global and ANSI/SPRI documents is loosely based on the ASCE 7 standard, so that the roof pressures obtained from the two documents are different from each other and also different from those obtained from ASCE 7. Consequently, both documents lack full compliance with ASCE 7 standard.

As an illustration of the differences, the field-of-roof wind pressures for a hypothetical building, as obtained from ASCE 7, FM Global, and ANSI/SPRI documents, are shown in *Table 1*. The eave height of this hypothetical building, with a low-slope roof (slope ≤ 7°) is 100 ft. in Exposure C. Roof wind pressures in the field of roof have been shown for Dallas, Texas (non-hurricane-prone region), and New Haven, Connecticut (hurricane-prone region), for Risk Categories, I, II and III.

Factor of Safety

A factor of safety (FOS) is applied to the calculated design pressure to obtain the required minimum wind pressure resistance, i.e., the required test strength of roof assembly (STR), from the following expression. Thus:

$$STR \geq (FOS)(DWP)$$
Equation 1

Where DWP is the calculated design wind pressure on the roof. Both design standards (ANSI/SPRI and FM Global) use FOS = 2.0. Hence, for an adequate design:

$$STR \geq (2.0)(DWP)$$
Equation 2

Thus, if the calculated DWP on a roof zone is 40 psf, the required minimum strength of the tested assembly used for that zone must equal 2.0(40) = 80 psf.

It may be instructive to note that FOS = 2.0 is endorsed by ASTM D6630, *Standard Guide for Low-Slope Insulated Roof Membrane Assembly Performance*, which recommends a "minimum" factor of safety = 2.0. However, as explained in the following section, the effective values of FOS used in both roof design standards is greater than 2.0.

4. EFFECTIVE FACTORS OF SAFETY USED IN DESIGN STANDARDS

When roof design is accomplished per FM Global or ANSI/SPRI standards, the effective FOS is higher than the 2.0 implied in these standards, because the wind pressures used in them are higher than the corresponding pressures given by ASCE

7, as shown in *Table 1*. In the ANSI/SPRI standard, the effective FOS is approximately 2.35 for all risk categories of buildings. This is because the roof pressures used are approximately 1.175 times the ASCE 7 roof pressures, giving an effective FOS of $(2.0)1.175 = 2.35$.

In other words, an additional safety margin is embedded in roof pressures given in the ANSI/SPRI standard. This additional safety margin is due to ANSI/SPRI disregarding the use of the wind directionality factor, $K_d = 0.85$. The wind directionality factor accounts for the extremely low probability that the peak (i.e., the design) wind speed will come from the least favorable orientation of the building or the building component. Disregarding K_d inflates the roof pressures by a factor of $(1/0.85) = 1.175$.

While the effective FOS in the ANSI/SPRI standards is 2.35 in all situations, in FM Global standard, it follows a complex pattern because:

1. The FM Global standard is based on the earlier (2005) version of ASCE 7 standard (ASCE 7-05).
2. FM Global disregards risk category classification of buildings and treats all buildings as belonging to the riskiest category (Risk Category III and IV of ASCE 7-05). This disregard increases the design wind pressure by 1.15 for a Risk Category II building and by 1.32 for a Risk Category I building of ASCE 7-05.
3. FM Global uses $K_d = 0.85$, as given by ASCE 7.
4. FM Global has established two design categories: (a) Minimum Acceptable Design and (b) Enhanced Design. These categories are unique to FM Global. The design wind speeds for the Minimum Acceptable Design category are generally the same as the basic wind speeds in ASCE 7-05, but are higher for the Enhanced Design category.

The approximate values of effective FOS used in both design standards are given in *Table 2*.

5. COMPLIANCE OF ROOF DESIGN STANDARDS WITH BUILDING CODES—RECOMMENDATIONS UNDER THE PRESENT FORMAT

Wind-resistant roofing design should use the same design procedures that are employed in the structural design of buildings in concrete, steel, wood, and masonry. The design standards developed by the respective associations of structural material industries (American Concrete Institute, American Institute of Steel Construction, American Wood Council, and Masonry Standards Joint Committee)[9] use loads obtained from ASCE 7 standard with no modifications.

The roofing industry should follow the practice of the structural material industries, i.e., establish an industry-recognized minimum value of FOS and use the roof wind pressures as given by ASCE 7 without modification. (If required, different minimum values of FOS for different situations may be recommended.)

Using a recognized FOS and unmodified ASCE 7 pressures should automatically satisfy building code requirement for compliance with ASCE 7 and greatly simplify the design standards. Additionally, revisions in design standards can be made independent of those made in ASCE 7 and can be modified as ASCE 7 evolves.

Another benefit of the use of unmodified ASCE 7 pressures in design standards is that it avoids the confusion caused from reading two different values of roof pressures for the same situation—one value given in ASCE 7-10 tables (e.g., Ref. 2, p. 328) and a different value given in the design standard (e.g., Ref. 7, p. 13).

Thus, if no change is sought in roof design obtained from the two design standards in their current versions, all that is needed for the design standards to comply with the building code is to revise them to use the current ASCE 7-10 pressures and alter the minimum FOS from 2.0 to 2.35 (for ANSI/SPRI) and revise FM Global FOS from 2.0 to the values given in *Table 2* (which vary from 2.0 to 3.5).

6. RECOMMENDATIONS FOR THE FUTURE

The above discussion leads us to the recommendations for the future. The wind provisions of the ASCE 7-10 standard have been revised significantly from its previous edition (ASCE 7-05). As stated in the introduction, the most significant revision pertains to the definition of the basic (design) wind speed for a location.

In ASCE 7-05, the basic wind speed for a location has a 50-year return period for a Risk Category II building. For a Risk Category III or IV building in the same location, we use the same basic wind speed but multiply the wind pressure by an importance factor of 1.15. The 15% increase in design wind pressures is statistically equivalent to increasing the return period of design wind speed to 100 years.

For a Risk Category I Building, an importance factor of 0.87 is applied to the pressures obtained from the use of the basic wind speed. This is equivalent to assuming that the design wind speed for a Category

ANSI/SPRI (2012)	FM Global (2012)
Effective FOS = 2.35 in all situations	Minimum Design (Dallas, TX)—nonhurricane-prone region Risk Category I: **Effective FOS = 2.8** Risk Category II: **Effective FOS = 2.4** Risk Category III & IV: **Effective FOS = 2.2**
	Enhanced Design (Dallas, TX)—nonhurricane-prone region Risk Category II: **Effective FOS = 3.5** Risk Category III & IV: **Effective FOS = 3.1**
	Minimum Design (New Haven, CT)—hurricane-prone region Risk Category I: **Effective FOS = 3.5** Risk Category II: **Effective FOS = 3.0** Risk Category III & IV: **Effective FOS = 2.6**
	Enhanced Design (New Haven, CT)—hurricane-prone region Risk Category II: **Effective FOS = 3.5** Risk Category III & IV: **Effective FOS = 3.0**

Note: The values of effective FOS for FM Global have been obtained by dividing FM Global pressures by the corresponding ASCE 7 pressures given in Table 1 and multiplying the ratio by 2.0.

Table 2 – Values of Effective Factors of Safety in ANSI/SPRI and FM Global Standards

I building has a return period of 25 years.

In other words, there is only one basic wind speed for a location in ASCE 7-05, whose return period is 50 years. Three different importance factors (1.15, 1.0, and 0.87) have been used to obtain wind pressures for three different risk categories. Wind pressures obtained using ASCE 7-05 basic wind speeds are called "nominal pressures." (Incidentally, ASCE 7-05 uses the term "occupancy categories" in place of the more appropriate term "risk categories" of ASCE 7-10.)

By contrast with ASCE 7-05, ASCE 7-10 uses three different basic wind speeds for three different risk categories (as described later). The three different wind speeds reflect the three different return periods for three different risk categories.

One Factor of Safety—The Allowable Strength Design (ASD) Approach

Wind-resistant design of roof assemblies requires that the calculated design wind pressures (DWP) on a roof equal or exceed the strength of the roof by an FOS. The FOS accounts for the fact that our calculations of DWP and our assessment of the strength of the assembly entail a great deal of uncertainty.

Because DWP in ASCE 7-05 represents nominal wind pressure, it does not contain any safety margin, so that the entire safety margin is included on the resistance (strength) side of the assembly, as shown in Equation 1. This design approach (in which one FOS, is used on the strength side of the equation) is known as the "allowable stress design" or "allowable strength design" (ASD) approach.

By including the entire safety on the strength side, the ASD approach ignores the reality of the situation. The reality is that uncertainty exists on both sides: 1) in determining the DWP (uncertainties in design wind speeds and various coefficients used to convert the design wind speed to wind pressures on the building), and 2) in determining the strength of the assembly (uncertainties in workmanship, quality of materials, and the differences between field and test conditions). Because the quantum of uncertainty on which the FOS value depends is probabilistic, the statistically correct approach is to include a part of the factor of safety in DWP and a part in wind resistance (strength) of the assembly.

Two Partial Safety Factors—Load-Resistance Factor Design (LRFD) Approach

The design approach in which two (partial) safety factors are used—one on the load (pressure) side and the other on the resistance (strength) side—is called a "load-resistance factor design" (LRFD) approach. The structural engineering profession is transitioning to the LRFD approach. Design in concrete abandoned the ASD approach several decades ago, and the other material industries are headed in the same direction. Several university programs teach only LRFD. It is, therefore, recommended that the roofing industry also transition to LRFD as soon as practical.

In LRFD approach, the nominal loads are increased by multiplying them with the load safety factors, more commonly referred to as the "load factors." A load factor (LF) is always greater than 1.0. The load (wind pressure) so obtained is called the "ultimate load" or "ultimate wind pressure." The ultimate wind pressure is the design wind pressure in ASCE 7-10. Thus:

ASCE 7-10 (ultimate) DWP = (LF)[ASCE 7-05 (nominal) DWP]

The value of LF is a function of the uncertainty in determining the design load. Its value for wind loads (pressures) in ASCE 7-05 standard = 1.6.

Load Factor and Importance Factor Absorbed in Basic Wind Speeds in ASCE 7-10

In ASCE 7-10 standard, LF has been absorbed into basic wind speed. Because the wind pressure is directly proportional to the square of wind speed, the basic wind speed for a location in ASCE 7-10 is larger than the corresponding ASCE 7-05 basic wind speed by a factor = $\sqrt{(1.6)}$ = 1.2649. In other words, the design wind pressure in ASCE 7-10 has the load factor of 1.6 included in it. Therefore:

(ASCE 7-10 DWP) = (1.6)(ASCE 7-05 DWP)

The importance factor (IF) of ASCE 7-05 that distinguishes between the three risk categories has also been absorbed in the basic wind speed. Thus:

(ASCE 7-10 basic wind speed) = $\sqrt{(1.6)}$ $\sqrt{(IF)}$ [ASCE 7-05 basic wind speed]

Therefore, ASCE 7-10 has three basic wind speeds for a location and one basic wind speed for each risk category. The basic wind speeds of ASCE 7-10 are called "ultimate wind speeds."

Partial Safety Factor—The Strength Reduction Factor

The second partial safety factor in LRFD approach is placed on the resistance (strength) side. This factor accounts for the uncertainty in determining the strength of the assembly to resist wind pressures. Thus, the strength of the assembly (obtained from calculations, specimen testing, or both) is reduced by multiplying it by a factor called the "strength reduction factor," referred to as the "f-factor." "f" is always ≤ 1.0. Therefore:

Practical strength of roof assembly = f (strength of roof assembly from test)

The value of "f" is obtained from a detailed statistical (structural reliability) analysis of structural failure and, as previously stated, depends on workmanship, quality of materials, type(s) of stress present in the member, the consequences of failure caused by the stress, and so on. For example, the American Concrete Institute recommends f = 0.9 for bending failure, f = 0.75 for shear failure, and f = 0.65 for compressive failure. In the absence of a similar analysis available for roof design, the values of "f" can only be inferred from the currently used values of overall FOS from the following equation:

$$FOS = LF\left(\frac{1}{\phi}\right)$$

Equation 3

Substituting LF = 1.6 in Eq. (3):

$$f = \frac{1.6}{FOS}$$

Equation 4

Thus, if the overall FOS = 2.0, f = 0.8. For overall FOS = 2.35, f = 0.68, and so on. Values of f, corresponding to the values of overall FOS in roof design, are given in *Table 3*, which also gives the corresponding values of $\frac{1}{\phi}$.

Suggested Roof Design Procedure as Per ASCE 7-10 Standard Using the New Safety Multiplier (NSM)

Because ASCE 7-10 basic wind speeds are ultimate wind speeds, a partial safety factor already exists in DWP. Therefore, the only safety margin needed for roof design should come from the value of "f," so that:

$$f \text{ (roof STR)} \geq \text{(ASCE 7-10 DWP)}$$

Equation 5

Or,
$$\text{Roof STR} \geq \frac{1}{\phi} \text{(ASCE 7-10 DWP)}$$

Equation 6

The roof design procedure recommended in this section is based on *Equation 6*. To obtain the required minimum strength of roof assembly using this equation, we first obtain ASCE 7-10 DWP and then multiply it with the required value of $\frac{1}{\phi}$.

Therefore, $\frac{1}{\phi}$ should be considered as the NSM.

Hence, *Equation 6* may be written as:

$$\text{Roof STR} \geq \text{(NSM)(ASCE 7-10 DWP)}$$

Equation 7

As shown in *Table 3*, NSM = 1.25 for an overall FOS of 2.0. If the overall FOS is 2.35 (ANSI/SPRI value), NSM = 1.47. A value of 1.5 may be used as an approximation.

Example 1: Determine the minimum required strength of roof assembly for Dallas, Texas, given in *Table 1*. Risk category is Category II. Overall, FOS = 2.0.

Solution: ASCE 7-10 pressure = 57.5 psf (Ref. 1, p. 96). NSM = 1.25 (*Table 3*). Therefore from Eq. (7), the minimum required strength of assembly = 1.25(57.5) = 71.9 psf ≈ 72 psf.

Example 2: Determine the minimum required strength of roof assembly of Example 1. Overall FOS = 2.35.

Solution: ASCE 7-10 pressure = 57.5 psf. NSM = 1.5 (*Table 3*). Therefore, from *Equation 7*, the minimum required strength of assembly = 1.5(57.5) = 86.3 psf ≈ 86 psf.

This procedure is similar to the one used in the ANSI/SPRI standard but does not require converting ASCE 7-10 pressure to nominal pressure by multiplying it with 0.6. It obviates the need for the standard to generate new, modified tables for design wind pressures. Note that 0.6 is an approximation for 1/1.6, whose exact value is 0.625.

Overall FOS	f	$\frac{1}{\phi}$ New Safety Multiplier (NSM)
2.0	0.8	1.25
2.4	0.67	1.5
2.8	0.57	1.75
3.2	0.50	2.0
3.6	0.44	2.25

Table 3 – Relationship Between FOS, f, and $\frac{1}{\phi}$ for Wind Design of Roofs

7. CONCLUDING REMARKS

The highlights of this paper are as follows:

Wind Pressures

The structural design profession has embraced the use of design based on the ultimate load (LRFD) approach, gradually discarding the nominal load (ASD) approach. ASCE 7 and IBC have adopted ultimate wind speeds for direct use with strength (LRFD) design. Therefore, low-slope roof wind resistance design standards should fully embrace the use of ultimate wind pressures. The wind pressure tables provided in roof design standards should give ultimate wind pressures in place of the nominal wind pressures. This has the following advantages:

1. The nominal wind pressure tables provided in roof design standards have been obtained using the multiplication factor of 0.6 instead of the more accurate factor of 0.625, incurring an error of 4 percent. This error can be avoided through the use of ultimate pressures.
2. If ultimate wind pressure tables are provided in roof design standards instead of nominal pressures, it will allow a curious and informed designer to easily verify the design standard tables with the simplified tables in the current ASCE 7 standard, which give ultimate wind pressures.
3. More importantly, because the roof design standards provide wind pressure tables for a limited set of conditions, reference to ASCE 7 standard becomes necessary when the building does not meet those conditions. Therefore, the more the design standards are in consonance with ASCE 7, the easier it is for a designer to switch from, and make cross-references between, the design standard and ASCE 7.
4. The use of ultimate pressures in roof design makes it consistent with the current structural design philosophy for buildings.

Separate Strength From Design Pressures

As stated in Section 2, the design of roofs for wind uplift resistance is a two-part process: 1) determining the wind pressures on the roof assembly, and 2) determining the strength of roof assembly. By and large, the research and development of standards related to loads and pressures on buildings are beyond the interest and expertise of the roof design profession.

On the other hand, the expertise related to the strength of roof assemblies to resist wind pressures lies entirely with roofing design and construction professionals. Therefore, the roof design standards should accept wind pressures as obtained from ASCE 7 standard without any modifications and deal only with the strength side of the equation by specifying the appropriate value(s) of partial safety factor to be applied to the tested strength of an assembly, in addition to dealing with several other related factors included in the current design standards, such as fastener arrangement, adhesive ribbon layout, size and layout of insulation boards, and so on.

Factor of Safety

The wide variation in the effective FOS values currently used in wind design of low-slope roofs (2.0 to 3.5 given in *Table 2*) points to the lack of consensus in the roofing industry on the minimum value(s) of FOS (despite ASTM D6630). As such, the current situation is confusing, particularly to those who are familiar with structural design procedures, where a single minimum

value of FOS is prescribed for a given mode of failure.

There is a need, therefore, for the roofing community to arrive at a consensus value of FOS, which will make design for wind uplift resistance of roofs consistent with design standards formulated by other material industries (concrete, steel, wood, and masonry). Because codes and standards must specify minimum requirements, the consensus value must represent the minimum value of FOS.

From the consensus value (or values) of FOS, the partial safety factor (the NSM) to be used with the ultimate wind pressures of ASCE 7-10 can be determined as shown in *Table 3*.

As a start (until a statistical reliability analysis of wind-resistant roof design is undertaken), the consensus value of FOS may be arrived at through an informed judgment of a panel of experts intimately related to the field. To minimize personal bias, conflict of ideas, interests, and undue influence of articulate personalities,

a structured set of questions can be formulated to extract anonymous responses from panel members.

Multiple rounds of questioning to fine-tune the questionnaire based on previous responses through an unbiased facilitator may be needed. Statistical analysis of results so obtained should lead to the final convergence of expert opinion on the value of FOS. This commonly used procedure generally requires the help of a knowledgeable but unbiased facilitator.

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