

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

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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.

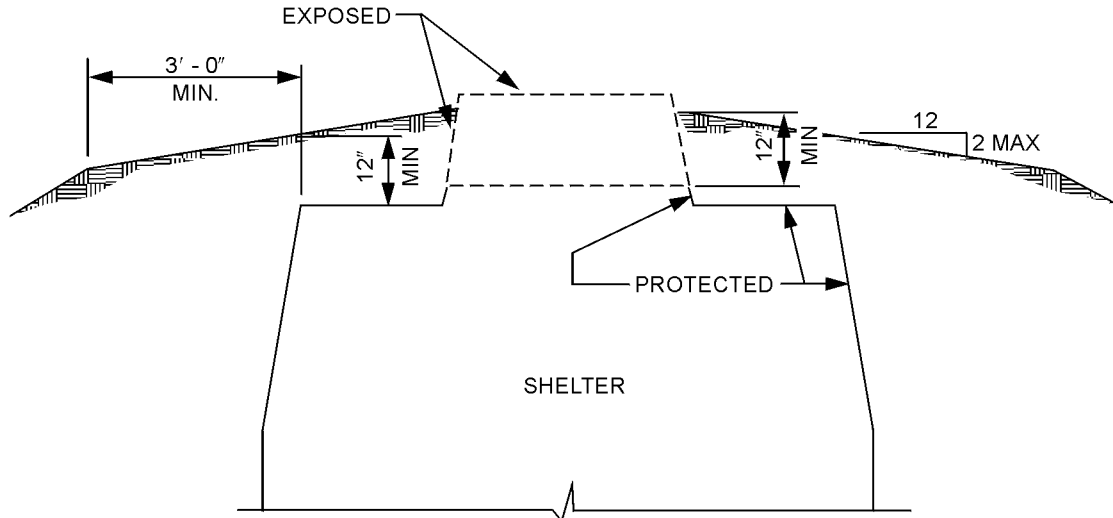
306.3 Wall and roof openings. All openings in the shelter envelope shall be protected by doors complying with Section 306.3.1, windows complying with Section 306.3.2, other impact-protective systems complying with Section 306.4 or baffled to prevent wind-borne debris from entering the shelter protected 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



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

FIGURE 305.2.2
UNDERGROUND SHELTER

the opening is protected by a device conforming to Section 306.4 located on the exterior side of the opening.

- Missile impact testing and pressure 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 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 805.3 and 805.4.

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 in accordance with Section 805.4.

306.4. Impact-protective systems. Impact-protective systems 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 Impact-protective systems in tornado shelters. Impact-protective systems in tornado shelters shall be per-

manently affixed. All operable impact-protective systems shall be 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 304.6.

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.

306.6 Anchorage of 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.

306.7 Door undercut. Door or shutter assemblies for use in the shelter envelope with a threshold at the level of exit discharge shall be limited to a $\frac{3}{4}$ -inch (19.1 mm) maximum undercut. A weather seal at the door undercut where doors are exposed to weather shall be provided.

306.8 Joints, gaps or voids in shelter envelope. Joints, gaps or voids in a shelter envelope that opens into the protected

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occupant area similar to masonry control joints, expansion joints, opening protective device shim spaces, air louver blades, grates, grilles, screens or precast panel joints shall be considered openings and shall be protected in accordance with Sections 306.3 and 306.4.

Exceptions:

1. Masonry control joints, masonry or concrete expansion joints or precast concrete panel joints $\frac{3}{8}$ -inch (9.5 mm) or less in width, sealed with joint material in accordance with TMS 602 for masonry or ASTM C920 for concrete.
2. Joints, gaps or voids that will not allow a direct debris path through the shelter envelope into the protected occupant area. Debris shall impact at least two surfaces meeting the missile impact criteria of Section 305.1 prior to arriving at the protected occupant area. Straight missile paths and elastic impacts are assumed in determining missile trajectories.

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.

Exception: Residential shelters that are fully enclosed in a host building constructed in compliance with the local building code.

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

SECTION 308 CONNECTION OF STORM SHELTERS TO FOUNDATIONS OR SLABS

308.1 Connections of storm shelters to foundations or slabs. Shelters shall be designed to resist all loads specified in Chapter 3 and to transfer the resultant forces into the ground.

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

308.1.1.1 Slabs-on-grade. New or existing slabs-on-grade shall be designed for the applicable loads in accordance with Section 301; however, the minimum

thickness shall be $3\frac{1}{2}$ inches (88.9 mm) and the minimum steel reinforcement for slabs-on-grade resisting forces on the storm shelter shall be $6 \times 6 - W1.4 \times W1.4$ welded wire reinforcement over the required area of slab or No. 4 bars, at a maximum spacing of 18 inches (457 mm) on center, in two perpendicular directions.

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 shall not exceed 2000 psf (95.8 kN/m²) for design loading conditions other than design storm shelter events and 3000 psf (143.7 kN/m²) for design storm shelter events.
2. The storm shelter is anchored at a minimum to the slab-on-grade at each corner of the structure and on each side of the doorway opening.
3. Reinforcing in the slab-on-grade shall not be required where the dead load of the slab is not required to resist overturning.

308.1.1.2 Joints in concrete slabs-on-grade. Design calculations for concrete slabs-on-grade supporting storm shelters shall include the effect of expansion joints, contraction joints or construction joints where such slabs-on-grade are utilized to resist tensile and shear loads from the supported storm shelters.

308.1.1.3 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 wind-borne and flood-borne debris on stability of the foundation shall be considered.

SECTION 309 PENETRATIONS OF STORM SHELTER ENVELOPE BY SYSTEMS AND UTILITIES

309.1 Penetrations of storm shelter envelope by mechanical, electrical and plumbing systems. Penetrations through the storm shelter envelope of mechanical, electrical and plumbing systems, including piping and utility lines, larger than $3\frac{1}{2}$ square inches (2258 mm²) in area for rectangular penetrations or $2\frac{1}{16}$ inches (52.38 mm) in diameter, 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.



For SI: 1 inch = 25.4 mm.

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