ASTM E 2112 (*Standard Practice for Installation of Exterior Windows, Doors and Skylights*) provides information pertaining to installation of doors, including the use of sill pan flashings with end dams and rear legs (see Figure 6-25). It is recommended that designers use E 2112 as a design resource.

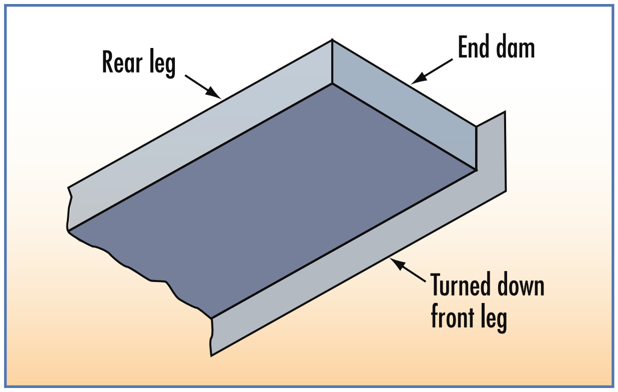


Figure 6-25
Door sill pan flashing with end dams, rear leg, and turned-down front leg

6.10.5 Weatherstripping

A variety of pre-manufactured weatherstripping components are available, including drips, door shoes and bottoms, thresholds, and jamb/head weatherstripping. A few examples of weatherstripping options are:

- **Drip.** These are intended to shed water away from the opening between the frame and door head, and the opening between the door bottom and the threshold (see Figures 6-26 and 6-27). Alternatively, a door sweep can be specified (see Figure 6-28); however, for high-traffic doors, periodic replacement of the neoprene will be necessary.

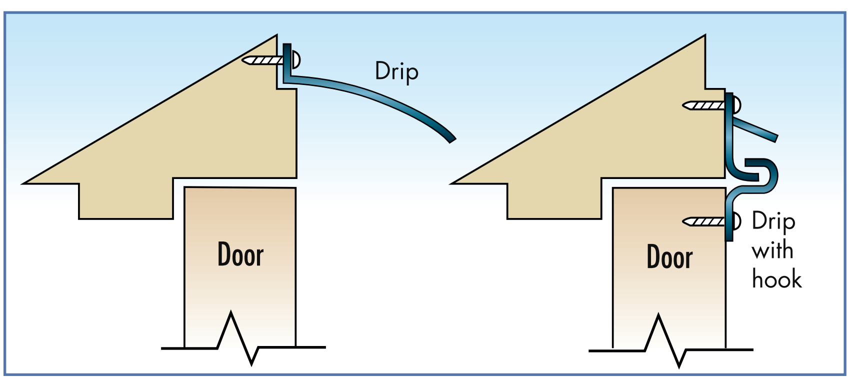


Figure 6-26
Drip at door head and drip with hook at head

SOURCE: FEMA 55, *COASTAL CONSTRUCTION MANUAL*, 2000

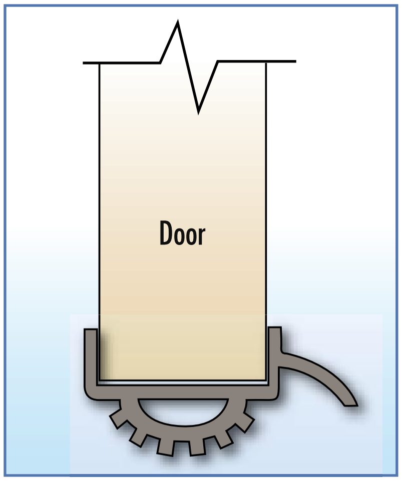


Figure 6-27
Door shoe with drip and vinyl seal
SOURCE: FEMA 55, *COASTAL CONSTRUCTION MANUAL*, 2000

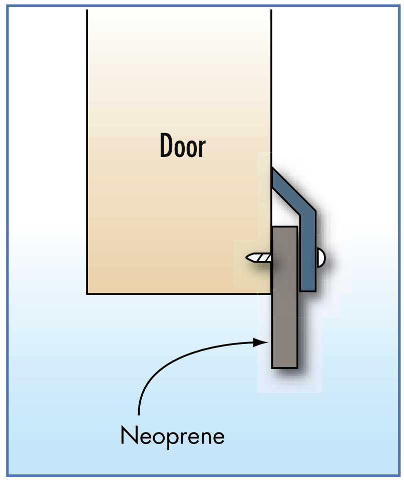


Figure 6-28
Neoprene door bottom sweep
SOURCE: FEMA 55, *COASTAL CONSTRUCTION MANUAL*, 2000

- **Door shoes and bottoms.** These are intended to minimize the gap between the door and threshold. Figure 6-27 illustrates a door shoe that incorporates a drip. Figure 6-29 illustrates an automatic door bottom. Door bottoms can be surface-mounted or mortised. For high-traffic doors, periodic replacement of the neoprene will be necessary.

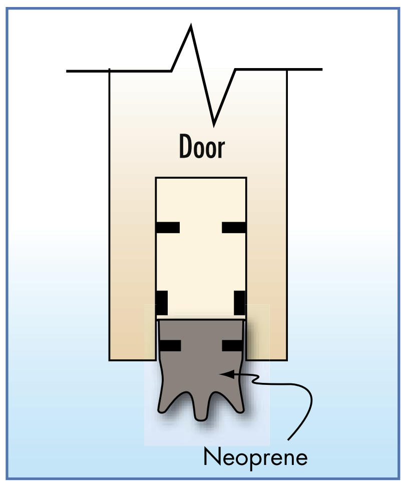


Figure 6-29
Automatic door bottom
SOURCE: FEMA 55, *COASTAL CONSTRUCTION MANUAL*, 2000

- **Thresholds.** These are available to suit a variety of conditions. Thresholds with vertical offsets offer enhanced resistance to wind-driven water infiltration. However, where Americans with Disabilities Act (ADA)-compliant thresholds are required, or at high-traffic doors, the offset is limited. However, at other doors, high offsets are preferred.

Thresholds can be interlocked with the door (see Figure 6-30) or thresholds can have a stop and seal (see Figure 6-31). In some instances, the threshold is set directly on the floor. Where this is appropriate, specify setting the threshold in butyl sealant to avoid water infiltration between the threshold and floor. In other instances, the threshold is set on a pan flashing as discussed in Section 6.10.4. If the threshold has weep holes, specify that the weep holes should not be obstructed (see Figure 6-30).

Figure 6-30
Interlocking threshold with drain pan

SOURCE: FEMA 55, *COASTAL CONSTRUCTION MANUAL*, 2000

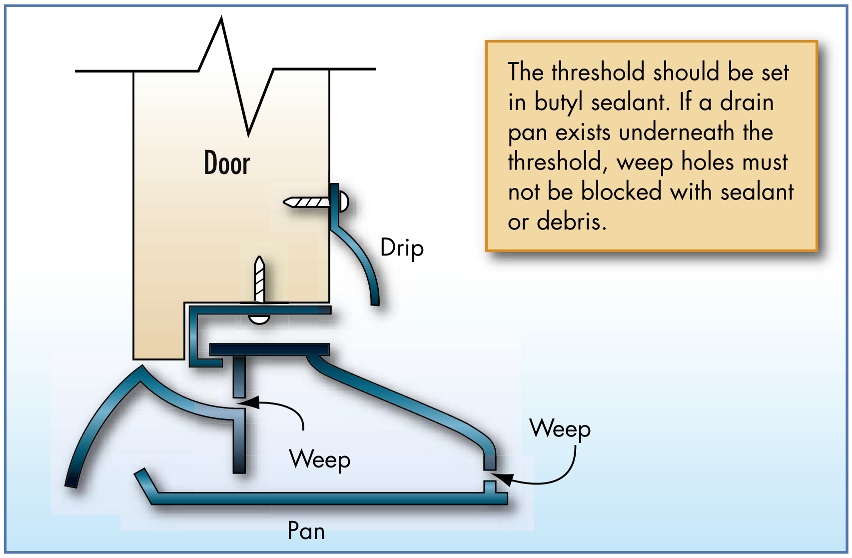
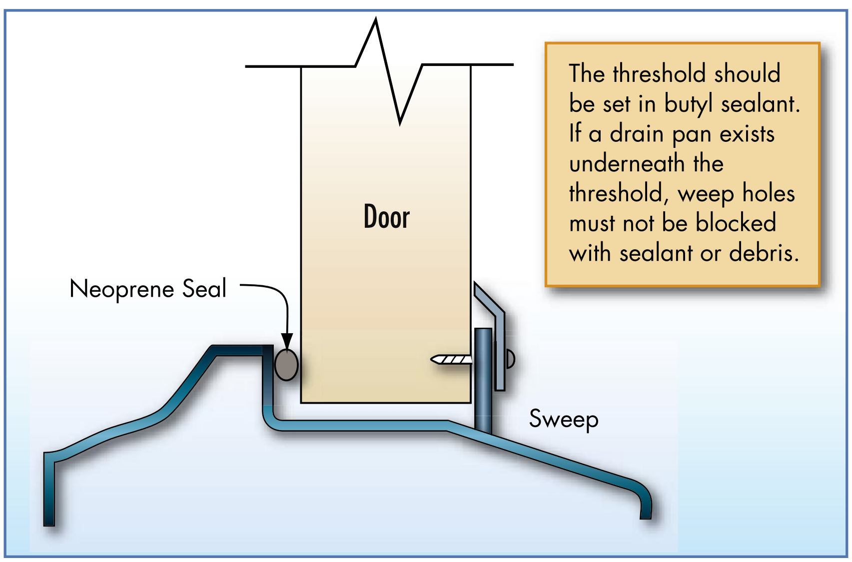


Figure 6-31
Threshold with stop and seal

SOURCE: FEMA 55, *COASTAL CONSTRUCTION MANUAL*, 2000



- **Adjustable jamb/head weatherstripping.** This type of jamb/head weatherstripping is recommended because these units have wide sponge neoprene that offers good contact with the door (see Figure 6-32). The adjustment feature also helps ensure good contact, provided the proper adjustment is maintained.

- **Meeting stile.** At the meeting stile of pairs of doors, an overlapping astragal weatherstripping offers greater protection than weatherstripping that does not overlap.

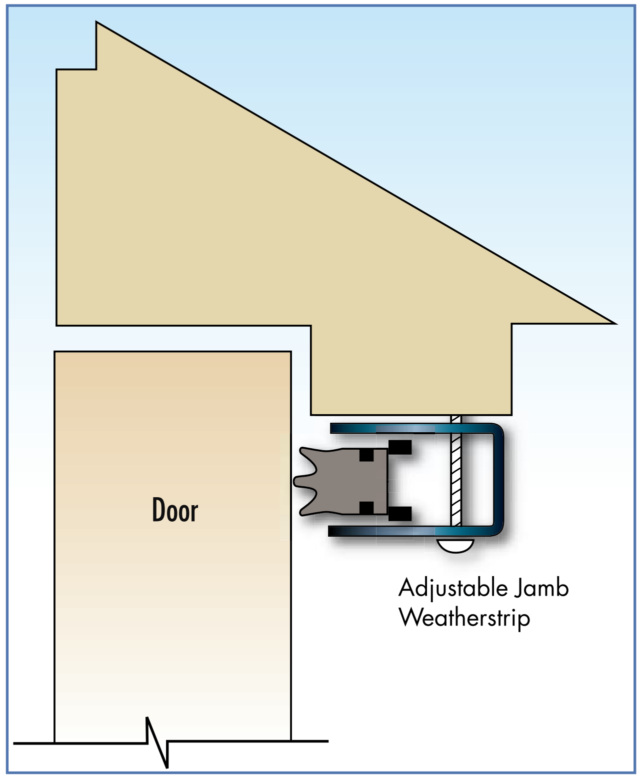


Figure 6-32 Adjustable jamb/head weatherstripping

SOURCE: FEMA 55, *COASTAL CONSTRUCTION MANUAL*, 2000

6.11 NON-LOAD BEARING WALLS, WALL COVERINGS, SOFFITS, AND UNDERSIDE OF ELEVATED FLOORS

This section addresses exterior non-load bearing walls and provides guidance for interior non-load bearing masonry walls. Exterior wall coverings and soffits, as well as the underside of elevated floors, are also discussed.

See Section 6.15.4 for schools located in hurricane-prone regions.

6.11.1 Loads and Resistance

The IBC requires that exterior non-load bearing walls, wall coverings, and soffits (see Figure 6-33) have sufficient strength to resist the positive and negative design wind pressure. Architects should specify that wall coverings and soffits comply with wind load testing in accordance with ASTM E 1233.

Depending upon wind direction, soffits can experience either positive or negative pressure. Besides the cost of repairing damaged soffits, wind-borne soffit debris can cause property damage and injuries.

Figure 6-33
This suspended metal soffit was not designed for upward-acting wind pressure.

Particular care should be given to the design and construction of exterior non-load bearing walls constructed of masonry. Although these walls are not intended to carry gravity loads, they must be designed to resist the positive and negative wind loads in order to avoid collapse. Because of their great weight, when these types of walls collapse, they represent a severe risk to life as shown in Figure 6-14.

Special consideration should also be given to interior non-load bearing masonry walls. Although these walls are not required by building codes to be designed to resist wind loads, if glazing is broken, the interior walls could be subjected to significant load as the school rapidly becomes fully pressurized. To avoid occupant injury (see Figure 6-34), it is recommended that interior non-load bearing masonry walls that are adjacent to student areas be designed to accommodate loads exerted by a design wind event, using the partially enclosed pressure coefficient. By doing so, wall collapse may be prevented if the building envelope is breached. This recommendation is applicable to schools in tornado-prone areas that do not have shelter space designed in accordance with FEMA 361, to schools located in areas with a basic wind speed greater than 120 mph, and to schools that will be used for hurricane shelters.

Figure 6-34
The interior walls of this classroom wing were constructed of unreinforced CMU.

SOURCE: FEMA 342, *OKLAHOMA AND KANSAS MIDWEST TORNADOES OF MAY 3, 1999*, 1999

6.11.2 Durability

Where corrosion is problematic, stainless steel fasteners are recommended for wall and soffit systems. For other components (e.g., furring, blocking, struts, and hangars), the following are recommended: nonferrous components (such as wood), stainless steel, or steel with a minimum of G-90 hot-dipped galvanized coating. In addition, if air can freely circulate in a cavity (e.g., above a soffit), access panels are recommended so components within the cavity can be periodically observed for corrosion.

6.11.3 Wall Coverings

There are a variety of exterior wall covering options. Brick veneer, exterior insulation finish systems (EIFS), metal wall panels, and aluminum and vinyl siding have often exhibited poor wind performance. Veneers (such as ceramic tile and stucco) over concrete and cement-fiber panels and siding have also blown off. Blow-off of wood siding and panels is rare.

Figure 6-35 shows brick veneer that was blown off. The bricks were attached to the back-up wall with corrugated metal ties. All of the following failure modes are commonly found in the vicinity of this type of common failure: 1) The nails pull out of the studs (smooth shank nails are typically used, hence they have limited withdrawal resistance; 2) The ties do not extend far enough into the mortar joint (i.e., the tie is not long enough); 3) Although the ties make contact with the mortar, they are not well-bonded to it; 4) The ties are spaced too far apart; and 5) The ties provide essentially no resistance to compression. Hence, when a great amount of positive pressure is applied to the bricks, the brick joints flex. This flexing weakens the mortar joint. Walls that have not had bricks blown away have been found to be capable of being deflected with hand pressure. Although they look sound, in this condition they are very vulnerable to failure. Good reliable wind performance of brick veneer is very demanding on the designer and applicator.

Figure 6-35
Failure of brick veneer

SOURCE: FEMA 342, *OKLAHOMA AND KANSAS MIDWEST TORNADOES OF MAY 3, 1999,* 1999

Figure 6-36 shows EIFS blow-off. In this case, the expanded polystyrene (EPS) was attached to gypsum board, which was attached to metal studs. The gypsum board detached from the studs, which is a common EIFS failure mode. When the gypsum board on the exterior side of the studs is blown away, it is common for gypsum board on the interior side to also be blown off. This then allows the school to become fully pressurized and allows entrance of wind-driven rain. Other common failure modes include separation of the EPS from its substrate and separation of the synthetic stucco from the EPS. Good reliable wind performance of EIFS is very demanding on the designer and applicator. Maintenance of EIFS and associated sealant joints is also demanding in order to minimize reduction of EIFS' wind resistance due to water infiltration.

Figure 6-36
EIFS blow-off near a wall corner. At one area, the metal fascia was also blown in.

SOURCE: FEMA 342, *OKLAHOMA AND KANSAS MIDWEST TORNADOES OF MAY 3, 1999*, 1999

Another issue associated with EIFS is the potential for misdiagnosis of the wall system. EIFS is sometimes mistaken to be a concrete wall. If school personnel believed that an EIFS wall covering was a concrete wall and sought shelter from a tornado, instead of being protected by several inches of concrete, only two layers of gypsum board (i.e., one layer on each side of the studs) and a layer of EPS would be between the occupants and windborne debris. The debris could easily penetrate such a wall.

EIFS can also be applied over concrete or CMU. In this scenario, the concrete or CMU could provide adequate missile protection provided it was thick enough and adequately reinforced. However, with this wall construction, there is still risk of blow-off of the EIFS. As discussed in Section 6.15.4, if the concrete or CMU is left exposed, there is no covering to be blown off.

Wind performance of metal wall panels is highly variable. Performance depends upon strength of the specified panel (which is a function of material, panel profile, panel width and whether or not the panel is a composite) and the adequacy of the attachment (which can either be by concealed clips or exposed fasteners). A common problem is excessive spacing between clips/fasteners. Clip/fastener spacing should be specified, along with the specific type and size of fastener to be used. Figures 6-13 and 6-43 illustrate metal wall panel problems.

To minimize water infiltration at metal wall panel joints, it is recommended that sealant tape be specified at sidelaps when the basic wind speed is in excess of 90 mph. However, end laps should be left unsealed so that moisture behind the panels can wick out. End laps should be a minimum of 3 inches (4 inches where the basic wind speed is greater than 120 mph) to avoid wind-driven rain infiltration. At the base of the wall, a 3-inch (4-inch) flashing should also be detailed, or the panels should be detailed to over-lap with the slab or other components by a minimum of 3 inches (4 inches).

Vinyl siding blow-off is typically caused by nails spaced too far apart and/or the use of vinyl siding that has inadequate wind-resistance. Vinyl siding is available with enhanced wind resistance features, such as an enhanced nailing hem, greater interlocking area, and greater thickness.

Secondary Protection. Almost all wall coverings permit the passage of some water past the exterior surface of the covering, particularly when rain is wind-driven. Hence, most wall coverings should be considered as water-shedding, rather than as waterproofing coverings. To avoid moisture related problems, it is recommended that a secondary line of protection with a moisture barrier (such as housewrap or asphalt-saturated felt) and flashings around door and window openings be provided. Designers should specify that horizontal laps of the moisture barrier be installed so that water is allowed to drain from the wall (i.e., the top sheet should lap over the bottom sheet so that water running down the sheets remains on their outer surface). The bottom of the moisture barrier needs to be detailed to allow drainage.

In areas that frequently experience strong winds, enhanced flashing details are recommended. Enhancements include use of flashings that have extra-long flanges, and use of sealant and tapes. Flashing design should recognize that wind-driven water can be pushed vertically. The height to which water can be pushed increases with wind speed. Water can also migrate vertically and horizontally by capillary action between layers of materials (e.g., between a flashing flange and housewrap). It is recommended that designers attempt to determine what type of flashing details have successfully been used in the area where the school will be constructed.

If EIFS is specified, it is strongly recommended that it be designed with a drainage system that allows for dissipation of water leaks.

6.11.4 Underside of Elevated Floors

If sheathing is applied to the underside of joists or trusses elevated on piles (e.g., to protect insulation installed between the joists/trusses), its attachment should be specified in order to avoid blow-off. Stainless steel or hot-dip galvanized nails or screws are recommended. ASCE 7 does not provide guidance for load determination.

6.12 ROOF SYSTEMS

Because roof covering damage has historically been the most frequent and costly type of wind damage, special attention needs to be given to roof system design.

Code Requirements. The IBC requires load resistance of the roof assembly to be evaluated by one of the test methods listed in IBC's Chapter 15. Architects are cautioned that designs that deviate from the tested assembly (either with material substitutions or change in thickness or arrangement) may adversely affect the wind performance of the assembly. The IBC does not specify a minimum safety factor. However, for the roof system, a safety factor of two is recommended. (To apply the safety factor, divide the test load by two to determine the allowable design load. Conversely, multiply the design load by two to determine the minimum required test resistance.)

For metal panel systems, the IBC requires test methods UL 580 or ASTM E 1592. It is recommended that architects specify use of E 1592 because it is more likely to give a better representation of the system's uplift performance capability.

Load Resistance. Specifying load resistance is commonly done by specifying a Factory Mutual Research (FMR) rating, such as Factory Mutual (FM) 1-75. The first number ("1") indicates that the roof assembly passed the FMR tests for a Class 1 fire rating. The second number ("75") indicates the uplift resistance in psf that the assembly achieved during testing. Applying a safety factor of two to this example, this assembly would be suitable where the design uplift load is 37.5 psf.

As previously discussed, because of building aerodynamics, the highest uplift load occurs at roof corners. The perimeter has a somewhat lower load; the field of the roof has the lowest load. FMG *Data Sheets* are formatted so that a roof assembly can be selected for the field of the roof. That assembly is then adjusted to meet the higher loads in the perimeter and corners by increasing the number of fasteners or decreasing the spacing of adhesive ribbons by a required amount; however, this assumes that the failure is the result of the pulling-out of the fastener from the deck, or that failure is in the vicinity of the fastener plate, which may not be the case. Also, the increased number of fasteners required by FM may not be sufficient to comply with the perimeter and corner loads derived from the building code. Therefore, if FM resistance data are specified, it is prudent for the architect to separately specify the resistance for the field of the roof (1-75 in the example above), the perimeter (1-130), and the corner (1-190).

Edge Flashings and Copings. Roof membrane blow-off is almost always a result of lifting and peeling of the metal edge flashing or coping, which serves to clamp down the membrane at the roof edge (see Figure 6-37). Therefore, it is important for the architect to carefully consider the design of metal edge flashings, copings, and the nailers to which they are attached. ANSI/SPRI ES-1, *Wind Design Standard for Edge Systems Used in Low Slope Roofing Systems* provides general design guidance, including a methodology for determining the outward-acting load on the vertical flange of the flashing/coping (ASCE 7 does not provide this guidance).

Figure 6-37
The metal edge flashing on this modified bitumen membrane roof was installed underneath the membrane, rather than on top of it and then stripped in. In this location, the edge flashing is unable to clamp the membrane down. At one area, the membrane was not sealed to the flashing (an ink pen was inserted into the opening prior to photographing). Wind can catch the opening and lift and peel the membrane.

A minimum safety factor of three for edge flashings, copings, and nailers is recommended for schools. ANSI/SPRI ES-1 also includes test methods for assessing flashing/coping resistance. For FMG-insured schools, FMR approved flashing should be used and *Data Sheet 1-49* should also be consulted.

The traditional edge flashing/coping attachment method relies on concealed cleats that can deform under wind load and lead to disengagement of the flashing/coping (see Figure 6-38) and subsequent lifting and peeling of the roof membrane (as shown in Figure 6-11). When a vertical flange disengages and lifts up (as shown in Figure 6-38), the edge flashing and membrane are very susceptible to failure. Normally, when a flange lifts such as shown in Figure 6-38, the failure continues to propagate and the metal edge flashing and roof membrane blow off.

Figure 6-38
This metal edge flashing had a continuous cleat, but the flashing disengaged from the cleat and the vertical flange lifted up. However, the horizontal flange of the flashing did not lift.

Storm-damage research has revealed that, in lieu of cleat attachment, use of exposed fasteners to attach the vertical flanges of copings and edge flashings has been found to be a very effective and reliable attachment method (see Figure 6-39).

If cleats are used for attachment, it is recommended that a bar be placed over the roof membrane near the edge flashing/coping as illustrated in Figure 6-40. The purpose of the bar is to provide secondary protection against membrane lifting and peeling in the event that the edge flashing/coping fails. A robust bar specifically made for bar-over mechanically attached single-ply systems is recommended. The bar needs to be very well anchored to the parapet or deck. Depending upon design wind loads, a spacing

Figure 6-39
This coping was attached with ¼-inch diameter stainless steel concrete spikes at 12 inches on center. When the fastener is placed in wood, #14 stainless steel screws with stainless steel washers are recommended. Also, in the corner areas, the fasteners should be more closely spaced (the spacing will depend upon the design wind loads). ANSI/SPRI ES-1 provides guidance on fastener spacing and thickness of the coping/ edge flashing.

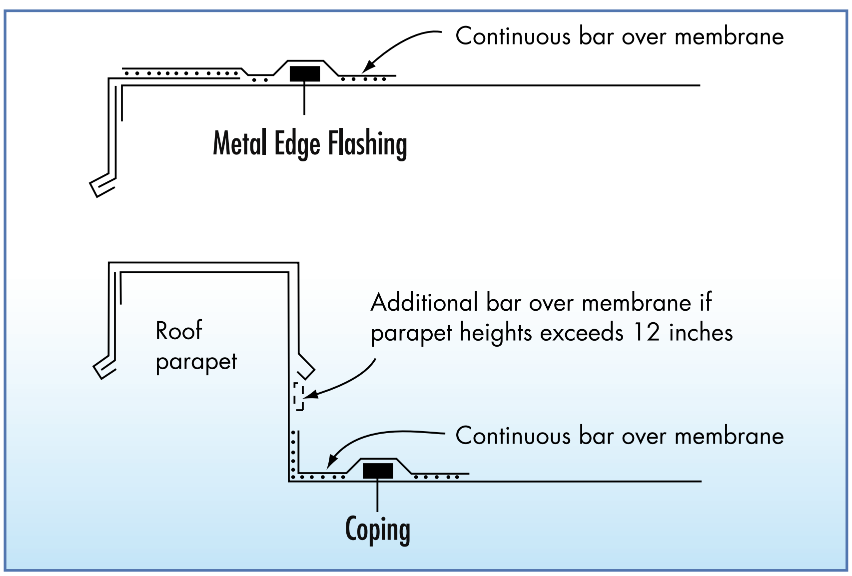


Figure 6-40
Continuous bar near the edge of edge flashing or coping. If the edge flashing or coping is blown off, the bar may prevent a catastrophic progressive failure.

SOURCE: FEMA 55, *COASTAL CONSTRUCTION MANUAL*, 2000

between 4 and 12 inches on center is recommended. A gap of a few inches should be left between each bar to allow for water flow across the membrane. After the bar is attached, it is stripped over with a stripping ply.

Gutters. Special design attention needs to be given to uplift attachment of gutters, particularly those in excess of 6 inches wide. Recommendations are provided in "Honing in on hangars," *Professional Roofing*, Thomas L. Smith, October 2002, pp. 32 (available on-line at www.nrca.net).

Roof System Performance. Storm-damage research has shown that sprayed polyurethane foam and liquid-applied roof systems are very reliable high-wind performers. If the substrate to which the foam or liquid-applied membrane was applied does not lift, it is highly unlikely that the sprayed polyurethane foam (SPF) or the liquid-applied membrane will blow-off. Both systems are also more tolerant of missiles than other systems. Built-up roofs (BURs) and modified bitumen systems have also demonstrated good wind performance provided the edge flashing/coping does not fail (edge flashing/coping failure is common). The exception is aggregate surfacing, which is prone to blow-off (see Figure 6-11). Modified bitumen adhered to a concrete deck has demonstrated excellent resistance to progressive peeling after blow-off of the metal edge flashing. Metal panel performance is highly variable. Some systems are very wind-resistant, while others are quite vulnerable.

Of the single-ply attachment methods, the paver-ballasted and fully adhered methods are the least problematic. Systems with aggregate ballast are prone to blow-off, unless care is taken in the design of the size of aggregate and the parapet height (see Figure 6-8). Performance of protected membrane roofs (PMRs) with factory-applied cementitious coating over insulation boards is highly variable. When these boards are installed over a loose-laid membrane, it is critical that an air retarder be incorporated to prevent the membrane from ballooning and disengaging the boards. ANSI/SPRI RP-4 (which is referenced in the IBC) provides wind guidance for ballasted systems using aggregate, pavers, and cementitious-coated boards.

The National Research Council of Canada, Institute for Research in Construction's *Wind Design Guide for Mechanically*

Attached Flexible Membrane Roofs, B1049 (2004) provides recommendations related to mechanically attached single-ply and modified bituminous systems. B1049 is a very comprehensive wind design guide and includes discussion of air retarders, which can be effective in reducing membrane flutter, in addition to their beneficial use in ballasted single-ply systems. When a mechanically attached system is specified, careful coordination with the structural engineer with respect to selection of deck type and thickness is important. If a steel deck is specified, it is critical to specify that the membrane fastener rows run perpendicular to the steel flanges in order to avoid overstressing attachment of the deck to the deck support structure (see Figures 6-41 and 6-42). In Figure 6-42, the flange with membrane fasteners carries essentially all of the uplift load because of the deck's inability to transfer any significant load to adjacent flanges. Hence, at the joists, the deck fasteners on either side of the flange with the membrane fasteners are the only connections to the joists that are carrying uplift load. Had the membrane fasteners shown in Figure 6-42 been run perpendicular to the deck flanges, each of the fasteners connecting the deck to the joists would have been carrying uplift load.

Figure 6-41
On this school, the fastener rows of the mechanically attached single-ply membrane ran parallel to the top flange of the steel deck. Hence, essentially all of the row's uplift load was transmitted to only two deck fasteners at each joist (as illustrated in Figure 6-42). Because the deck fasteners were overstressed, a portion of the deck blew off and the membrane progressively tore.

Figure 6-42
View of the underside of a steel deck. The mechanically attached single-ply membrane fastener rows ran parallel to the top flange of the steel deck.

Recommendations related to metal panels is provided in "Insights on Metal Roof Performance in High-wind Regions," *Professional Roofing*, Thomas L. Smith, February 1995, pp. 12 (available on-line at www.nrca.net).

Parapet Base Flashings. Loads on parapet base flashings were first introduced in the 2002 edition of ASCE 7. The loads on base flashings are greater than the loads on the roof covering if the parapet's exterior side is air-permeable. When base flashing is fully adhered, it has sufficient wind resistance in most cases. However, when base flashing is mechanically fastened, typical fastening patterns may be inadequate, depending upon design wind conditions (see Figure 6-43). Therefore, it is imperative that base flashing loads be calculated and attachments be designed to accommodate the loads. It is also important for designers to recognize and specify different attachment spacings in parapet corner regions versus regions between corners. Further discussion is provided in "Detailing ASCE 7's changes," *Professional Roofing*, Thomas L. Smith, July 2003, pp. 26 (available on-line at www.nrca.net).

Figure 6-43
The parapet on this school was sheathed with metal wall panels. The panels were fastened at 2 feet on center along their bottom edge, which was inadequate to resist the wind load.

Lightning Protection Systems. When not adequately integrated into a roof system, a lightning protection system can become detached from the roof during high winds. The detached system can damage the roof covering (see Figure 6-44). In addition, a detached system is no longer capable of providing lightning protection. Most manufacturers of lightning protection systems and most roofing manufacturers provide vague or inadequate details for securing a lightning protection system to a roof.

During prolonged high winds, repeated slashing of the membrane by loose conductors ("cables") and puncturing by air terminals can result in lifting and peeling of the membrane. It is, therefore, important to adequately design the attachment of the lightning protection system. Recommendations pertaining to wind-resistant design, and specification and installation of lightning protection systems are provided in "Integrating a Lightning Protection System in a Roof System," Thomas L. Smith, 12th International Roofing and Waterproofing Conference Proceedings (CD), National Roofing Contractors Association, 2002.

Steep-slope Coverings. For discussion and recommendations pertaining to steep-slope roof coverings, see FEMA 55, *Coastal Construction Manual*, Third Edition, 2000.

Figure 6-44
This air terminal ("lightning rod") was dislodged and whipped around during a windstorm. The single-ply membrane was punctured by the sharp tip in several locations.

SOURCE: FEMA, *BUILDING TO MINIMUM TYPHOON DAMAGE: DESIGN GUIDELINES FOR BUILDINGS*, JULY 1998

Hurricane-prone Regions. See Section 6.15.5 for schools in hurricane-prone regions.

Tornado-prone Regions. In order to reduce the number of wind-borne missiles, it is recommended that aggregate surfacings, pavers, tile, and slate not be specified on schools in tornado-prone regions (as defined in Section 6.7.1; see Figure 6-8).

6.13 WINDOWS AND SKYLIGHTS

This section addresses exterior windows and skylights. See Section 6.15.6 for schools located in hurricane-prone regions.

6.13.1 Loads and Resistance

The IBC requires the window, curtain wall, or skylight assembly (i.e., the glazing, frame, and frame attachment to the wall or roof) to have sufficient strength to resist the positive and negative design wind pressure (see Figure 6-45). Architects should specify that these assemblies comply with wind load testing in accordance with ASTM E 1233. It is important to specify an adequate load path and to check its continuity during submittal review.

Figure 6-45
Two complete windows, including their frames, blew out. The frames were attached with an inadequate number of fasteners, which were somewhat corroded.

SOURCE: FEMA, *BUILDING TO MINIMUM TYPHOON DAMAGE: DESIGN GUIDELINES FOR BUILDINGS*, JULY 1998

In tornado-prone regions, some school districts may desire to have laminated glazing installed at exterior openings in order to provide wind-borne debris protection during weak tornadoes. Laminated glazing may also offer protection during strong tornadoes, but should not be relied upon for violent tornadoes. Further discussion is provided in Section 6.15.6.

6.13.2 Durability

Where corrosion is problematic, anodized aluminum or stainless steel frames and stainless steel frame anchors are recommended.

6.13.3 Water Infiltration

When heavy rain accompanies high winds (e.g., thunderstorms, tropical storms, and hurricanes), it can cause wind-driven water infiltration problems; the magnitude of the problem increases with the wind speed. Leakage can occur at the glazing/frame interface, at the frame itself, or between the frame and wall. When the basic wind speed is greater than 120 mph, because of the very high design wind pressures and numerous opportunities for leakage path development, some leakage should be anticipated when design wind speed conditions are approached.

The challenge with windows and curtain walls is successful integration between these elements and the walls. To the extent possible, detailing of the interface between the wall and the window or curtain wall units should rely on sealants as the secondary line of defense against water infiltration, rather than making the sealant the primary protection.

When designing joints between walls and windows and curtain wall units, consider the shape of the sealant joint (i.e., a square joint is typically preferred) and the type of sealant to be specified. The sealant joint should be detailed so the sealant is able to bond on only two opposing surfaces (i.e., a backer rod or bond-breaker tape should be specified). For concealed sealants, butyl is recommended. For exposed sealants, polyurethane is recommended. During installation, cleanliness of the sealant substrate is important (particularly if polyurethane or silicone sealants are specified), as well as tooling of the sealant. ASTM E 2112 provides guidance on design of sealant joints, as well other information pertaining to installation of windows, including the use of sill pan flashings with end dams and rear legs (see Figure 6-46). It is recommended that designers use ASTM E 2112 as a design resource.

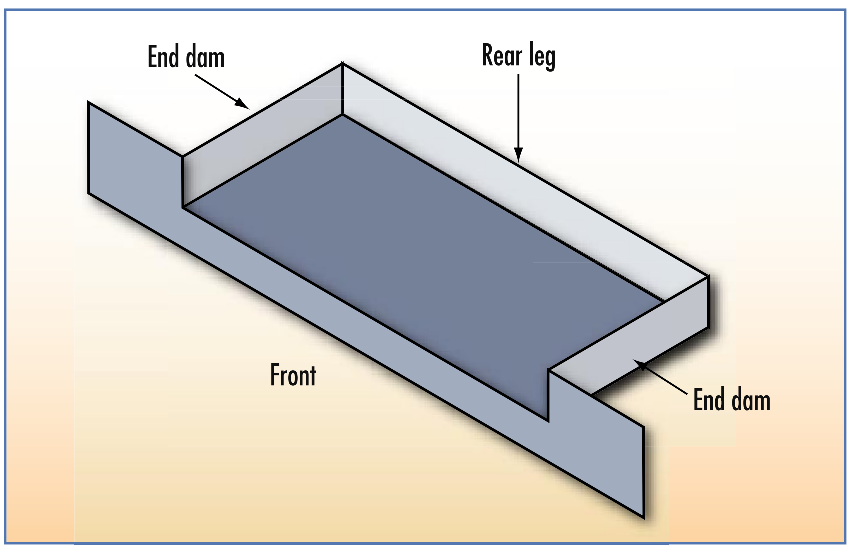


Figure 6-46
View of a typical window sill pan flashing with end dams and rear legs. Windows that do not have nailing flanges should typically be installed over a pan flashing.

SOURCE: ASTM E2112

Sealant joints can be protected with a removable stop as illustrated in Figure 6-47. The stop protects the sealant from direct exposure to the weather and reduces the wind-driven rain demand on the sealant.

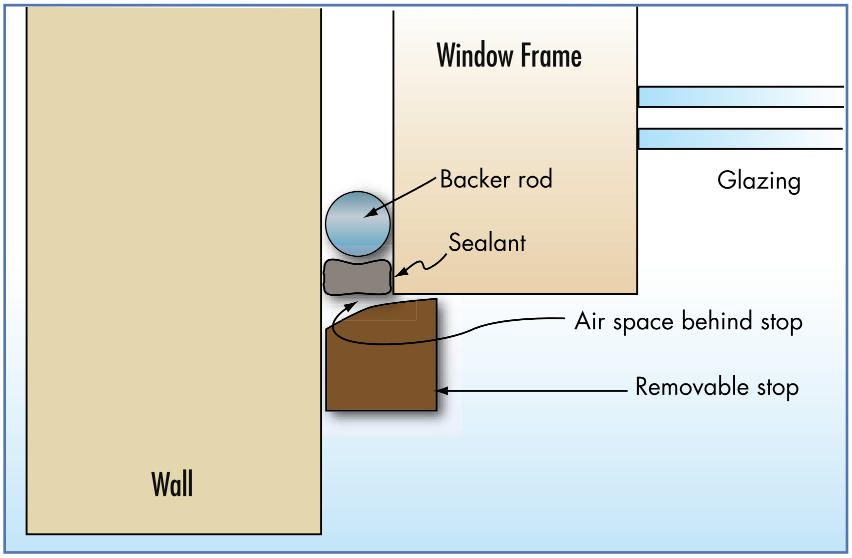


Figure 6-47
Protection of sealant with a stop. The stop retards weathering of the sealant and reduces the wind-driven rain demand on the sealant.

SOURCE: FEMA 55, *COASTAL CONSTRUCTION MANUAL*, 2000

Where water infiltration protection is particularly demanding and important, it is recommended that on-site water infiltration testing in accordance with ASTM E 1105 be specified.

6.14 EXTERIOR-MOUNTED MECHANICAL, ELECTRICAL, AND COMMUNICATIONS EQUIPMENT

Exterior-mounted mechanical (e.g., exhaust fans, HVAC units, relief air hoods, boiler stacks), electrical, and communications equipment (e.g., light fixtures, antennae, satellite dishes) are often damaged during high winds. Damaged equipment can impair the use of the school, the equipment can become missiles, and water can enter the facility where equipment was displaced (see Figures 6-19 and 6-48).

Problems typically relate to inadequate equipment anchorage, inadequate strength of the equipment itself, and corrosion.

Figure 6-48
The rooftop mechanical equipment on this school was blown over. The displaced equipment can puncture the roof membrane and, as in this case, rain can enter the school through the large opening that is no longer protected by the equipment.

6.14.1 Loads and Attachment

Rooftop Equipment. Criteria for determining loads on rooftop equipment were added to the 2002 edition of ASCE 7. A minimum safety factor of three is recommended for the design of equipment anchorage.

To anchor membrane fans, small HVAC units, and relief air hoods, the following minimum prescriptive attachment schedule is recommended:

- For curb-mounted units, specify #14 screws with gasketed washers.
- For curbs with sides less than 12 inches, specify one screw at each side of the curb.
- For curbs between 12 inches and 24 inches, specify two screws per side.
- For curbs between 24 inches and 36 inches, specify three screws per side.
- For units that have flanges attached directly to the roof, attachment with #14 pan-head screws is recommended. A minimum of two screws per side, with a maximum spacing of 12 inches on center is recommended.

Figure 6-49 illustrates the use of supplemental securement straps to anchor equipment. The supplemental attachment was marginal; the straps were too light and the fasteners used to secure them were corroded. This illustrates the validity of the supplemental securement, and it also illustrates the need to execute the securement with attention to detail. In lieu of one screw at each end of the strap, two side-by-side screws offer a stronger and more reliable connection (this of course requires a slightly wider strap).

Figure 6-49
This HVAC equipment had two supplemental securement straps. Both straps are still on this unit, but some of the other units on the roof had broken straps.

SOURCE: FEMA, *BUILDING TO MINIMUM TYPHOON DAMAGE: DESIGN GUIDELINES FOR BUILDINGS*, JULY 1998

Electrical and Communications Equipment. Damage to exterior-mounted electrical equipment is infrequent, in large part, because of the small size of most equipment (e.g., disconnect switches). Exceptions are communication masts (see Figure 6-50), surveillance cameras, service masts, and satellite dishes. These failures are typically caused by failure to perform wind load calculations and anchorage design. Service mast failure is typically caused by collapse of overhead power lines; this can be avoided by underground service. Where overhead service is provided, it is recommended that the service mast not penetrate the roof. Otherwise, a downed service line could pull the mast and rupture the roof membrane.

Figure 6-50
The communications mast on this school was pulled out of the deck, resulting in a progressive peeling failure of the fully adhered single-ply membrane. There are several exhaust fans in the background that were blown off their curbs, but were retained on the roof by the parapet.

SOURCE: FEMA, *BUILDING TO MINIMUM TYPHOON DAMAGE: DESIGN GUIDELINES FOR BUILDINGS*, JULY 1998

ASCE 7 provides load calculation criteria for trussed towers. The ASCE 7 criteria are consistent with ANSI/EIA/TIA-222-E. The ASCE 7 approach is a simplified procedure. The IBC allows use of either approach. ASCE 7 does not provide guidance for on-site power distribution poles nor for light fixture poles. However, the National Electrical Safety Code, ANSI/C2 provides guidance for determining wind loads on power poles. The AASHTO S*tandard Specification for Structural Support for Highway Signs, Luminaries and Traffic Signals* provides guidance for determining wind loads on light fixture poles.

See Section 6.8.1 regarding siting of light fixture poles, power poles, and electrical and communications towers.

6.14.2 Equipment Strength

It is common for equipment components such as fan cowlings and access panels to be blown off during storms. Design of these elements is the responsibility of the equipment manufacturer. Although poor equipment performance has been documented, manufacturers have not offered enhanced equipment for high-wind regions. Therefore, it is incumbent upon the architect/engineer to give special design attention to equipment strength.

Damage investigations have revealed that cable tie-downs have been effective in securing fan cowlings when a sufficiently strong cable and anchor details were used (see Figure 6-51). For fan cowlings less than 4 feet in diameter, 1/8-inch diameter stainless steel cables are recommended. For larger cowlings, use 3/16-inch diameter cables. When the basic wind speed is 120 mph or less, specify two cables. Where the basic wind speed is greater than 120 mph, specify four cables. (As an alternative to cables, heavy stainless steel straps could be screwed to the cowling and curb.) To minimize leakage potential at the anchor point, it is recommended that the cables be anchored to the equipment curb (rather than anchored to the roof deck). The attachment of the curb itself also needs to be designed and specified.

Figure 6-51
To overcome blow-off of the fan cowling, which is a common problem, this cowling was attached to the curb with cables. The curb needs to be adequately attached to carry the wind load exerted on the fan.

SOURCE: FEMA, *BUILDING TO MINIMUM TYPHOON DAMAGE: DESIGN GUIDELINES FOR BUILDINGS*, JULY 1998

To minimize blow-off of equipment access panels, job-site modification will typically be necessary (such as the attachment of hasps and locking devices such as a carabineer). The modification details will need to be tailored for the equipment, which may necessitate detail design after the equipment has been delivered to the job site. Alternatively, factored loads on the equipment could be specified, along with the requirement for the manufacturer to demonstrate compliance with the load requirement.

6.14.3 Durability

To avoid corrosion-induced blow-off, it is recommended that exterior-mounted mechanical, electrical, and communications equipment be nonferrous, stainless steel, or steel with minimum G-90 hot-dip galvanized coating for the equipment itself, equipment stands, anchors, and fasteners. When equipment with enhanced corrosion protection is not available, the designer should advise the school district that periodic equipment maintenance and inspection is particularly important to avoid advanced corrosion and subsequent equipment damage during a windstorm.

The recommendations given in Sections 6.8 through 6.14 are summarized in Table 6-1.

Table 6-1: Summation of Risk Reduction Design Methods

Site	See Section 6.8.1.
Exposure	Locate in Exposure B if possible. Avoid escarpments and upper half of hills.
Are there trees or poles?	Locate to avoid blow-down on school.
Site access	Minimum of two roads.
Are there, or will there eventually be portables?	Locate downwind of school.
General design issues	**See Section 6.8.2**
Calculate loads on MWFRS, building envelope and rooftop equipment	Use ASCE 7 or local building code, whichever procedure results in highest loads.
Determine load resistance via calculations and/or test data	Give load resistance criteria in contract documents, and clearly indicate load path continuity.
Durability	Give special attention to material selection and detailing to avoid problems due to corrosion, wood decay, and termite attack.
Rain penetration	Detail to minimize wind-driven rain penetration into the building envelope.

Table 6-1: Summation of Risk Reduction Design Methods (continued)

Structural Systems (MWFRS)	**See Section 6.9.**
Is it a pre-engineered structural system?	Take special steps to ensure structure is not vulnerable to progressive collapse.
Are there exterior bearing walls?	Design as MWFRS and Components and Cladding. Reinforce CMU. Sufficiently connect precast concrete panels.
Roof decks	Concrete, steel, or wood sheathing is recommended. Attach steel decks with screws. Use special fasteners for wood sheathing. Anchor precast concrete to resist uplift load. For precast Tees, design reinforcing to resist uplift. If FMG-rated assembly, deck must comply with FMG criteria. If mechanically attached roof membrane, refer to recommendations in National Research Council of Canada, *Institute for Research in Construction, Wind Design Guide for Mechanically Attached Flexible Membrane Roofs*, B1049, 2004.
Exterior Doors and Non-Load Bearing Exterior Walls	**See Section 6.10 and 6.11.**
Door, frame and frame fasteners	Resist positive and negative design load, verified by ASTM E 1233 testing. Specify type, size, and spacing of frame fasteners.
Water infiltration	Consider vestibules, door swing, weatherstripping. Refer to ASTM E 2112 for design guidance.
Are there exterior non-load bearing walls, wall coverings, soffits, or elevated floors?	See Section 6.11.
Load resistance	Resist positive and negative design load, verified by ASTM E 1233 testing. Design as Components and Cladding.
Secondary protection	Provide moisture barrier underneath wall coverings that are water-shedding.
Roof Systems	**See Section 6.12.**
Testing	Avoid designs that deviate from a tested assembly. If deviation is evident, perform rational analysis. For metal panel systems, test per ASTM E 1592.
Edge flashings and copings	Follow ANSI/SPRI ES-1. Use a safety factor of three. Consider face-fasteners (Figure 6-39). Consider continuous bars (Figure 6-40).
System selection	Select systems that offer high reliability, commensurate with the wind-regime where the school is located.
Are there parapet base flashings?	Calculate loads and resistance. This is particularly important if base flashing is mechanically attached.
Is there a lightning protection system?	Design and specify anchorage to the roof.
Is there a steep-slope roof system?	See *Coastal Construction Manual*, Third Edition, FEMA 55, 2000.

Table 6-1: Summation of Risk Reduction Design Methods (continued)

Windows and Skylights	**See Section 6.13.**
Glazing, frame, and frame fasteners	Resist positive and negative design load, verified by ASTM E 1233 testing. Specify type, size, and spacing of frame fasteners.
Water infiltration	Carefully design juncture between walls and windows/curtain walls. Avoid relying on sealant as the first line of defense. Refer to ASTM E 2112 for design guidance. Where infiltration is demanding, consider on-site water infiltration testing per ASTM E 1105.
Exterior-mounted Mechanical, Electrical, and Communications Equipment	**See Section 6.14.**
Load resistance	Specify anchorage of all rooftop and wall-mounted equipment. Use a safety factor of three for rooftop equipment anchorage.
Equipment strength	Specify cable tie-downs for fan cowlings. Specify hasps and locking devises for equipment access panels.
Electrical service mast	Avoid penetration through the roof.
After Completion of Contract Documents	
Peer review	Consider peer review. See Section 6.8.3.
Submittals	Ensure required submittals are submitted and that they include the necessary information. Verify that each submittal demonstrates development of a load path through the system and into its supporting element. See Section 6.8.4.
Field observations	Analyze design to determine which elements are critical to ensuring high-wind performance. Determine observation frequency of critical elements. See Section 6.8.4.
Post-occupancy inspections, maintenance, and repair	Advise the school administration of the importance of periodic inspections, special inspections after unusually high winds, maintenance, and timely repair. See Section 6.8.5.

6.15 SCHOOLS LOCATED IN HURRICANE-PRONE REGIONS

The IBC, through ASCE 7, prescribes that exterior glazing in schools in wind-borne debris regions be provided with wind-borne debris protection (either by use of laminated glass or shutters, as discussed in Section 6.15.6). Schools in hurricane-prone regions also have to be designed for a 100-year mean recurrence interval wind event if they are to be used as shelters. These are the only hurricane-related requirements currently in the IBC. These requirements do not provide adequate protection to occupants in a school during a hurricane, because the missile requirements only pertain to glazing. Hence, a code-compliant school can be designed, yet still allow the entrance of missiles through the roof or walls. To account for this deficiency, recommendations are given below regarding missile penetration through exterior walls and the roof. For a more conservative hurricane shelter, refer to FEMA 361.

Publication 4496 by the American Red Cross (ARC) provides information regarding assessing existing buildings for use as hurricane shelters. Unless a school has been specifically designed for use as a shelter, it should only be used as a last resort and only if the school meets the criteria given in ARC 4496.

Schools located in hurricane-prone regions should receive special design attention because of the unique characteristics of this type of windstorm. In addition to being capable of delivering very high winds, hurricanes can cause strong winds for many hours, which can eventually lead to fatigue failure. The direction of the wind can also change, thereby increasing the probability that the wind will approach the school at the most critical angle. Hurricanes also typically generate a large amount of missiles, which can be very damaging to schools and cause injury or death.

For schools in hurricane-prone regions that will be used for a hurricane shelter and/or for emergency response after a storm, the following design parameters are recommended (these recommendations are in addition to the recommendations previously given in Sections 6.8 through 6.14):

1. During the design phase, the architect should determine from the school district whether or not the school will be designated or used as a shelter or emergency response facility. The school should only be used for a shelter if it was designed for that purpose.

2. For schools in coastal Alaska and other areas that experience frequent high wind events (such as parts of Colorado), several of the following recommendations are also applicable to these schools, with the exception of the wind-borne debris recommendations.

6.15.1 Design Loads

For the importance factor, use a value of 1.15.

6.15.2 Structural Systems

Because of the exceptionally good wind performance that reinforced cast-in-place concrete structures offer, a reinforced concrete roof deck and reinforced concrete and/or reinforced and fully grouted CMU exterior walls are recommended.

In order to achieve enhanced missile resistance, the following roof decks are recommended, in descending order of preference: cast-in-place concrete, precast concrete, and concrete topping over steel decking. For exterior walls, the following are recommended: 6-inch (minimum) thick concrete reinforced with #4 rebars at 12 inches on center each way, or 8-inch (minimum) thick fully grouted CMU reinforced with #4 rebars in each cell.

6.15.3 Exterior Doors

For glazing in doors, see the recommendations in Section 6.15.6.

Although the ASCE-7 wind-borne debris provisions only apply to glazing within a portion of hurricane-prone regions, it is recommended that all schools that will be used for evacuation shelters within the entire hurricane-prone region comply with the following recommendation: To minimize the potential of missiles penetrating exterior doors and striking people within the school, it is recommended that doors without glazing and the unglazed portions of doors with glazing be designed to resist the missile loads specified in ASTM E 1996 and that they be tested in accordance with ASTM E 1886. The test assembly should include the door, door frame and hardware. Further information on missile resistance of doors is found in FEMA 361, *Design and Construction Guidance for Community Shelters.*

6.15.4 Non-load Bearing Walls, Wall Coverings, and Soffits

In order to achieve enhanced missile resistance, the following types of exterior walls are recommended: reinforced cast-in-place concrete, or reinforced and fully grouted CMU.

To minimize long-term problems with non-load bearing walls, wall coverings, and soffits, it is recommended that non-load bearing exterior walls, wall coverings, and soffits be avoided to the extent possible. Reinforced concrete or CMU offers greater reliability (i.e., they have no coverings that can be blown off).

6.15.5 Roof Systems

The following types of roof systems are recommended on schools in hurricane-prone regions because they are more likely to avoid water infiltration if the roof is hit by wind-borne debris. Also, the following systems are less likely to become sources of wind-borne debris:

- In tropical climates where insulation is not needed above the roof deck: 1) liquid-applied membrane over cast-in-place concrete deck, or 2) modified bitumen membrane torched directly to cast-in-place concrete deck.

- Install a secondary membrane over a concrete deck (if another type of deck is specified, a cover board may be needed over the deck). Seal the secondary membrane at perimeters and penetrations. Specify a minimum 2-inch thick rigid insulation and a layer of 5/8-inch thick glass mat gypsum roof board over the secondary membrane to absorb missile energy. If the primary membrane is punctured during a storm, the secondary membrane should provide watertight protection unless the roof is hit with missiles of very high energy. A modified bitumen membrane is recommended for the primary membrane because of its enhanced resistance to puncture by small missiles.

- For an SPF roof system over a concrete deck, specify that the foam be a minimum of 3 inches thick to avoid missile penetration through the entire layer of foam.

- For a PMR, it is recommended that pavers weighing a minimum of 22 psf be specified. In addition, base flashings should be protected with metal. Parapets are recommended at roof edges. The parapet should be at least 3 feet high or higher if so indicated by ANSI/SPRI RP-4. Note: If the basic wind speed exceeds 130 mph, a PMR is not recommended on schools in hurricane-prone regions.

- For structural metal roof panels with concealed clips, it is recommended that mechanically seamed ribs spaced at 12 inches on center over a concrete deck be specified. If a steel deck is specified, specify a self-adhering modified bitumen membrane and 3-inch thick rigid insulation, followed by the metal panels installed on wood nailers. At the self-adhering membrane laps, specify metal strips over the deck where the laps do not occur over the deck ribs, or specify a suitable cover board between the deck and self-adhering membrane. If the metal panels are punctured during a storm, the secondary membrane should provide watertight protection unless the roof is hit with missiles of very high energy. Note: Architectural metal panels are not recommended on schools in hurricane-prone regions.

In order to avoid the possibility of roofing debris blowing off and striking people arriving at the school during the storm, the following types of roof coverings are not recommended: aggregate surfacings (either on BUR [shown in Figure 6-11], single-plies [shown in Figure 6-8] or SPF), lightweight concrete pavers, cementitious-coated insulation boards, slate, and tile (see Figure 6-52). Wind-borne debris from heavy roof coverings such as tiles have great potential to cause serious injury to people arriving at a school during a hurricane or other high wind event.

Figure 6-52
These wire-tied tiles were installed over a concrete deck. They were attached with stainless steel clips at the perimeter rows and all of the tiles had tail hooks. Adhesive was also used between the tail and head of the tiles.

SOURCE: FEMA, *BUILDING TO MINIMUM TYPHOON DAMAGE: DESIGN GUIDELINES FOR BUILDINGS*, JULY 1998

Because mechanically attached and air-pressure equalized single-ply membrane systems are susceptible to massive progressive failure after missile impact (see Figure 6-53), these systems are not recommended on schools in hurricane-prone regions. Fully adhered single-ply membranes are also very vulnerable to missiles (see Figure 6-54); therefore, they also are not recommended unless they are ballasted with pavers.

Figure 6-53
At this school, a missile struck the fully adhered low-sloped roof (see arrow) and slid into the steep-sloped reinforced mechanically attached single-ply membrane. A large area of the mechanically attached membrane was blown away due to progressive membrane tearing.

Figure 6-54
This fully adhered single-ply membrane was struck by a large number of missiles during a hurricane.

6.15.6 Windows and Skylights

ASCE 7 requires the use of impact-resistant glazing (i.e., laminated glass) or shutters in wind-borne debris regions. ASCE 7 refers to ASTM E 1996 for missile loads and to ASTM E 1886 for the test method to be used to demonstrate compliance with the E

1996 load criteria. In addition to testing for impact resistance, the window unit is subjected to pressure cycling after missile impact to evaluate whether or not the window can still resist wind loads.

If wind-borne debris glazing protection is provided by shutters, the glazing is still required by ASCE 7 to meet the positive and negative design air pressures.

For those schools that desire to provide blast-resistant glazing, the windows and glazed doors can be designed to accommodate wind pressure, missile loads, and blast pressure. However, the window and door units need to be tested for missile loads and cyclic air pressure, as well as for blast. A unit that meets blast criteria will not necessarily meet the E 1996 and E 1886 criteria, and vice versa.

With the advent of building codes requiring glazing protection in wind-borne debris regions, a variety of shutter designs have entered the market. Figure 6-55 illustrates an effective shutter. A metal track was permanently mounted to the wall above and below the window frame. Upon notification of an approaching hurricane, the metal shutter panels were inserted into the frame and locked into position with wing nuts.

Figure 6-55
View of a metal shutter designed to provide missile protection for windows

Shutters typically have a lower initial cost than laminated glass. However, unless the shutter is permanently anchored to the school (e.g., an accordion shutter), space will be needed to store the shutters. Also, when a hurricane is forecast, costs will also be incurred each time shutters are installed and removed afterward. To avoid the difficulty of installing shutters on upper-level glazing, motorized shutters could be specified, although laminated glass may be more economical in these locations.

6.15.7 Emergency Power

Schools intended for use as shelters and/or emergency response after a storm should be equipped with an emergency generator.

6.15.8 Construction Contract Administration

It is important for the school district to obtain the services of a professional contractor who will execute the work described in the contract documents in a diligent and technically proficient manner.

The frequency of field observations and extent of special inspections and testing should be greater than those employed on schools that are not designated as shelters.

6.15.9 Periodic Inspections, Maintenance, and Repair

The recommendations previously given for periodic and post-storm inspections, maintenance, and repair are critically important for schools used as shelters and emergency response after a storm because, if failure occurs, the risk of injury or death to occupants is great, and the needed continued operation of the school would be jeopardized.

The recommendations given in Section 6.15 are summarized in Table 6-2. These recommendations are in addition to those given in Sections 6.8 to 6.14, as summarized in Table 6-1.

Table 6-2: Summation of Design of Schools Used for Hurricane Shelters and/or for Emergency Response After a Storm

For wind-load calculations	Use an importance factor of 1.15.
Structural system	Reinforced cast-in-place concrete is recommended. If roof deck is not cast-in-place, pre-cast concrete or concrete topping over steel decking is recommended.
Exterior walls	Reinforced concrete or fully grouted and reinforced CMU is recommended, without wall coverings other than paint.
Exterior doors	Designed and tested to resist missiles.
Roof covering	Avoid aggregate surfacings, lightweight concrete pavers, cementitious-coated insulation boards, slate and tile. Avoid single-ply membranes unless ballasted with heavy pavers. Design a roof covering that can accommodate missiles – see Section 6.15.5.
Exterior windows and skylights	Laminated glass or shutters designed and tested to resist missiles. If equipped with shutters, glazing is still required to resist wind pressure loads.
Emergency power	School equipped with an emergency generator.
Construction contract administration	Construction executed by professional contractor and subcontractors. More frequent field observations, special inspections and testing.
Periodic inspections, maintenance, and repair	After construction, diligent periodic inspections and special inspections after storms. Diligent maintenance and prompt execution of needed repairs.
Is enhanced occupant protection sheltering desired?	For a more conservative hurricane shelter, refer to FEMA 361, *Design and Construction Guidance for Community Shelters.*

6.16 DESIGN FOR TORNADO SHELTERS

Terrorist threat: If it is desired to incorporate a tornado shelter, and if it is also desired for the shelter to provide protection from terrorism, refer to FEMA 428 and 453 for additional shelter enhancements.

Tornado risk assessment and tornado-prone regions were discussed in Section 6.7 and the cost of tornado shelters was discussed in Section 6.5.2. Following up on those discussions, strong and violent tornadoes produce wind speeds that are substantially greater than those delivered by the strongest hurricanes; hence, the wind pressures that these tornadoes exert on buildings is tremendous and far exceed the minimum pressures required by building codes. In addition, strong and violent tornadoes can generate very powerful missiles (see Figure 6-56), including vehicles. The missile sticking out of the roof in the foreground of Figure 6-56 is a double 2-inch by 6-inch. The portion sticking out of the roof is 13 feet long. It penetrated a ballasted ethylene propylene diene monomer (EPDM) membrane and approximately 3 inches of polyisocyanurate roof insulation and the steel roof deck. The missile laying on the roof just beyond is 2 inches by 10 inches by 16 feet long.

Missile loads that are used for the design of tornado shelters are significantly greater than the missile loads used for the design of glazing protection in wind-borne debris regions of hurricane-prone regions.

Figure 6-56
A violent tornado passed by this high school and showered the roof with missiles.

SOURCE: FEMA 342, *OKLAHOMA AND KANSAS MIDWEST TORNADOES OF MAY 3, 1999*, 1999

As discussed in Section 6.5.2, FEMA 361, *Design and Construction Guidance for Community Shelters*, includes software for assessing the benefit/cost ratio of incorporating specially designed tornado shelters within schools. In addition, it includes comprehensive information regarding the design of shelters. If shelter design is contemplated, use of FEMA 361 is recommended.

Existing Schools without Tornado Shelters. Where the number of recorded F3, F4, and F5 tornadoes per 3,700 square miles is one or greater (see Figure 6-2), if the school does not have a tornado shelter, the best available refuge areas should be identified. FEMA 431, *Tornado Protection, Selecting Refuge Areas in Buildings* provides useful information for school administrators, and for architects and engineers who perform evaluations of existing schools.

To minimize deaths and injuries of students, faculty, and other occupants, it is critically important that the best available refuge areas be pre-identified by a qualified architect/engineer.[8] Once identified, those areas need to be clearly marked so that occupants can quickly seek refuge. Don't wait for the arrival of a tornado on the school grounds to try to find the best available refuge areas; by that time, it is too late. If refuge areas have not been pre-identified, occupants can easily take cover in areas that can become death traps (see Figure 6-57).

When a true shelter is desired for a school that does not have one, retrofitting a shelter within the school can be very expensive. An economical alternative is an addition to the existing school that can function as a shelter as well as serve another purpose. This approach works well for smaller schools, but, for a very large school, construction of two or more shelter additions should be considered in order to reduce the time it takes to reach the shelter (often there is ample warning time, but sometimes an approaching tornado is not noticed until a couple of minutes before it strikes).

[8] It should be realized that, unless the refuge area was specifically designed as a tornado shelter, occupants in a "best available refuge area" are vulnerable to injury or death.

Figure 6-57
View of an elementary school corridor after passage of a violent tornado. Although corridors sometimes offer protection, they can be death traps as illustrated in this figure (fortunately the school was not occupied when it was struck).

SOURCE: FEMA 342, *OKLAHOMA AND KANSAS MIDWEST TORNADOES OF MAY 3, 1999*, 1999

Portable Classrooms. Portable classrooms should not be occupied during times when a tornado watch has been issued by the National Weather Service (a watch means that conditions are favorable for tornado development). Do not wait for issuance of a tornado warning (i.e., a tornado has been spotted) by the National Weather Service to seek refuge in the main school building. If a tornado is nearby, students could be caught outdoors.

The recommendations given in Section 6.16 are summarized in Table 6-3 .

Table 6-3: Summation of Design for Tornado Shelters

Proposed New School	
1. Is proposed school in a tornado-prone region: yes or no? If yes, go to step 2.	See Section 6.7.1 for decision analysis.
2. If yes, perform benefit/cost analysis to assist in deciding whether or not to incorporate a shelter(s) within the school.	See FEMA 361, *Design and Construction Guidance for Community Shelters*, benefit/cost analysis.
3. Perform steps 1 and 2 prior to setting project budget.	If sheltering is not considered until after setting the budget, funds may not be available.
4. It is decided to incorporate a shelter(s).	Refer to FEMA 361, *Design and Construction Guidance for Community Shelters*, for design guidance.

Table 6-3: Summation of Design for Tornado Shelters (continued)

Existing schools without specifically designed tornado shelters	
1. If 1 or more F3-F5 tornadoes per 3,700 square miles, pre-identify best available refuge areas.	See Figure 6-2 for history frequency and FEMA 431, *Tornado Protection, Selecting Refuge Areas in Buildings* for identification guidance.
2. If 1 or more F3-F5 tornadoes per 3,700 square miles, consider incorporating a shelter(s) within a new building addition(s).	See FEMA 361, *Design and Construction Guidance for Community Shelters*, for benefit/cost analysis and design guidance.

6.17 REMEDIAL WORK ON EXISTING SCHOOLS

Section 6.6.1 discussed prioritizing and Section 6.6.2 discussed cost. Following up on those discussions, many existing schools need building envelope component strengthening or structural strengthening. The need for this work is due either to deterioration over time and/or inadequate facility strength at the time the school was built.

It is prudent for school districts to have their existing facilities evaluated. This also applies to recently constructed schools that are located in an area where the basic wind speed is greater than 90 mph (peak gust), and those schools that will be used for emergency response after a storm and schools that will be used for a hurricane shelter.

For new schools, areas of concern would typically be the building envelope and exterior-mounted mechanical, electrical, and communications equipment. By identifying weaknesses and prioritizing and executing the work, many failures can be averted. A proactive approach can save significant sums of money and decrease the number of instances when schools are impaired or immobilized after a storm.

For roofs with weak metal edge flashing or coping attachment, face-attachment of the edge flashing/coping (as shown in Figure 6-39) is a cost-effective approach to greatly improve wind-resistance of the roof system. Fastening rooftop equipment to curbs is a cost-effective approach to avoid the type of problems shown in Figure 6-19.

During planned roof covering replacement, by tearing off the existing roof covering rather than re-covering, there is the opportunity to evaluate the structural integrity of the deck and deck attachment and upgrade its attachment if necessary. Many older decks are poorly attached (Figure 6-58); hence, if their attachment is not upgraded, blow-off of the deck and the new roof covering could occur. The two deck panels shown in Figure 6-58 blew away because their attachment to the roof structure was inadequate. An SPF roof covering was over the deck panels that blew away because of the characteristics of this type of covering, membrane propagation failure did not occur, as would have been the case with built-up, modified bitumen, or single-ply roof membranes. Cementitious wood-fiber decks were commonly used on schools built in the 1950s and 1960s. Decks constructed during that era typically had very limited uplift resistance due to weak connections to the support structure.

Design guidance pertaining to existing decks is presented in "*Uplift Resistance of Existing Roof Decks: Recommendations for Enhanced Attachment During Reroofing Work*," RCI Interface, Thomas L. Smith, January 2003, pp. 14.

Figure 6-58
This school had a cementitious wood-fiber deck (commonly referred to by the proprietary name "Tectum").

Weak non-load bearing masonry walls, poorly connected precast concrete panels, long-span structures (e.g., at gyms) with limited uplift resistance, and weak glass curtain walls are common problems with many older schools. Although the technical solutions to these problems are not difficult, the cost of the remedial work is normally quite expensive. If remediation funds are not available, it is important to minimize the risk of injury and death by evacuating areas that have this type of construction when winds above 60 mph are forecast.

For schools located in wind-borne debris regions, if the exterior glazing is not missile-resistant, equipping the openings with shutters is a cost-effective approach to provide protection.

The recommendations given in Section 6.17 are summarized in Table 6-4.

Table 6-4: Summation of Remedial Work on Existing Schools

Perform district-wide assessment of all schools	Evaluate all hazards. Prioritize the various schools and the work items at each school. Life-safety items are first priority; property damage and school interruption are second priority. See Section 6.6.1.
Are there weak non-load bearing masonry walls, weak curtain walls, poorly connected precast concrete panels, or weak long-span roof structures?	If strength is inadequate to resist winds that are likely to occur while the school is occupied (such as strong thunderstorms), implement remedial work.
Are edge flashings or copings inadequately attached?	Face-attach the vertical flanges. See Figure 6-39.
Are rooftop equipment units unanchored or poorly anchored?	Add screws or bolts to anchor equipment to curbs. Add cables to secure fan cowlings. Add latches to secure equipment access panels. See Section 6.14.
Are roof deck or roof structure connections weak?	During planned roof covering replacement, remove roof covering and strengthen attachment of deck and/or roof structure. See Section 6.12.
If the school is in a wind-borne debris region, does exterior glazing have protection (via laminated glass or shutters)?	Even if the school will not be used as a shelter, equip with shutters to avoid interior wind and water damage. For more conservative protection, consider the wind-borne debris region to include areas where the basic wind speed is equal to or greater to 110 mph (100 mph if the school is located within 1 mile of the coast).
Will the school be used as a hurricane evacuation shelter and/or for emergency response after a storm?	To the extent reasonably possible, upgrade the school so that it complies with the provisions in Section 6.15.
Is the school located in a tornado-prone area?	See Section 6.16.

6.18 REFERENCES AND SOURCES OF ADDITIONAL INFORMATION

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National Research Council of Canada, Institute for Research in Construction, *Wind Design Guide for Mechanically Attached Flexible Membrane Roofs*, B1049, 2004.

Rousseau, M.Z., *Facts and Fictions of Rain-Screen Walls*, Construction Canada, 1990, pp. 40.

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Smith, Thomas L., "Uplift Resistance of Existing Roof Decks: Recommendations for Enhanced Attachment During Reroofing Work," *RCI Interface*, January 2003, pp. 14.

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6.19 GLOSSARY OF WIND TERMS

Basic wind speed. A 3-second gust speed at 33 feet above the ground in Exposure C. (Exposure C is flat open terrain with scattered obstructions having heights generally less than 30 feet.) Note: Since 1995, ASCE 7 has used a 3-second peak gust measuring time. A 3-second peak gust is the maximum instantaneous speed with a duration of approximately 3 seconds. A 3-second peak gust speed could be associated with a given windstorm (e.g., a particular storm could have a 40-mile per hour peak gust speed), or a 3-second peak gust speed could be associated with a design-level event (e.g., the basic wind speed prescribed in ASCE 7).

Building, enclosed. A building that does not comply with the requirements for open or partially enclosed buildings.

Building, open. A building having each wall at least 80 percent open. This condition is expressed by an equation in ASCE 7.

Building, partially enclosed. A building that complies with both of the following conditions:

1. The total area of openings in a wall that receives positive external pressure exceeds the sum of the areas of openings in the balance of the building envelope (walls and roof) by more than 10 percent, and
2. The total area of openings in a wall that receives positive external pressure exceeds 4 square feet or 1 percent of the area of that wall, whichever is smaller, and the percentage of openings in the balance of the building envelope does not exceed 20 percent.

These conditions are expressed by equations in ASCE 7.

Building, regular shaped. A building having no unusual geometrical irregularity in spatial form.

Building, simple diaphragm. An enclosed or partially enclosed building in which wind loads are transmitted through floor and roof diaphragms to the vertical main wind-force resisting system.

Components and cladding. Elements of the building envelope that do not qualify as part of the main wind-force resisting system.

Escarpment. Also known as a scarp, with respect to topographic effects, a cliff or steep slope generally separating two levels or gently sloping areas.

Exposure. The characteristics of the ground roughness and surface irregularities in the vicinity of a building. ASCE 7 defines three exposure categories - Exposures B, C, and D.

Glazing. Glass or transparent or translucent plastic sheet used in windows, doors, and skylights.

Glazing, impact-resistant. Glazing that has been shown by an approved test method to withstand the impact of wind-borne missiles likely to be generated in wind-borne debris regions during design winds.

Hill. With respect to topographic effects, a land surface characterized by strong relief in any horizontal direction.

Hurricane-prone regions. Areas vulnerable to hurricanes; in the U.S. and its territories defined as:

1. The U.S. Atlantic Ocean and Gulf of Mexico coasts where the basic wind speed is greater than 90 miles per hour, and
2. Hawaii, Puerto Rico, Guam, U.S. Virgin Islands, and American Samoa.

Impact-resistant covering. A covering designed to protect glazing, which has been shown by an approved test method to withstand the impact of wind-borne missiles likely to be generated in wind-borne debris regions during design winds.

Importance factor, I. A factor that accounts for the degree of hazard to human life and damage to property. The importance factor adjusts the mean recurrence interval. Importance factors are given in ASCE 7.

Main wind-force resisting system. An assemblage of structural elements assigned to provide support and stability for the overall structure. The system generally receives wind loading from more than one surface.

Mean roof height, h. The average of the roof eave height and the height to the highest point on the roof surface, except that, for roof angles of less than or equal to 10 degrees, the mean roof height shall be the roof eave height.

Missiles. Debris that became or could become ingested into the wind stream.

Openings. Apertures or holes in the building envelope that allow air to flow through the building envelope and that are designed as "open" during design winds. A door that is intended to be in the closed position during a windstorm would not be considered an opening. Glazed openings are also not typically considered an opening. However, if the building is located in a wind-borne debris region and the glazing is not impact-resistant or protected with an impact-resistant covering, the glazing is considered an opening.

Ridge. With respect to topographic effects, an elongated crest of a hill characterized by strong relief in two directions.

Wind-borne debris regions. Areas within hurricane-prone regions located:

1. Within 1 mile of the coastal mean high water line where the basic wind speed is equal to or greater than 110 mph and in Hawaii; or
2. In areas where the basic wind speed is equal to or greater than 120 mph.