

WIND FAILURES

Avoiding a Roof Failure Requires an Understanding of Many Factors Other Than Wind Speed

By DEREK A. HODGIN, P.E., RRO

Can your roof withstand a wind of 110 miles per hour? How do you know? Most building owners do not know the wind speed that their roof assembly can withstand without failure. Building codes set forth minimum construction standards which include a design wind speed. Roofing manufacturers make claims regarding their products' ability to resist specific wind speeds. Unfortunately, designing a roof to truly withstand a designated wind speed requires an understanding of many other variables. For example, the forces resulting from a 100-mph wind speed acting on a 100-foot tall ocean-front structure are much more significant than the forces resulting from the same wind speed acting on a single-story structure located within an inland urban area. Far too often, the wind performance of building products is determined using controlled laboratory conditions. While this information is considered useful in establishing baseline performance criteria, it serves little purpose in the design process of a specific roof assembly.

When wind acts against the surface of a roof, it exerts positive and negative pressures which must be considered in the roof design. These pressures, expressed in pounds per square foot (psf), vary greatly, depending on many factors. Wind speed is only one of the factors considered when determining the pressures that act on the surface of a roof. In the real world, buildings are constructed at different heights, at different geographic locations, and with every imaginable roof slope and geometry. They are subjected to winds that approach at various angles of attack and over a wide range of speeds. Each of these variables influence the pressures that must be considered in the roof design process. While a thorough discussion of each step of the design process is beyond the scope of this paper, an attempt has been made to provide a basic understanding of the concepts that must be considered in wind design. Additionally, this paper will demonstrate the relative importance of each of the design variables that affect the overall wind performance of a roof system.

The design procedure discussed by this paper is based on ASCE 7-93¹, an industry standard which has been incorporated into most building codes by reference. To begin the basic design process, the velocity pressure (q_z) is determined. The velocity pressure represents the base pressure (positive or negative) which acts on the surface of the roof and is calculated as follows:

$$q_z = 0.00256K_z (IV)^2$$

Where: K_z = the velocity pressure coefficient

Exposure Category	Description
A	Large city centers with at least 50% of the buildings having a height in excess of 70 feet.
B	Urban and suburban areas, wooded areas, or other terrain with numerous closely-spaced obstructions having the size of single-family dwellings or larger.
C	Open terrain with scattered obstructions having heights generally less than 30 feet. This category includes flat, open country and grasslands.
D	Flat, unobstructed areas exposed to wind flowing over large bodies of water. This exposure shall apply only to those buildings and other structures exposed to wind coming from over the water.

Table 1: Reprinted, with permission, from ASCE 7-88, American Society of Civil Engineers, JULY 1990.

- I = the importance factor
- V = the design wind speed

The constant of 0.00256 reflects the mass density of air for standard atmospheric conditions and units associated with wind speed in miles per hour. The velocity pressure coefficient, K_z , is based on the height of the roof and its exposure to wind. ASCE 7-93 has been revised (ASCE 7-95²) to include a topographic factor (K_{zt}) to adjust for specific topographic conditions which may affect wind pressure. The importance factors prescribed by ASCE 7-93 range from 0.95 to 1.11 and reflect the degree of hazard to human life and damage to property.

To complete the design process, the velocity pressure is further modified by external and internal pressure coefficients. These coefficients depend on the geometry and design of the building, as well as the specific roof component which is being evaluated. Additionally, the pressures at the perimeter and corners of a roof are much greater than those in the field of a roof. These conditions are addressed by the external pressure coefficients used to adjust the velocity pressure. A more detailed discussion of the design variables, and their individual relationship to the velocity pressure, is provided below.

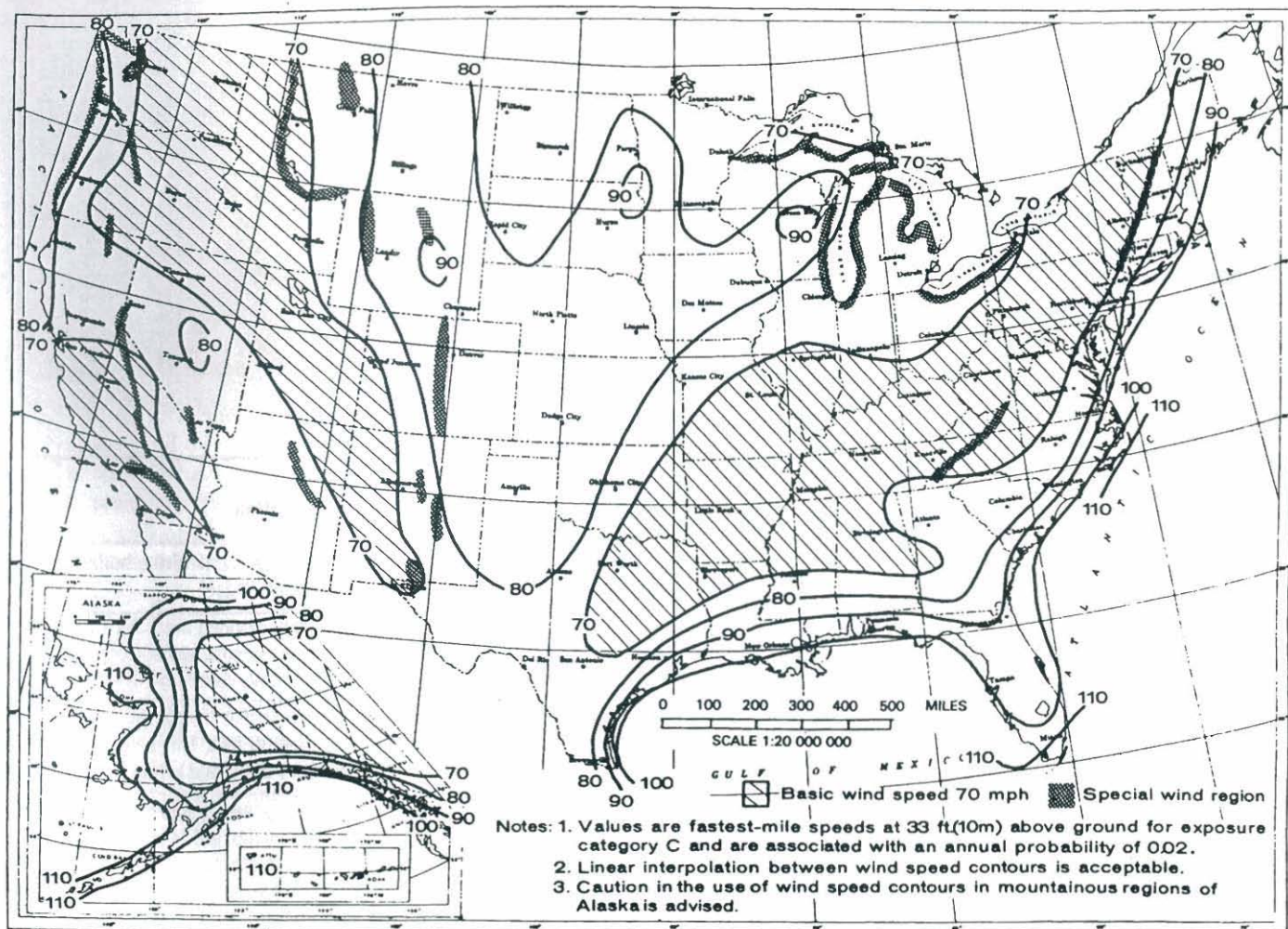


Figure 1. Basic Wind Speed (mph). Reprinted, with permission, from ASCE 7-88, American Society of Civil Engineers, JULY 1990

Wind Speed

Determining the basic wind speed is a relatively simple process which typically involves consulting the applicable building code. However, additional inquiry with the local building official is recommended. While most municipalities have adopted wind speeds from the established building codes, some have elected to require designs using a slightly higher wind speed. The basic wind speed is typically obtained from an isotach map (see Figure 1) which delineates wind speeds in a fashion similar to elevations on a topography map. Linear interpolation is permitted when a project location lies between isotach lines. The map used by this paper is from ASCE 7-93¹ which describes wind speeds in terms of fastest-mile at 33 feet (10 meters) above the ground for exposure category C (see Table 1) with a 50-year mean recurrence interval. The speed is measured for the length of time it takes "one mile" of wind to pass a measuring device. The equipment for measuring this type of wind speed is no longer in use.

ASCE 7-95 includes an isotach map based on wind speeds in terms of three-second peak gusts. This revision has not been widely adopted by building code officials due to the limited time between its publication and the code update cycle. To further complicate matters, the National Hurricane Center uses an

entirely different method of measuring and reporting wind speeds associated with a storm event. The Hurricane Center uses the term "maximum sustained wind"—the speed averaged over a one minute interval at a height of 33 feet. At the very least, the differences in wind speed terminology raise some basic questions regarding roof design: Which 110-mph wind do you design for? A fastest-mile or peak gust? Which exposure category? Which height? What do roofing manufacturers really mean when they say that their product will withstand a 110-mph wind? The bottom line is to understand the terminology used by applicable building codes, code officials, designers, and roofing manufacturers. The design wind speed should meet applicable code requirements and be consistent with the roofing manufacturer's specifications.

For illustrative purposes, several of the design variables discussed in this paper have been evaluated individually to determine their effect on the calculated velocity pressure. The results are shown graphically to illustrate these relationships.

Figure 2 shows the relationship between wind speed and velocity pressure. In this graph, three different wind speeds were used while all other variables were held constant. Specifically, the velocity pressure was calculated for wind speeds of 70, 90, and 110-mph using exposure category C at a roof height of 33 feet. Additionally, an importance factor of 1.0 was used in all

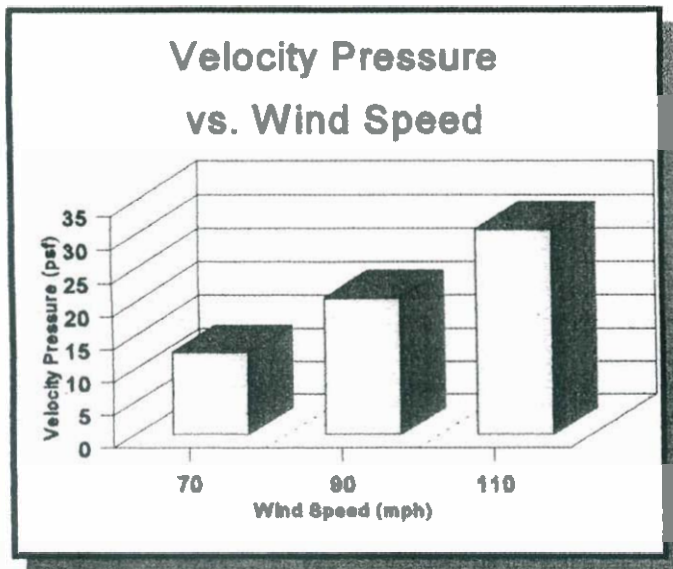


Figure 2

cases. The results in Figure 2 show the velocity pressure increases by a factor of approximately 2.5 between the 70 and 110-mph scenarios. This graph clearly shows the direct relationship between wind speed and velocity pressure. If it were that simple, this paper could have been kept short. However, there are many other factors to consider.

Exposure Categories

The geographic location of the building determines its exposure to wind. A building at the coast is unprotected from winds. A building located in a wooded rural setting is afforded a great deal of protection by adjacent land features. A third exposure scenario would be an urban setting with adjacent structures in close proximity. This scenario requires additional consideration. Specifically, if the building elevation is high enough, it may not be afforded any protection from adjacent structures. On the other hand, if the building elevation is lower than adjacent buildings, a channeling effect may occur in which wind speeds

are increased as the wind passes between two buildings. The exposure of a building is selected from one of the following categories described by ASCE:

Flat, unobstructed areas exposed to wind flowing over large bodies of water. This exposure shall apply only to those buildings and other structures exposed to wind coming from over the water.

Figure 3 shows the relationship between velocity pressure and the exposure categories described above. Each exposure category was evaluated while all other variables were held constant. The velocity pressure was calculated for a roof height of 33 feet and a wind speed of 100-mph. As expected, the results of the calculations reveal an increase in velocity pressure in areas with greater wind exposures. The velocity pressure was noted to increase by a factor of 7.0 between exposure categories A and D. As previously discussed, buildings designed in exposure category A should be considered for possible channeling effects which can increase the velocity pressure due to the building being located in the

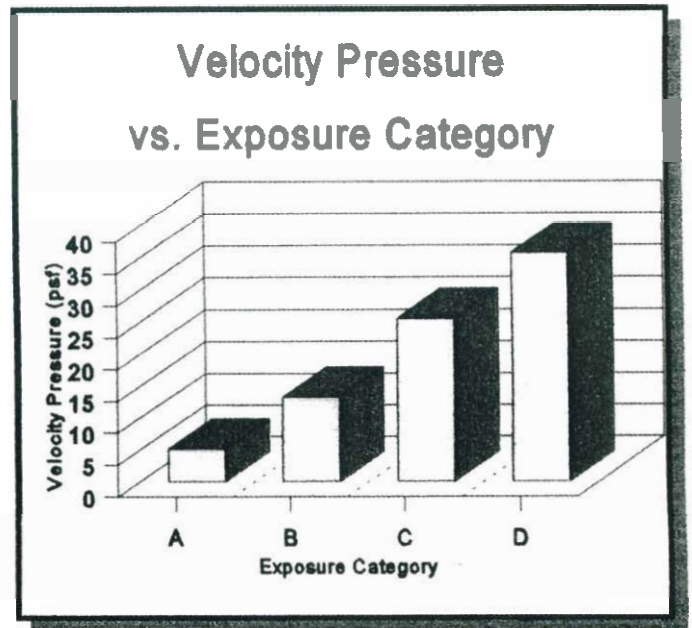


Figure 3

ROLLIN'...
Moving forward in continuous revolutions

THE HEAT IS ON WITH OUR NEW 10 FOOT WIDE SHEETS • THE HEAT IS ON WITH OUR NEW 10 FOOT WIDE • THE HEAT IS ON WITH OUR NEW

Velocity Pressure vs. Roof Height

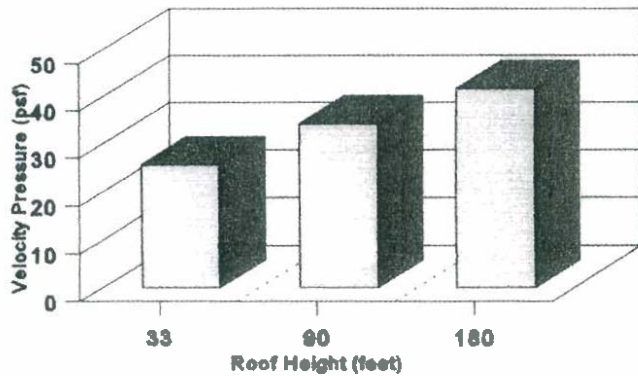


Figure 4

wake of adjacent buildings. It should also be noted that when evaluating components and cladding (as defined by ASCE) on buildings with a roof height less than or equal to 60 feet, the velocity pressure is calculated based on exposure category C regardless of its true exposure. However, ASCE 7-95 allows a 15 percent reduction of the calculated velocity pressure for buildings located within exposure category B.

Roof Height

The height of the roof can greatly affect the design pressures. While wind speeds are commonly measured at 33 feet above the ground, wind speeds increase at higher elevations. To account for these conditions, the designer incorporates a velocity pressure coefficient (K_z). K_z is 1.0 at 33 feet above ground for exposure category C and is adjusted for other heights and exposure categories. The differences in K_z can be significant. For example, a residential structure with a roof height of 20 feet in a rural (exposure category B) setting corresponds to a K_z of 0.42. Whereas, a commercial structure with a roof height of 160 feet located at the ocean (exposure category D) corresponds to a K_z of 1.92. The velocity pressure coefficient corresponds directly to the resulting design pressure and is independent of the wind speed. Therefore, the design pressures calculated for the ocean-front building would be a factor of 4.57 ($1.92 / 0.42$) greater than the pressures calculated for the residential structure, regardless of the design wind speed.

Figure 4 shows the relationship between roof height and velocity pressure. For this graph, three different roof heights were used while all other variables were held constant. The velocity pressure was calculated for roof heights of 33, 90, and 180 feet using exposure category C and a wind speed of 100-mph. In Figure 4, the velocity pressure increases by a factor of approximately 1.6 between the 33 and 180-foot roof height scenarios.

Roof Geometry

The geometry of a roof surface greatly affects the pressure distribution caused by wind. For discussion purposes, the roof geometry can include the roof slope (low or steep), the roof configuration (gable, hip, stepped, arched, etc.), roof protrusions such as dormers and mechanical rooms, or the presence or absence of a parapet. All of these features play a role in the distribution of wind pressure over the roof surface. While ASCE 7-95 provides a variety of useful references which allow for a more detailed analysis of specific roof designs, buildings with unusual or irregular geometric shape require special consideration. These buildings typically include domes, barrel vaults, multiple setbacks, or prominent geometric features. A careful evaluation of the roof should be performed to determine if any features exist which may result in high wind-related pressures.

Striking the windward side of a building, wind results in a direct loading of the wall and roof surfaces in the form of positive pressure. On the leeward side of the roof, a negative (uplift) pressure occurs. While steep slope roofs can receive a moderate amount of positive pressure, roof failures do not often occur solely due to positive wind pressure. Wind-related roof failures on both steep and low slope roofs are typically associated with negative pressures.

In the design process, the specific geometry of the roof is considered to modify the previously determined velocity pressure. External pressure coefficients are used to adjust the velocity pressure for individual geometries and roof areas. For example, separate external pressure coefficients are used for roof slopes of less than 10 degrees, 10 to 30 degrees, and 30 to 45 degrees. The external pressure coefficient used is also dependent on the specific portion of the roof being evaluated. The distribution of positive pressures is considered to be uniform across the roof surface. However, as discussed previously, roof perimeters and corners are subject to much higher negative pressures. To further describe this point, Figure 5 compares the external pressure coefficients used for a roof corner on three different roof slopes. The external pressure coefficients are negative to represent an uplift

External Pressure Coefficient vs. Roof Slope

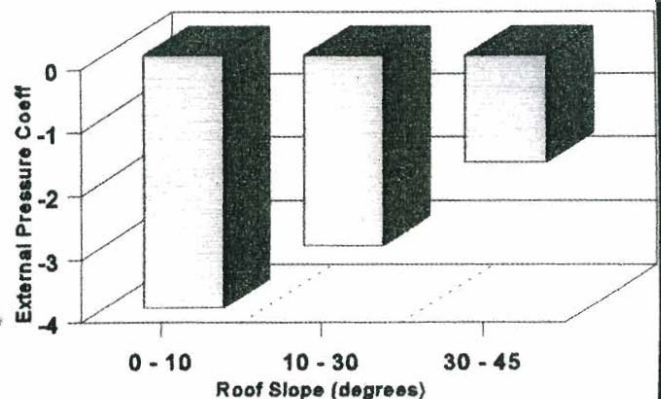


Figure 5

force. The external pressure coefficient is used in conjunction with an internal pressure coefficient to adjust the velocity pressure to determine the design wind forces. The variation in pressure coefficients is significant in that it directly relates to the design pressures that the roof must withstand.

Internal pressure coefficients account for the potential of the roof to be pressurized from below. The internal pressure coefficient can be positive or negative and is combined with the external pressure coefficient to determine the critical loading conditions. Since the most significant external forces are typically negative (uplift forces), the critical combination includes a positive internal pressure coefficient. This condition exists when wind uplift occurs on the exterior roof surface while the bottom of the roof is pressurized from below.

Conclusions

As demonstrated in this paper, wind speed is only one of many design variables that are important in determining the positive and negative pressures that act upon the surface of a roof. A proper roof evaluation must include consideration of all of the applicable design variables to determine the pressures that the roof must withstand. It should also be noted that a roof assembly is only as good as its weakest link. Therefore, all roof components, including roof coverings (shingles, panels, membranes, etc.), fasteners, decking, flashing, and related accessories must be evaluated individually. Using this approach, the designer can determine and reasonably control the mode of roof failure. Wind related roof failures too often occur due to overlooking the details which hold the roof together. Unfortunately, it is common to see several thousand square feet of roof compromised due to the failure of a few feet of improperly fastened flashing. The majority of roof covering failures resulting from windstorm involve improperly designed or constructed perimeter flashings³. Each component of the roof assembly must be designed in a consistent manner to prevent failure. Additionally, depending on the use of the building, it may be appropriate to incorporate a factor of safety of 1.4 to 2.0 into the wind design calculations.

Caution should be exercised when reviewing product litera-

ABOUT THE AUTHOR

Derek A. Hodgin, P.E., RRO, is a forensic engineer employed by Campbell • Schneider and Associates (CSA), a consulting firm based in Charleston, SC. Hodgin is licensed as a professional engineer in nine states along the Atlantic and Gulf coasts. He manages a branch office for CSA in Ramseur, NC. Hodgin specializes in failure investigations of all types of building envelopes and roof systems. He has investigated numerous types of residential and commercial roof failures related to hurricanes, tornados, hail, fire, ice, and deficient construction. He has also designed high wind resistant roof assemblies for projects in the southeastern U.S. and Caribbean.



**Derek A. Hodgin,
P.E., RRO**

ture regarding wind resistance. Information regarding resistance to pressure (not wind speed) is the most useful information for the roof designer. While code approvals and wind resistance ratings are good marketing tools that may help a designer "short list" his available roofing options, they do not provide design information that is relevant to a specific roof project. Each roof system is unique and should be evaluated accordingly.

So the next time that someone tells you that their roof can withstand a 110-mph wind, your response should be "What exactly do you mean?" and be prepared to take notes.

References

1. *Minimum Design Loads for Buildings and Other Structures*, American Society of Civil Engineers 7-93.
2. *Minimum Design Loads for Buildings and Other Structures*, American Society of Civil Engineers 7-95.
3. *Perimeter Flashing*, Factory Mutual Property Loss Prevention Data Sheet 1-49, 1985 Factory Mutual Engineering Corporation.

ROLLIN'...
Moving along a surface in an uninterrupted motion

THE HEAT IS ON WITH OUR NEW 10 FOOT WIDE SHEETS • THE HEAT IS ON WITH OUR NEW 10 FOOT WIDE • THE HEAT IS ON WITH OUR NEW 10 FOOT WIDE SHEETS

