CHAPTER 3
STRUCTURAL DESIGN CRITERIA

SECTION 301
GENERAL

301.1 Scope. Loads and load combinations shall be determined in accordance with ASCE 7 unless otherwise noted.

Structural elements of the storm shelter shall be designed in accordance with the appropriate material design standard specified in the applicable building code to sustain the loads prescribed in ASCE 7, as modified by this chapter, and combined in accordance with the load combinations of ASCE 7, as modified by Section 302.

301.1.1 Design or testing. Where the strength requirements cannot be determined by engineering calculations in accordance with appropriate material design standards referenced by the applicable building code, roof and wall assemblies shall meet the pressure requirements of Section 805.

SECTION 302
LOAD COMBINATIONS

302.1 Strength design. For Strength Design or Load and Resistance Factor Design (LRFD), use the load combinations stated in ASCE 7, Section 2.3.2, with the following additional load combinations with W in these additional load combinations being based on Section 304:

1. In load combination 3, replace 0.8W with 0.5W.
2. In load combinations 4 and 6, replace 1.6W with 1.0W.
3. Exception 1 shall not apply.

302.2 Allowable stress design. For Allowable Stress Design (ASD), use the load combinations stated in ASCE 7, Section 2.4.1 with the following additional load combinations with W in these additional load combinations being based on Section 304:

In load combinations 5, 6 and 7, replace W with 0.6W.

SECTION 303
LOADS

303.1 Rain loads. Rain loads shall be determined in accordance with ASCE 7.

303.1.1 Rainfall rate. For hurricane shelters, rainfall rate shall be determined by adding a rate of 3 inches (76.2 mm) of rainfall per hour to the rainfall rate established from Figure 303.2.

303.2 Roof live loads. Storm shelter roofs shall be designed for minimum live loads specified in ASCE 7, but not less than the following:

Tornado shelters: 100 pounds per square foot (4.8 kN/m^2)

Hurricane shelters: 50 pounds per square foot (2.4 kN/m^2)

303.3 Hydrostatic loads. Underground portions of storm shelters shall be designed for buoyancy forces and hydrostatic loads assuming that the groundwater level is at the surface of the ground at the entrance to the storm shelter, unless adequate drainage is available to justify designing for a lower groundwater level.

SECTION 304
WIND LOADS

304.1 General. Design wind pressures shall be determined using Method 2, Analytical Procedure, from Section 6 of ASCE 7 except as modified by this section.

304.2 Design wind speed. For tornado shelters, the design wind speed shall be in accordance with Figure 304.2(1). For hurricane shelters, the design wind speed shall be in accordance with Figure 304.2(2).

304.3 Wind directionality factor. The directionality factor shall be taken as $K_d = 1.0$.

304.4 Importance factor. The importance factor, I, shall be taken as 1.0.

304.5 Exposure. Wind pressures shall be based on exposure category C.

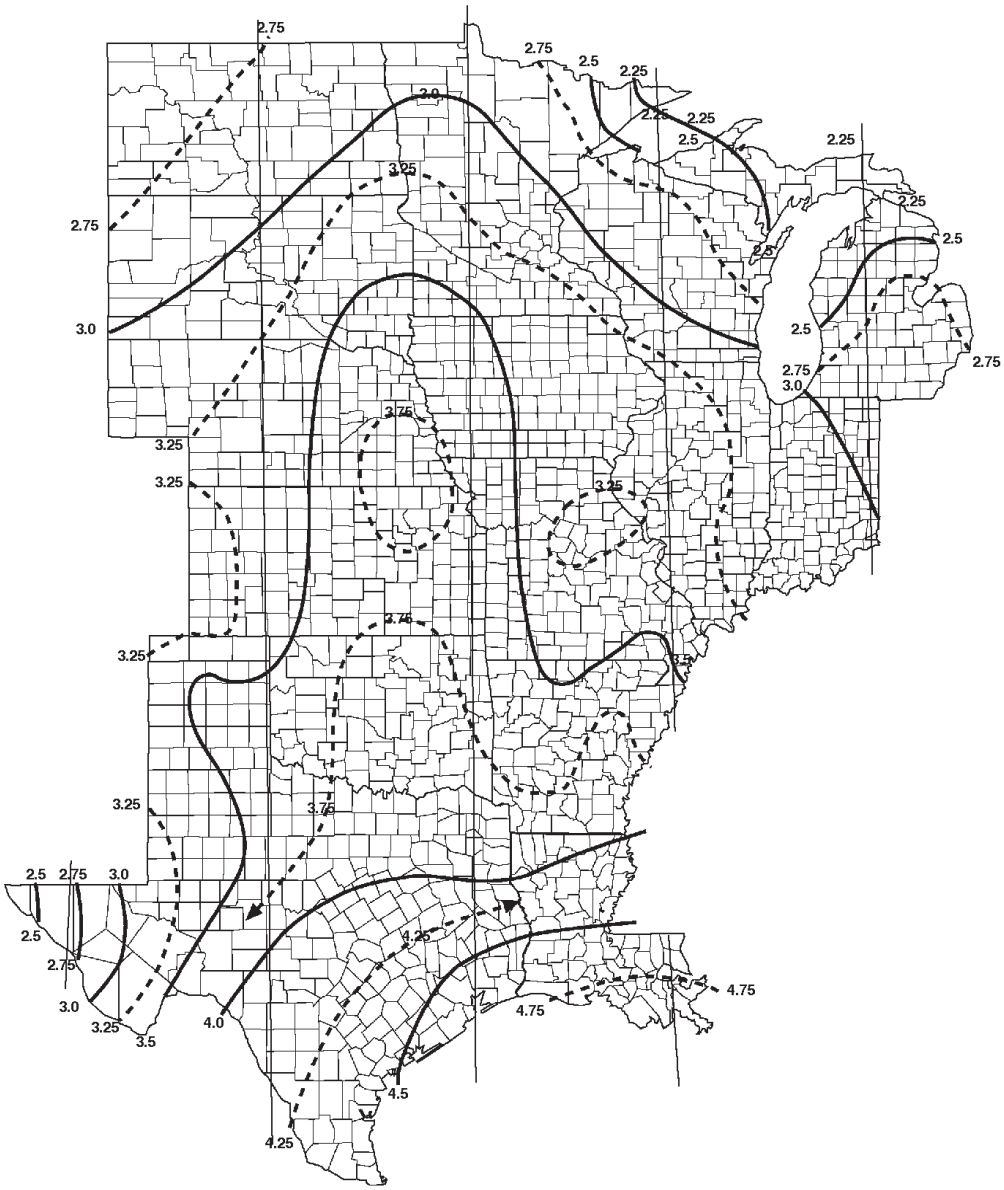
Exception: For hurricane shelters, where exposure category B exists for all wind directions, MWFRS wind pressures shall be permitted to be based upon exposure category B.

304.6 Topographic effects. For tornado shelters, the topographic factor K_{zt} need not exceed 1.0.

304.7 Enclosure classifications. Enclosure classifications for storm shelters shall be determined in accordance with ASCE 7, Section 6.2. For determining the enclosure classification for community storm shelters, the largest door or window on a wall that receives positive external pressure shall be considered as an opening.

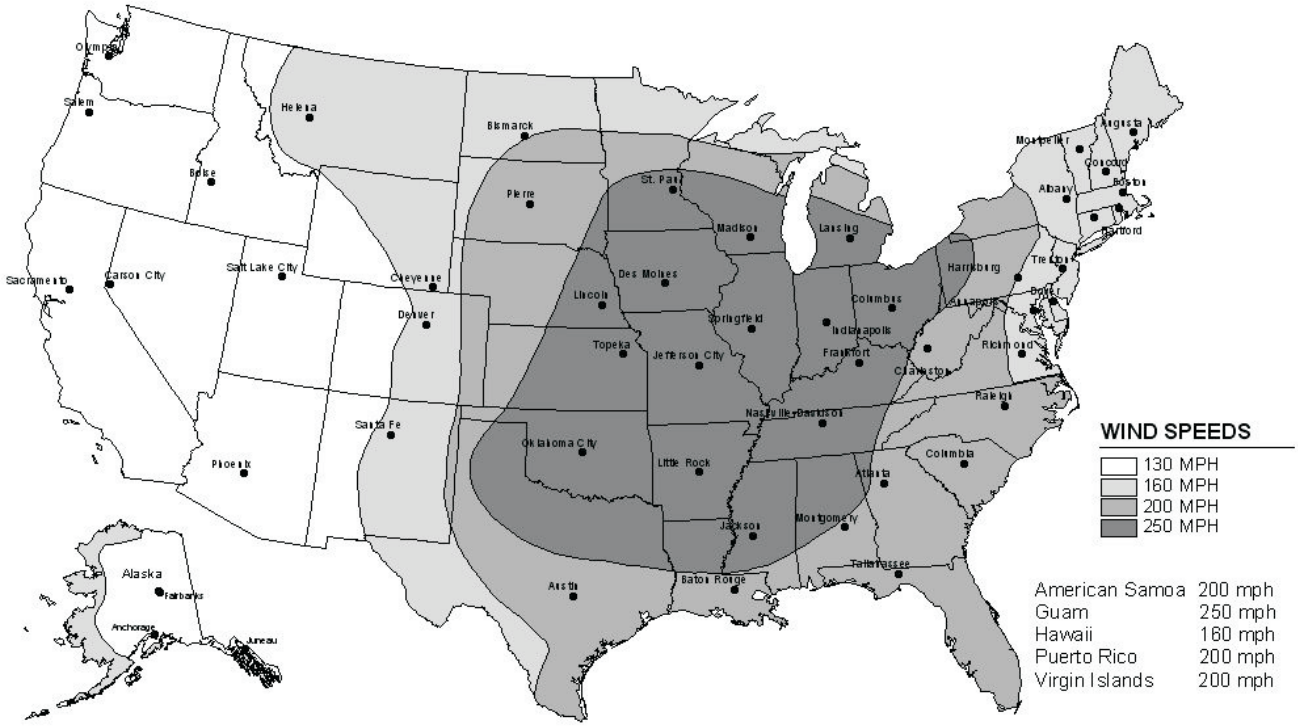
For SI: 1 inch = 25.4 mm.

FIGURE 303.2
100-YEAR, 1-HOUR RAINFALL (INCHES), EASTERN UNITED STATES



For SI: 1 inch = 25.4 mm.

FIGURE 303.2—continued
100-YEAR, 1-HOUR RAINFALL (INCHES), CENTRAL UNITED STATES

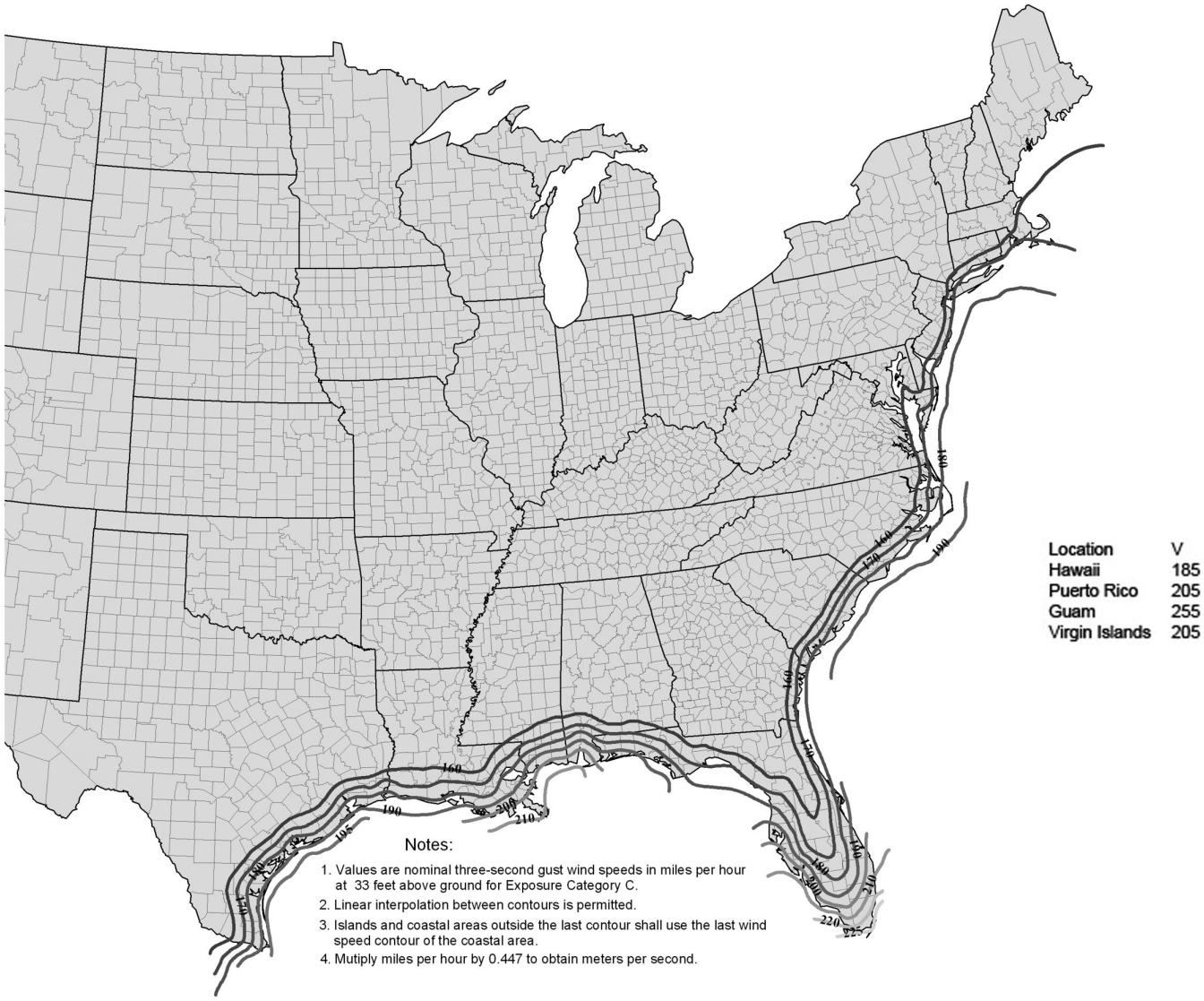


Notes:

1. Values are nominal three-second gust wind speeds in miles per hour at 33 feet above ground for Exposure Category C.
2. Multiply miles per hour by 0.447 to obtain meters per second.

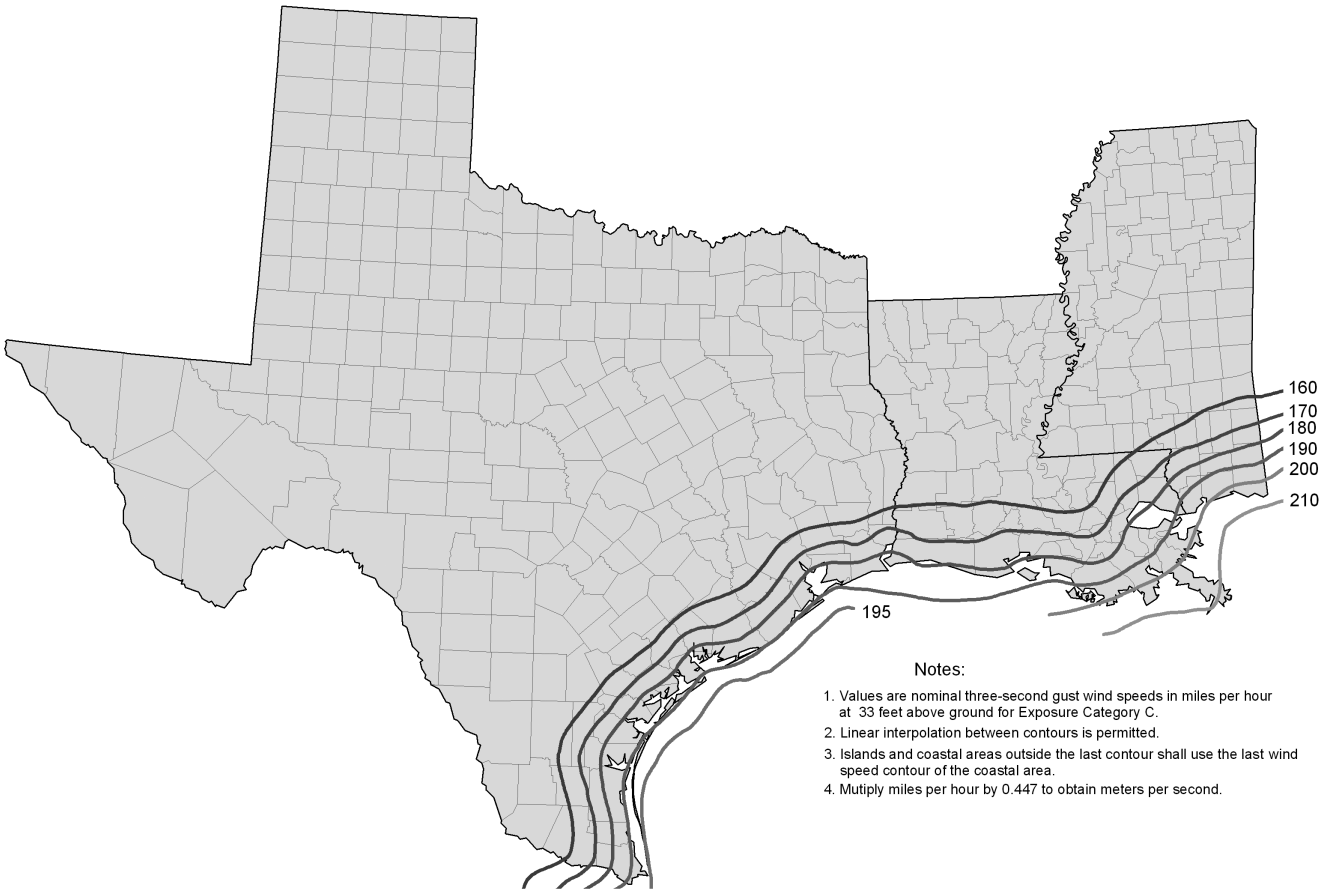
For SI: 1 foot = 304.8 mm, 1 mile per hour = 0.447 m/s.

FIGURE 304.2(1)
SHELTER DESIGN WIND SPEEDS FOR TORNADOES



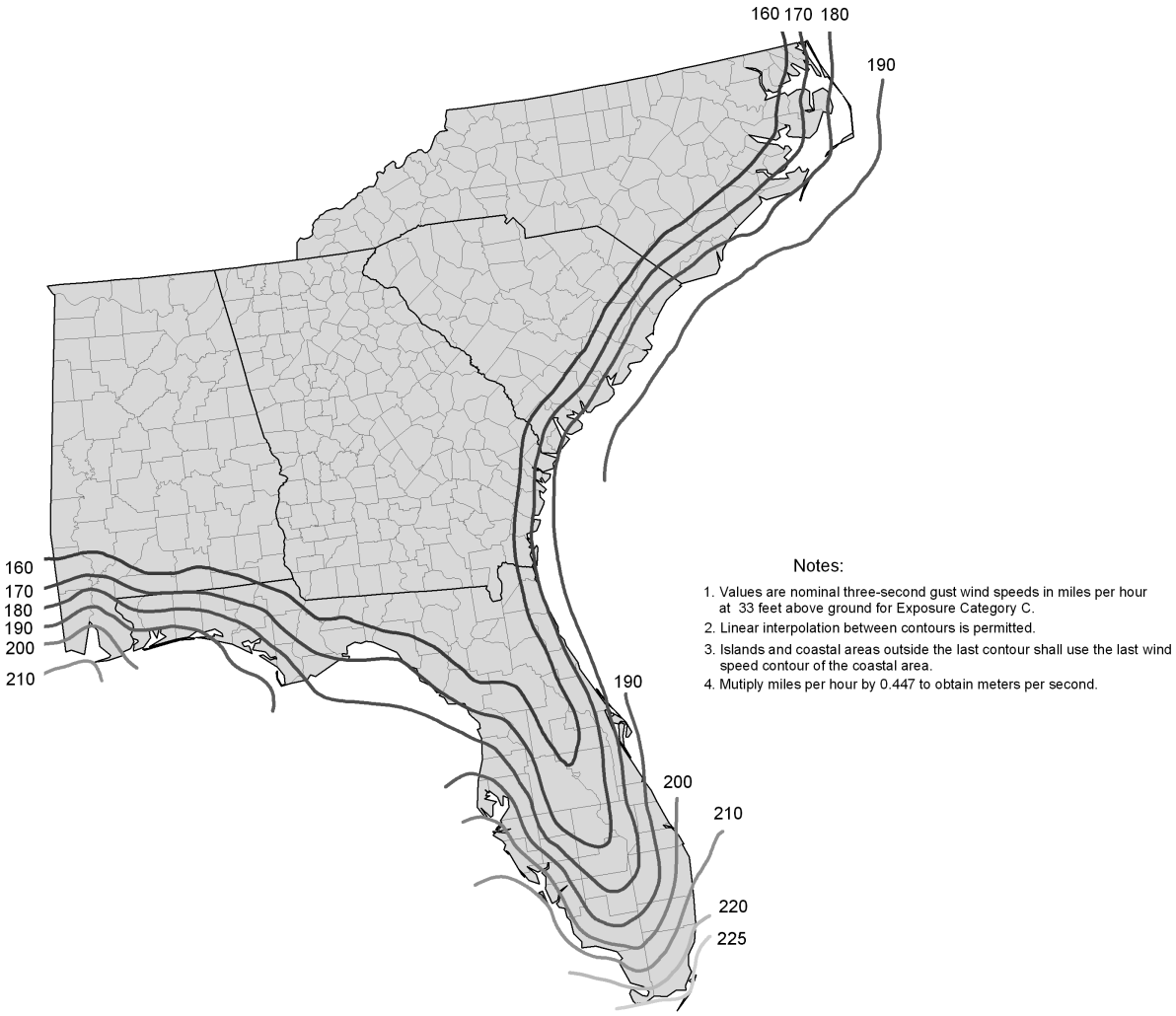
For SI: 1 foot = 304.8 mm, 1 mile per hour = 0.447 m/s.

FIGURE 304.2(2)
SHELTER DESIGN WIND SPEEDS FOR HURRICANES



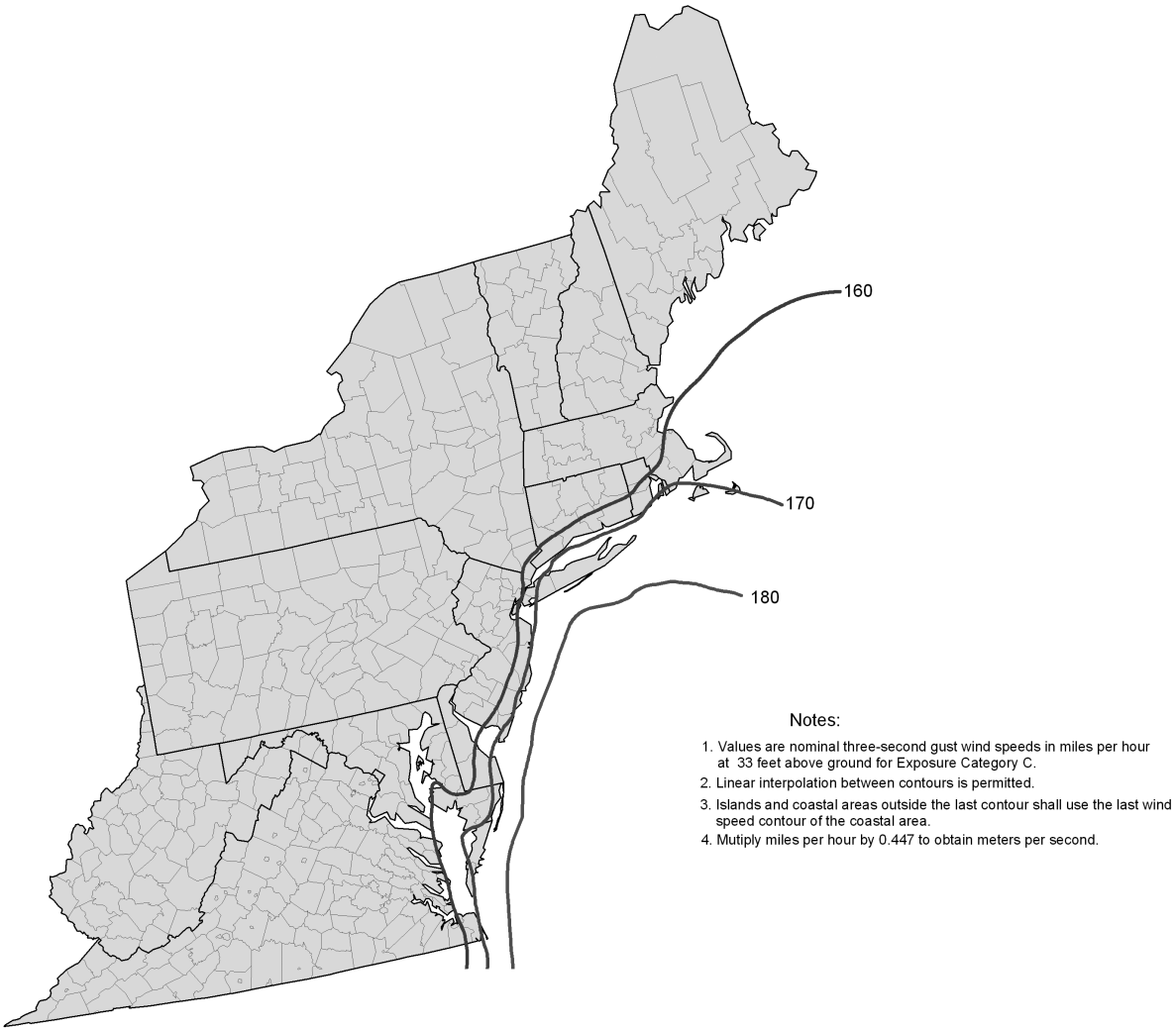
For SI: 1 foot = 304.8 mm, 1 mile per hour = 0.447 m/s.

FIGURE 304.2(2)—continued
SHELTER DESIGN WIND SPEEDS FOR HURRICANES—WESTERN GULF OF MEXICO



For SI: 1 foot = 304.8 mm, 1 mile per hour = 0.447 m/s.

FIGURE 304.2(2)—continued
SHELTER DESIGN WIND SPEEDS FOR HURRICANES—EASTERN GULF OF MEXICO



For SI: 1 foot = 304.8 mm, 1 mile per hour = 0.447 m/s.

FIGURE 304.2(2)—continued
SHELTER DESIGN WIND SPEEDS FOR HURRICANES—MID-NORTHERN ATLANTIC

304.8 Atmospheric pressure change (APC). For tornado shelters classified as enclosed buildings, the additional internal pressures caused by atmospheric pressure change shall be considered. The internal pressure coefficient, GC_{pi}, shall be taken as ±0.18 when APC venting area of 1 square foot (0.0929 m^2) per 1,000 cubic feet (28.3 m^3) of interior shelter volume is provided. APC venting shall consist of openings in the shelter roof having a pitch not greater than 10 degrees from the horizontal or openings divided equally (within 10 percent of one another) on opposite walls. A combination of APC venting meeting the above requirements is permitted.

Exception: Calculation of venting area to relieve APC is not required for hurricane shelters or for tornado shelters classified as partially enclosed buildings. An internal pressure coefficient of GC_{pi} = ±0.55 shall be used for tornado shelters where APC venting meeting the requirements of Section 304.8 is not provided, or where APC venting area requirements are not calculated.

SECTION 305
DEBRIS HAZARDS

305.1 Windborne debris. All shelters shall be designed for the impact of windborne debris in accordance with this section.

305.1.1 Missile criteria for tornado shelters. The debris impact test missile for all components of the shelter envelope of tornado shelters shall be a 15-pound (6.8 kg) sawn lumber 2 by 4 traveling at the speeds shown in Table 305.1.1.

TABLE 305.1.1
SPEEDS FOR 15-lb SAWN LUMBER 2 x 4 MISSILE FOR TORNADO SHELTERS

DESIGN WIND SPEED	MISSILE SPEED AND SHELTER IMPACT SURFACE
130 mph	80 mph Vertical Surfaces 53 mph Horizontal Surfaces
160 mph	84 mph Vertical Surfaces 56 mph Horizontal Surfaces
200 mph	90 mph Vertical Surfaces 60 mph Horizontal Surfaces
250 mph	100 mph Vertical Surfaces 67 mph Horizontal Surfaces

For SI: 1 mile per hour = 0.447 m/s.

305.1.2 Missile criteria for hurricane shelters. The debris impact test missile for all components of the shelter envelope of hurricane shelters shall be a 9-pound (4.1 kg) sawn lumber 2 by 4. The speed of the test missile impacting vertical shelter surfaces shall be a minimum of 0.40 times the shelter design wind speed. The speed of the test missile impacting horizontal surfaces shall be 0.10 times the shelter design wind speed.

305.2 Testing for missile impacts. Testing for missile impact of all components of the shelter envelope shall be in accordance with Section 305 following the test procedures of Section 804.

305.2.1 Vertical or horizontal surfaces. Walls, doors, and other shelter envelope surfaces inclined 30 degrees (.52 rad) or more from the horizontal shall be considered vertical surfaces. Surfaces inclined less than 30 degrees (.52 rad) from the horizontal shall be treated as horizontal surfaces.

305.2.2 Soil-covered portions of shelters. Portions of soil-covered shelters, with less than 12 inches (304.8 mm) of soil cover protecting shelter horizontal surfaces, or with less than 36 inches (914.4 mm) of soil cover protecting shelter vertical surfaces, shall be tested for resistance to missile perforation as though the surfaces were exposed. To qualify for shielding from soil cover, the soil surfaces shall slope away from the entrance walls or other near-grade enclosure surfaces of underground shelters at a slope of not more than 2 inches per foot for a horizontal distance of not less than 3 feet (914 mm) from the exposed portions of the shelter or unexposed portions deemed to be protected by soil cover. See Figure 305.2.2.

305.3 Other debris hazards. Lay down, rollover and collapse hazards shall be considered by the design professional when determining the location of shelters on the site.

SECTION 306
COMPONENT DESIGN AND TESTING

306.1 Shelters meeting tornado impact test requirements. Shelter envelope components meeting missile impact test requirements for tornado shelters shall be considered acceptable for hurricane shelters provided they meet structural design load requirements for hurricane shelters.

306.2 Roof and wall assemblies. Roof and wall assemblies shall meet the missile impact criteria of Section 305.1, and the pressure requirements of Section 304.1.

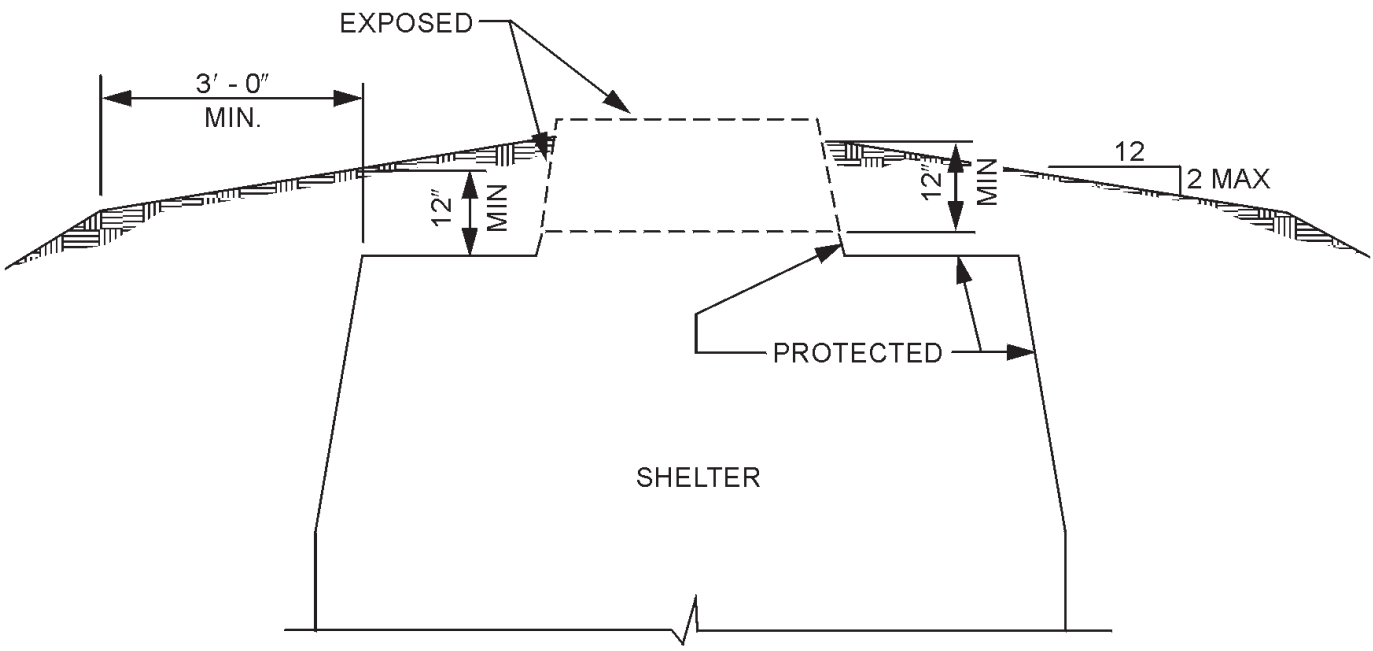
306.3 Wall and roof openings. All openings in the shelter envelope shall be protected by doors complying with Section 306.3.1, windows complying with Section 306.3.2, other opening protective device complying with Section 306.4, or baffled to prevent windborne debris from entering the shelter protected occupant area in accordance with Section 306.5.

306.3.1 Testing of shelter door assemblies. Door assemblies for use in the shelter envelope shall be tested in accordance with missile impact and pressure test procedures described in Chapter 8.

306.3.2 Testing of window assemblies and other glazed openings. Window assemblies (operable and nonoperable) and other glazed openings including skylights, side lights and transoms, shall be tested for missile impact in accordance with Section 804 and pressure in accordance with Section 805 and with cyclic pressures in accordance with ASTM E 1996.

Exceptions:

1. Missile impact testing shall not be required for window assemblies and other glazed openings where the opening is protected by a device conforming to Section 306.4 located on the exterior side of the opening.
2. Missile impact testing and pressure testing shall not be required for window assemblies and other glazed openings where the opening is protected by



For SI:: 1 inch = 25.4 mm, 1 foot = 304.8 mm.

FIGURE 305.2.2
UNDERGROUND SHELTER

a device conforming to Section 306.4 located on the interior side of the opening.

306.3.2.1 Window and skylight assemblies for tornado shelters. Window and skylight assemblies for use in tornado shelters shall comply with the missile impact requirements of Section 305.1.1 and the pressure requirements of Section 304. Window and skylight assemblies for use in tornado shelters shall be tested for missile impact in accordance with Section 804 and pressure in accordance with Sections 805.4 and 806.4.1.

306.3.2.2 Window and skylight assemblies for hurricane shelters. Window and skylight assemblies for use in hurricane shelters shall comply with the missile impact requirements of Section 305.1.2 and the pressure requirements of Section 304. Window and skylight assemblies for use in hurricane shelters shall be tested for missile impact in accordance with Section 804 and cyclic pressure test in accordance with Section 805.3, 805.4, and 806.4.2.

306.4 Opening protective devices. Opening protective devices such as shutters and protective screens shall be tested for missile impact in accordance with Chapter 8.

Exception: Nonoperable, permanently affixed shields or cowlings are excluded from pressure testing requirements of Section 806.5.

306.4.1 Opening protective devices in tornado shelters. Opening protective devices in tornado shelters shall be permanently affixed, and manually operable from inside the shelter.

306.5 Alcove or baffled entry systems. All protective elements of alcove or baffled entry systems shall be designed to meet the wind load requirements of Section 304 and the debris impact test requirements of Section 305. Where a door is employed as part of the protection in such an entry system, the door shall meet the debris impact test requirements of Section 804.9.7 and the pressure testing requirements of Sections 805 and 806.6. The enclosure classification for shelters with baffled or alcove entries shall be determined in accordance with Section 304.7.

Exception: When the entry system for a residential shelter is equipped with a door assembly that meets the pressure requirements of Section 304, the enclosure classification shall remain unchanged by the alcove or baffled entry system.

SECTION 307
WEATHER PROTECTION

307.1 Exterior cladding of hurricane shelters. All exposed components and cladding assemblies and roof coverings of hurricane shelters shall be designed to resist rainwater penetration during the design windstorm and shall be designed and installed to meet the wind load requirements of Section 304.

307.2 Electrical grounding of shelters. Exposed metal interior surfaces of shelters which are electrically grounded and electrical fixtures within shelters shall be grounded only to the host building external grounding system.

SECTION 308
SHELTERS ENCLOSED OR PARTIALLY ENCLOSED IN A HOST BUILDING

308.1 Connection of shelter elements to a host building. Where the host building does not otherwise qualify as a storm shelter under the provisions of this standard, connection of shelter elements shall be permitted to host building framing which is designed for wind forces equal to or greater than the design wind forces for the storm shelter.

308.1.1 Stability. In addition to structural stability requirements of Section 309, structural stability of a storm shelter shall also be determined for building code design wind speeds (wind speeds which are below the shelter design wind speeds) where the host building could transmit forces in connections to the storm shelter that are equal to 1.5 times the nominal strength of the connections.

308.2 Storm shelters enclosed in host buildings. Storm shelters enclosed in host buildings shall be designed and installed to meet the wind load requirements of Section 304.

SECTION 309
CONNECTION OF STORM SHELTERS TO FOUNDATIONS OR SLABS

309.1 Connection of storm shelters to foundations or slabs. Shelters shall be designed to resist the combined uplift and lateral forces resulting from the design wind speed and transfer those forces into the ground.

309.1.1 Structural stability of storm shelter foundations. Other than host buildings designed in accordance with Section 308.1.1, foundations and slabs that provide structural stability for storm shelters shall be designed to resist the combined uplift and lateral forces on the shelter that are calculated for the storm shelter design wind speed assuming the host building is totally destroyed by the windstorm.

309.1.2 Calculation of resistance. Structural stability of storm shelters shall be determined by engineering calculations for design wind pressures determined in accordance with Section 304. For storm shelters anchored to foundations or slabs on grade whose top surfaces extending outward from the shelter walls are at grade shall not be considered to have wind uplift forces acting on top surfaces of the slab.

309.1.2.1 Slabs on grade. Slabs on grade shall be designed for the applicable loads in accordance with Section 301. Where a slab on grade is being used to resist loads, the minimum thickness shall be 3 $^1/_2$ inches (88.9 mm) and the minimum steel reinforcement for slabs on grade resisting forces on the storm shelter shall be 6 by 6 – W1.4 by W1.4 or No. 4 bars, 18 inches on center in either direction.

Exception: Concrete and concrete masonry storm shelters shall be permitted to be constructed within existing one- and two-family dwellings on existing slabs on grade without a foundation, under the following conditions:

1. Calculated soil pressure under the slabs on grade supporting the storm shelter walls does not exceed 2000 psf (95.8 kN/m^2) for design loading conditions other than design storm shelter events and 3000 psf (143.7 kN/m^2) for design storm shelter events.
2. The storm shelter is anchored to the slab on grade at each corner of the structure and on each side of the doorway opening minimum.
3. The reinforcement requirements in the slab on grade are waived if dead load of the slab is not required to resist overturning.

309.1.2.2 Joints in concrete slabs on grade. Design calculations shall include the effect of expansion joints, contraction joints, or construction joints that are utilized to resist loads in concrete slabs on grade supporting storm shelters.

309.1.2.3 Elevated storm shelter foundations. Where storm shelters are constructed with the top of the supporting foundation structure located at an elevation higher than the surrounding finished grade level, the structural stability of the storm shelter and elevated supporting foundation structure shall be computed assuming that both are fully exposed to the shelter design wind and flood forces. Where applicable, and in accordance with ASCE 7, the impacts of windborne and flood-borne debris on stability of the foundation shall be considered.

SECTION 310
PENETRATIONS OF STORM SHELTER ENVELOPE BY SYSTEMS AND UTILITIES

310.1 Penetrations of storm shelter envelope by systems and utilities. Penetrations through the storm shelter envelope larger than 3 $^1/_2$ square inches (2258 mm^2) or 2$^1/_{16}$ inches (52.38 mm) for systems and utilities installed for any purpose, shall be considered openings and shall be protected in accordance with Section 306.3. Penetrations of the storm shelter envelope shall not degrade the structural integrity of the storm shelter and missile impact resistance of the storm shelter envelope.

Penetrations of the shelter envelope by hazardous gas or liquid lines shall have automatic shutoffs to protect against leakage due to movement of the utility line. The threshold movements for shutoff shall be as defined by the codes and standards governing such utility lines.