



Topic: ICC 500 Tornado and Hurricane Shelter Requirements

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Problem:

How to determine if a storm shelter opening meets requirements listed in ICC 500.

Solution:

See attached.



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.

301.1.2 Anchor calculations—doors, windows and shutters. Where anchorage of door, window or shutter framing to the shelter structure is required by means other than those provided in the manufacturer's listing or installation instructions in accordance with Section 107, alternate anchorage shall be designed for pull-out and shear and the anchor placement detailed in accordance with accepted engineering practice. The alternate anchorage details and calculations shall be provided as part of the construction documents.

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 with W determined in accordance with Section 304 of this standard. Exception 1 to ASCE 7 Section 2.3.2 shall not apply.

302.2 Allowable stress design. For allowable stress design (ASD), use the load combinations stated in ASCE 7, Section 2.4 with W determined in accordance with Section 304 of this standard.

SECTION 303 LOADS

303.1 Rain loads. Rain loads shall be determined in accordance with ASCE 7. Rainfall rates for hurricane shelter roofs shall meet the following requirements:

303.1.1. Rainfall rate. The rainfall rate shall be determined by adding 6 inches (152.4 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/m²)

Hurricane shelters: 50 pounds per square foot (2.4 kN/m²)

303.3 Hydrostatic loads. Underground portions of storm shelters shall be designed for buoyancy forces and hydrostatic loads assuming that the ground water 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 ground water level.

303.4 Flood loads. Flood loads shall be determined in accordance with ASCE 7. The design flood elevation shall equal the minimum floor elevation as specified in Section 401 of this standard.

SECTION 304 WIND LOADS

304.1 General. Wind loads shall be determined using 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 $K_d = 1.0$.

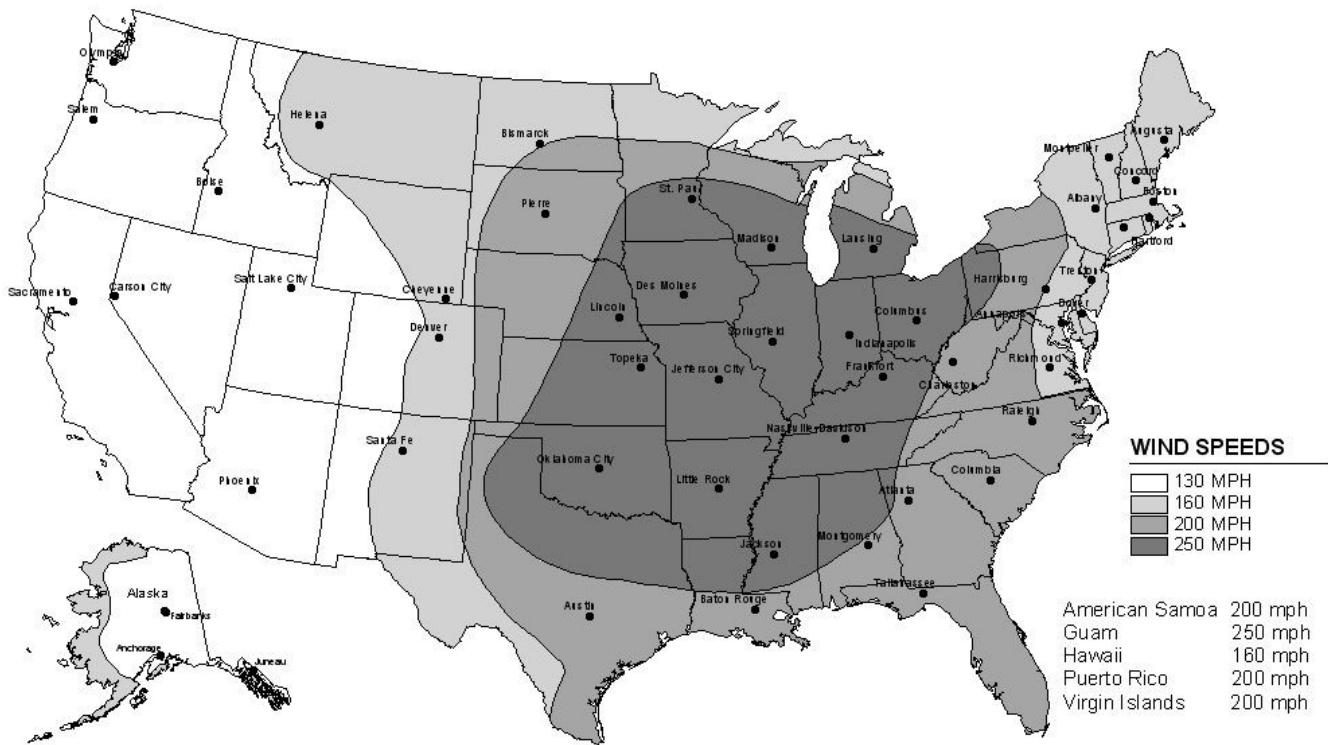
304.4 Exposure category. For tornado shelters, wind loads shall be based on exposure category C. For hurricane shelters, use of exposure category B is not permitted.

Exception: For hurricane shelters, wind loads for the main windforce-resisting system (MWFRS) only shall be permitted to be based on exposure category B, where exposure category B exists for all wind directions and is likely to remain exposure category B after a hurricane with wind speeds as determined from Section 304.2.

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

304.6 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.

304.7 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 m²) per 1,000 cubic feet (28.3 m³) 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

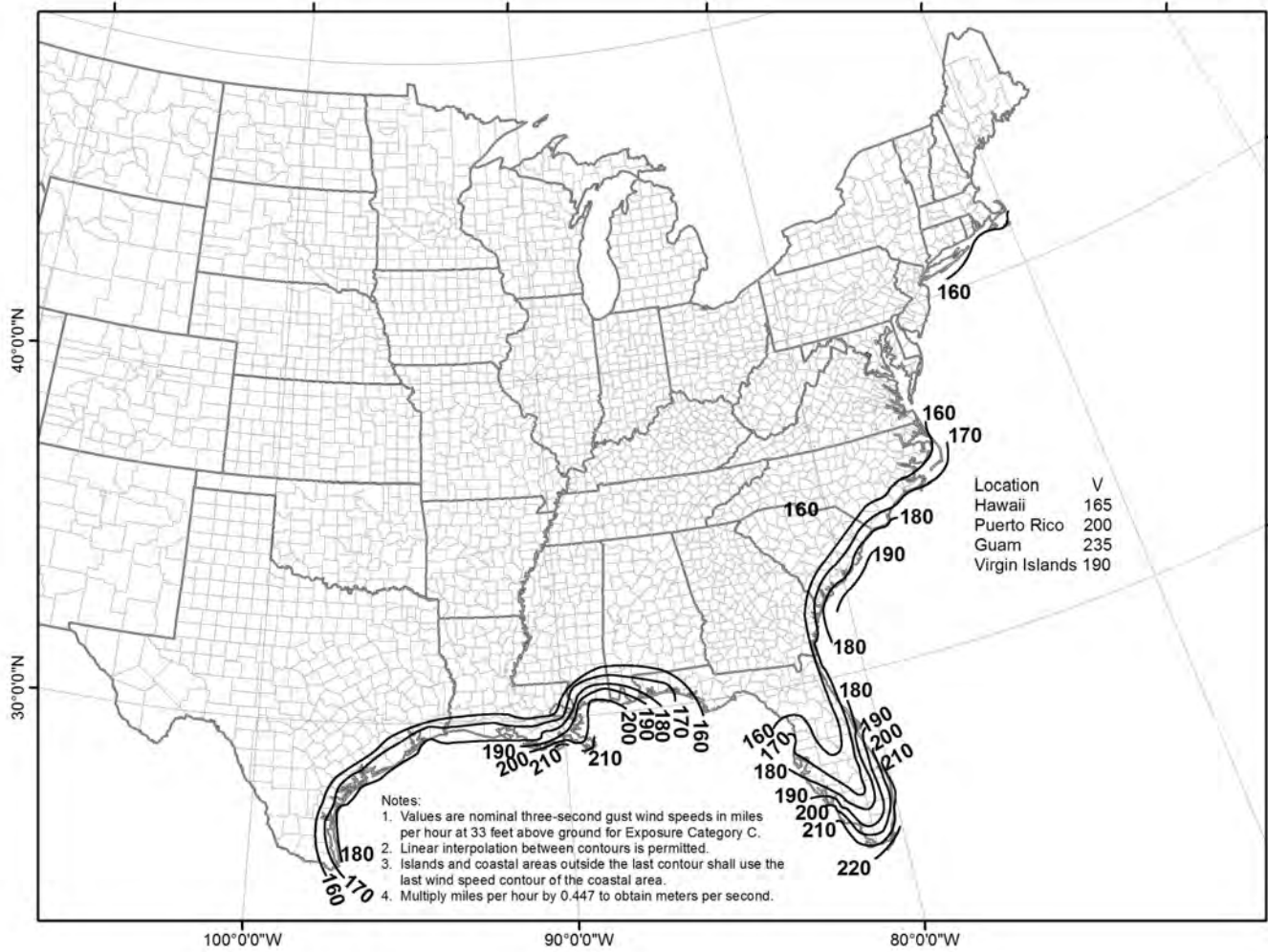


Notes:

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

STRUCTURAL DESIGN CRITERIA

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 tornado shelters classified as partially enclosed buildings. An internal pressure coefficient of $GC_{pi} = \pm 0.55$ shall be used for tornado shelters where APC venting meeting the requirements of Section 304.7 is not provided, or where APC venting area requirements are not calculated.

304.8 Shielding of storm shelters by host and adjacent buildings. Storm shelters enclosed in, partially enclosed in or adjacent to host buildings or adjacent to other buildings not designed for the load requirements of Chapter 3 shall be designed considering the host building and adjacent buildings to be destroyed and the shelter to be fully exposed.

304.9 Storm shelters connected to host buildings. Where an element or component of the host building is connected to a storm shelter, the storm shelter shall be designed to resist the maximum force that could be transmitted to the shelter equal to the ultimate failure strength of the connection or element being connected, whichever is lower, concurrent with the other wind loads on the storm shelter required by Chapter 3.

SECTION 305 DEBRIS HAZARDS

305.1 Wind-borne debris. All shelters shall be designed for the impact of wind-borne 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 × 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 0.50 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 impact-protective systems complying with Section 306.4 or baffled to prevent wind-borne 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. Operable and nonoperable windows and other glazed openings including skylights, side lights and transoms, shall be tested for missile impact in accordance with Section 804 and cyclic pressure in accordance with Section 805.

Exceptions:

1. Missile impact testing shall not be required for window assemblies and other glazed openings where

CHAPTER 8

TEST METHODS FOR IMPACT AND PRESSURE TESTING

SECTION 801 GENERAL

801.1 Scope. This testing protocol covers procedures for conducting impact and pressure testing of components of the shelter envelope required to meet wind-borne debris impact provisions, as detailed in Section 305 of this standard.

SECTION 802 TERMINOLOGY

802.1 General terminology. General terminology of building construction used in this test method is defined in ASTM E631.

802.2 Definitions of terms specific to this test method.

IMPACT-PROTECTIVE SYSTEM. A system or device such as a shutter, door or other device mounted on the inside or outside of the exterior wall of a shelter that has been demonstrated by testing to be capable of withstanding the impact of test missiles as detailed in this standard.

SPECIMEN. The entire assembled unit submitted for test, including but not limited to anchorage devices and structure to which product is to be mounted.

TEST CHAMBER. An airtight enclosure of sufficient depth to allow unobstructed deflection of the specimen during pressure cycling, including ports for air supply and removal, and equipped with instruments to measure test pressure differentials.

SECTION 803 TEST SPECIMENS

803.1 Test assembly. All parts of the test specimen shall be full size, using the same materials, details, methods of construction and methods of attachment as proposed for actual use. Testing of components consisting of wall, roof, door or window assemblies shall be allowed in lieu of testing entire shelters. Except where failure of framing members may control the impact performance, wall and roof sections subjected to debris impact testing shall be a minimum of 4 feet (1219 mm) wide by 4 feet (1219 mm) high unless dimensions of the actual assembly are less than these dimensions. Wall and roof sections subjected to pressure testing and wall sections where impact resistance may be controlled by framing members shall be a minimum of 4 feet (1219 mm) wide and the full length of the span of the wall section from support to support.

Doors, windows and impact-protective systems are to be tested at the maximum and minimum size listed for use. Operable doors or windows shall be tested for the conditions of swing and latching as specified for use of the product. The specimen shall consist of the entire assembled unit and shall, when practical, be mounted as it will be installed in a shelter, and shall contain all devices used to resist wind forces and

wind-borne debris. When it is not practical to install for testing a door or window frame as it will be mounted in a shelter, then the unit or assembly shall be mounted in a test buck to connect the specimen to the test frame/stand/chamber. Details of the mounting shall be described in the test report.

803.2 Number of test specimens. Where both pressure and impact tests are required, testing of a single specimen subjected separately to each effect or two specimens, one subject to each load effect, shall be permitted.

803.3 Specimen conditioning. Samples shall be conditioned at ambient temperature [59° to 95° F (15° to 35° C)] for a minimum of 2 hours prior to testing.

803.4 Specifications/drawings. The manufacturer or constructor shall provide the test laboratory with applicable product specifications and/or drawings detailing materials of construction and applicable installation details. The testing agency shall verify conformance of the test specimen to the product specifications and/or drawings.

SECTION 804 MISSILE IMPACT TESTING

804.1 Apparatus. The general description of the apparatus for performing the missile impact testing requirements of this standard is detailed in Section 6 of ASTM E1886. Any equipment, properly certified, calibrated and approved by a qualified lab capable of performing this test within the allowable tolerance is permitted.

804.2 Calibration. Calibration of the speed measuring system shall be performed per the procedure detailed in Section 9 of ASTM E1886.

804.3 Missile impact procedure. Test specimens shall be impact tested with test missiles of size and speed as specified in Section 305 of this standard. Impact procedure shall be performed as detailed in Sections 11.1 through 11.3 of ASTM E1886. The minimum number of impact locations shall be as detailed in Section 804.9.

804.4 Missile properties. The test missile weight shall be selected to meet the requirements of Section 305 of this standard and shall comply with Sections 804.4.1 through 804.4.3.

804.4.1 Wood species. Any common softwood lumber species as defined by DOC PS 20 shall be permitted to be used provided it meets length tolerances detailed below. The lumber shall be grade stamped No. 2 or better and be free of splits, checks, wane or other significant defects. The 2 by 4s used shall be straight such that any bow or warp measured by stretching a string or wire on the side of the board from end to end is within 0.5 inch of the 2 by 4s surface over its entire length.

804.4.2 Missile length and weight tolerance. The wood density, including moisture content, shall be such that the

804.9.2 Solid wall/roof sections of concrete or other materials. Wall and roof sections of solid concrete or other solid material shall be impacted in the center of the wall/roof section, and at one interface corner as detailed in Figures 804.9.2(1) and 804.9.2(2). When interface joints are used for joining at corners or panel-to-panel joints, an additional section shall be impacted directly on the interface joints as detailed in Figure 804.9.2(2).

Where an interior stud or support is present, additional impacts shall be performed within 3 inches (76.2 mm) of the stud/support, and directly on the stud support as detailed in Figures 804.9.2(1) and 804.9.2(2).

No more than three impacts shall be made on one specimen. Where more than three impacts are required, multiple identical test specimens shall be provided.

Exception: More than three impacts may be made on a test specimen by mutual consent of owner and test laboratory.

804.9.3 Masonry unit walls/roofs. Walls and roof sections of masonry units shall be impacted in the center of the wall/roof section, and at one interface corner or joint as detailed in Figure 804.9.3(1). Mortared joints shall be impacted directly on the interface joints as detailed in Figure 804.9.3(2).

No more than three impacts shall be made on one specimen or specimen panel. Where more than three impacts are

required, multiple identical test specimens shall be provided.

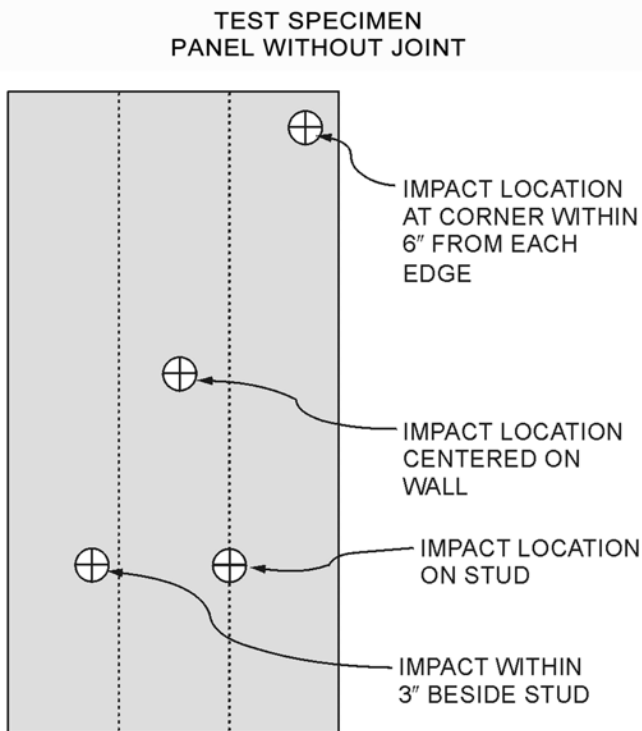
Exception: More than three impacts may be made on a test specimen by mutual consent of owner and test laboratory.

804.9.4 Windows and other glazed openings. All window assemblies and other glazed openings shall be impacted in the center of the smallest glazed section, and at one interface corner as detailed in Figure 804.9.4(1). Where interior mullions or other glazed section joints and/or latches are present, additional impacts shall be applied on these features as shown in Figure 804.9.4(2).

No more than two impacts shall be made on one specimen. Where more than two impacts are required, multiple identical test specimens shall be provided.

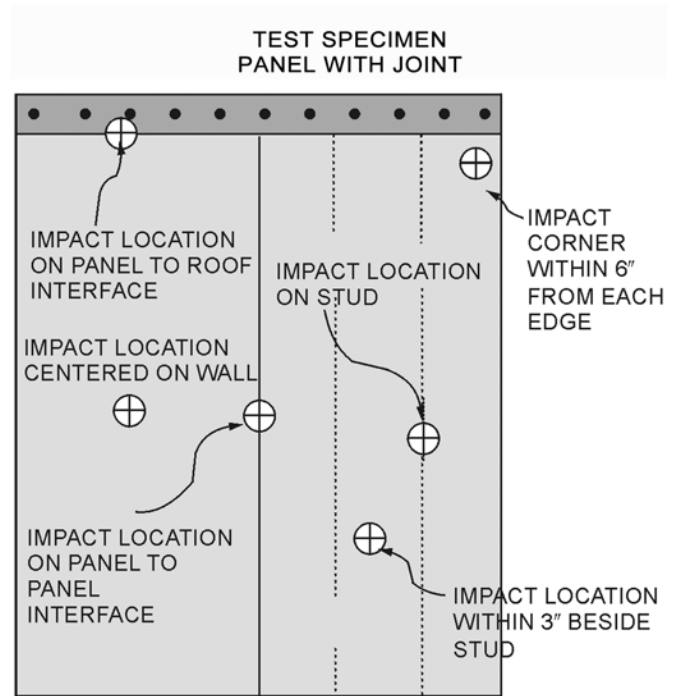
Exception: More than two impacts may be made on a test specimen by mutual consent of owner and test laboratory.

804.9.5 Doors or other entry/egress systems. All door assemblies and other entry/egress systems shall be impacted within 6 inches (152.4 mm) of an interface hinge joint, within 6 inches (152.4 mm) of an upper latch point and within 6 inches (152.4 mm) of center primary latches or operators as shown in Figure 804.9.5(1).



For SI: 1 inch = 25.4 mm.

**FIGURE 804.9.2(1)
SOLID WALLS/ROOF SECTION OF CONCRETE
OR OTHER MATERIALS**



For SI: 1 inch = 25.4 mm.

**FIGURE 804.9.2(2)
SOLID WALLS/ROOF SECTION OF CONCRETE
OR OTHER MATERIALS**

TEST METHODS FOR IMPACT AND PRESSURE TESTING

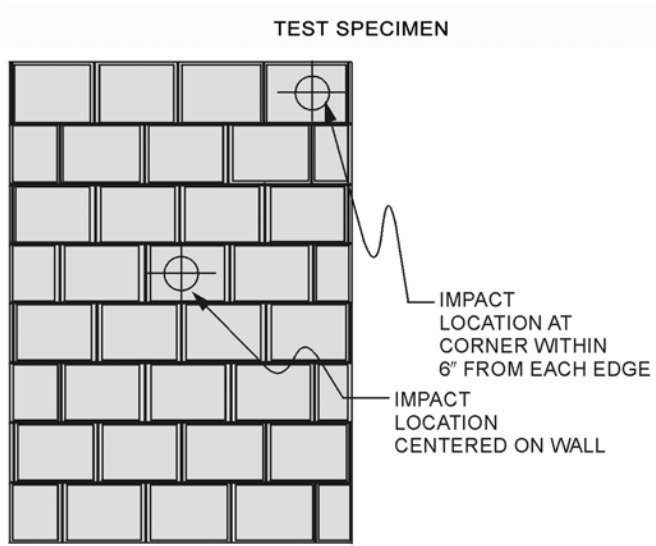


FIGURE 804.9.3(1)
MASONRY UNIT WALLS/ROOFS

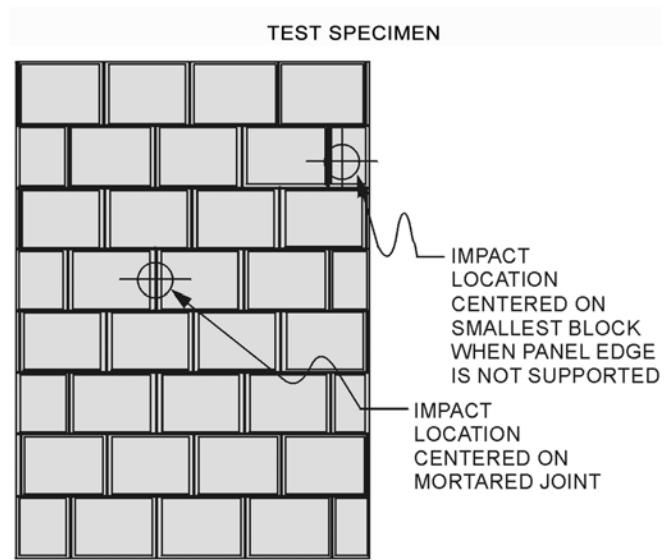


FIGURE 804.9.3(2)
MASONRY UNIT WALLS/ROOFS

For SI: 1 inch = 25.4 mm.

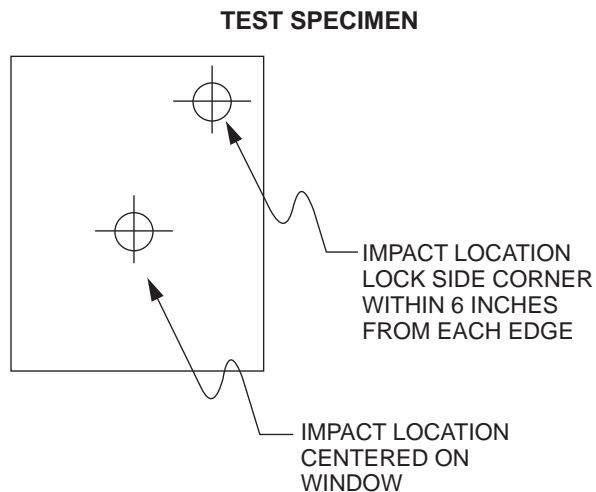


FIGURE 804.9.4(1)
WINDOWS AND OTHER GLAZED OPENINGS

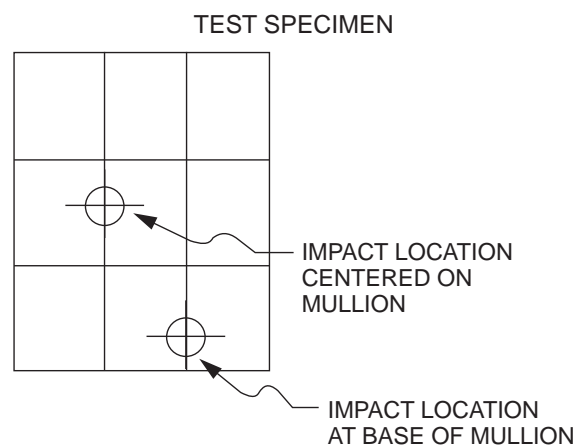


FIGURE 804.9.4(2)
WINDOWS AND OTHER GLAZED OPENINGS

For SI: 1 inch = 25.4 mm.

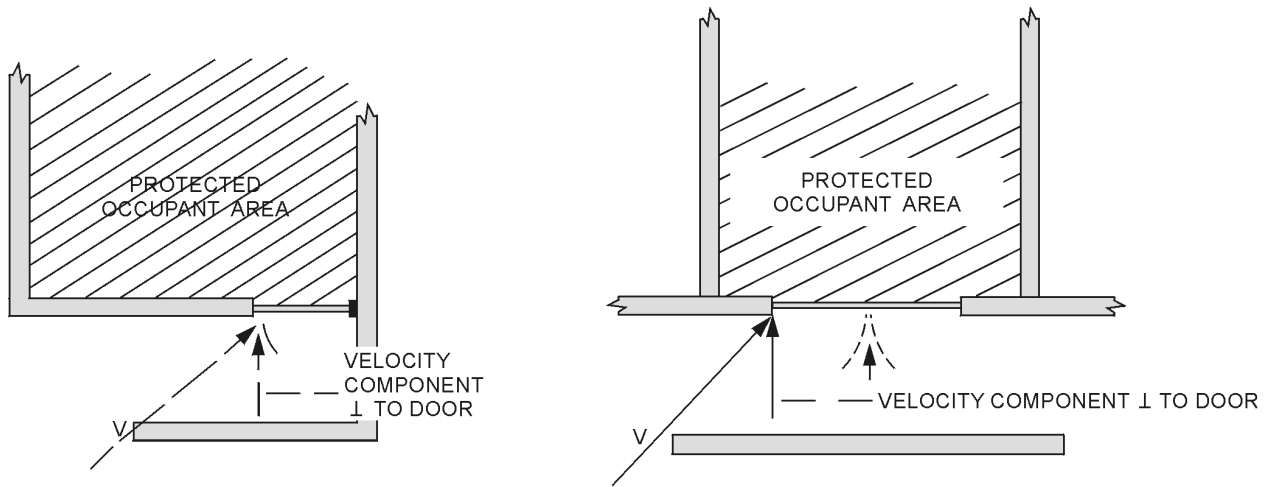


FIGURE 804.9.7.3
DOORS SUBJECT TO FIRST IMPACT

804.10.2 Dislodgment and disengagement. Specimens and load-bearing fasteners, where used, shall not become disengaged or dislodged during the test procedures so as to endanger occupants. Dislodgement that occurs in a test shall be demonstrated to be harmless by failing to perforate a #70 unbleached kraft paper witness screen with its surface secured in place on a rigid frame installed within 5 inches (127 mm) of the interior surface of the shelter component. The rigid frame shall maintain tautness of the kraft paper and shall have continuous supports in one direction at intervals no greater than 3 feet (914 mm).

804.10.3 Spall. Excessive spall shall not be released from the interior surface of any specimen. Excessive spall is defined as that which perforates a #70 unbleached kraft paper witness screen with its surface secured in place on a rigid frame 5 inches (127 mm) from the interior surface of the test specimen. The witness screen rigid frame shall maintain tautness of the kraft paper and shall have continuous supports in one direction at intervals no greater than 3 feet (914 mm).

Exception: Where warnings are to be provided marking the protected occupant area beyond the 5-inch (127 mm) limit defined above, the witness screen is permitted to be positioned at the boundary of the protected area, and excessive spall defined as that which will perforate the witness screen in this position.

804.10.4 Permanent deformation. Permanent deformation of an interior surface of the test specimen shall be determined by measuring the distance from a straight edge held between two undeformed points on the specimen. The maximum permanent deformation shall be measured to the nearest $\frac{1}{8}$ inch (3.2 mm) and shall not exceed 3 inches (76.2 mm).

SECTION 805 PRESSURE TESTING

805.1 Apparatus. The general description of the apparatus for performing the pressure testing requirements of this standard is detailed in Section 6 of ASTM E330 when performing the static pressure test, or ASTM E1886 when performing the cyclic test. Any equipment, properly certified, calibrated and approved by a qualified lab, capable of performing this test, within the allowable tolerance, is permitted.

805.2 Calibration. Calibration of the pressure measuring system shall be performed in accordance with the procedure detailed in Section 9 of ASTM E330 or ASTM E1886.

805.3 Cyclic pressure testing after impact. Test specimens requiring cyclic pressure testing to establish the ability to meet the wind pressure requirements set forth in Section 304 of this standard shall be cyclic tested using the loading sequence detailed in ASTM E1886 specified to the design wind pressure as defined in Section 304.1. Pressure testing procedures shall be performed as detailed in Sections 11.1 through 11.2.11 of ASTM E1886.

805.4 Testing temperature. The testing shall be conducted at room temperature in the range of 59°F (15°C) to 95°F (35°C).

SECTION 806 PRESSURE TESTING PROCEDURES

806.1 Pressure testing procedures. Procedures for pressure testing wall assemblies, roof assemblies, door assemblies, window assemblies and impact-protective systems requiring pressure testing are presented in this section.

806.2 Roof and wall assemblies. When testing of roof and wall assemblies is required, they shall be pressure tested in the as-supplied condition. Required pressure testing shall be

done as detailed in ASTM E330 to a pressure equal to or higher than 1.2 times the pressures specified in Section 304.

806.3 Door assemblies. Door assemblies shall be pressure tested in the as-supplied condition and, when required, they shall be static pressure tested or cyclically tested as specified in the following sections:

806.3.1 Door assemblies without glazing. Door assemblies without glazing that require testing to meet the qualification of Section 306.3 shall be pressure tested according to procedures specified in this section.

806.3.1.1 Door assemblies without glazing for tornado shelters. Door assemblies without glazing for use in tornado shelters shall be static pressure tested away from the door stops to a pressure of at least 1.2 times the pressures specified in Section 304. Pressure tests are permitted to be conducted separately from missile impact tests.

806.3.1.2 Door assemblies without glazing for hurricane shelters. Door assemblies without glazing for use in hurricane shelters shall be static pressure proof tested away from the door stops to a pressure of at least 1.2 times the design wind pressure, then subjected to required debris impact tests, and then to cyclic pressure tests following procedures of ASTM E1886.

Alternatively, door assemblies without glazing for hurricane shelters shall be statically pressure tested away from the door stops to a pressure of 1.5 times the design wind pressure before impact tests and then to required debris impact tests. Cyclic pressure testing after impact tests is not required for these door assemblies that have been pressure tested to pressures equal to or greater than 1.5 times the design wind pressure.

806.3.2 Door assemblies with glazing, sidelights or transoms. Door assemblies with glazing, sidelights or transoms shall be pressure tested according to procedures specified in this section. Where glazed openings are present, with a size of less than or equal to 12 inches by 12 inches (304.8 mm by 304.8 mm), an additional sample shall be impacted in the center of the glazed opening in accordance with Section 804 and cyclic pressure tested as detailed in Section 805.3. Where glazed openings have a dimension greater than 12 inches (304.8 mm), the glazed opening shall be treated as a window and tested in accordance with Section 806.5 of this standard.

806.3.2.1 Door assemblies with glazing, sidelights or transoms for tornado shelters. Door assemblies with glazing, sidelights or transoms for tornado shelters shall be static pressure tested away from the door stops following procedures of ASTM E330 to a pressure of at least 1.2 times the pressures specified in Section 304. Pressure tests are permitted to be conducted separately from debris impact tests.

806.3.2.2 Door assemblies with glazing, sidelights or transoms for hurricane shelters. Door assemblies with glazing, sidelights or transoms for hurricane shelters shall be static pressure proof tested away from the door stops to a pressure of at least 1.2 times the design

wind pressure. Any required debris impact tests shall follow pressure proof testing. After impact tests the door assembly shall be subjected to cyclic pressure tests following procedures of ASTM E1886.

806.4 Window assemblies and other glazed openings. Window assemblies and other glazed openings shall be pressure tested according to procedures specified in this section.

806.4.1 Window assemblies and other glazed openings for tornado shelters. Window assemblies and other glazed openings for tornado shelters shall be static pressure tested away from stops to a pressure of at least 1.2 times the design wind pressure following procedures detailed in ASTM E330. Pressure tests are allowed to be conducted separately from debris impact tests.

806.4.2 Window assemblies and other glazed openings for hurricane shelters. Window assemblies and other glazed openings for hurricane shelters shall be static pressure tested away from stops to a pressure of at least 1.2 times the design wind pressure. Any required debris impact tests shall follow pressure proof testing. After impact tests the window assembly shall be subjected to cyclic pressure tests following procedures of ASTM E1886.

806.5 Impact-protective systems. External impact-protective systems shall be tested for the ability to withstand prescribed pressures if withstanding pressure is critical to their function when installed. Devices such as nonoperable, permanently affixed shields or cowlings whose only function is to protect against debris intrusion need not be pressure tested when the shields or cowlings have been designed and anchored to resist the design loads as determined in this standard.

806.5.1 Impact-protective systems for tornado shelters. External impact-protective systems for tornado shelters whose ability to withstand wind-induced pressure when installed is critical to their function shall be static pressure tested following procedures specified in ASTM E330 to a pressure of at least 1.2 times the pressures specified in Section 304. Debris impact tests and pressure tests are permitted to be conducted separately.

Exception: Impact-protective systems with a jamb or stop need to be tested with pressure only away from the stop.

806.5.2 Opening protective devices for hurricane shelters. External protective devices for hurricane shelters whose ability to withstand wind-induced pressure when installed is critical to their function shall be static pressure tested to a pressure of at least 1.2 times the shelter design wind pressures specified in Section 304 following the procedures specified in ASTM E330. Cyclic pressure tests conducted in accordance with Section 805.5 shall be conducted after debris impact tests.

806.6 Alcove or baffled entry systems. Any element of the entry system whose ability to resist wind-induced pressure is critical to the function of the entry system shall be designed to meet the requirements of Section 304 or shall be pressure tested in accordance with Section 806.