CHAPTER 3
STRUCTURAL DESIGN AND TESTING CRITERIA

SECTION 301
GENERAL

301.1 Scope. The requirements of this chapter shall govern the structural design and testing criteria of *storm shelters*.

301.2 General design requirements. *Storm shelters* shall be designed to resist the loads and load combinations as prescribed by this chapter in addition to the loads and load combinations prescribed in the *applicable code*.

301.3 General testing requirements. Where the capacity of *storm shelter envelope* components cannot be determined by engineering calculations in accordance with Section 301.2, it shall be determined through testing in accordance with Section 306.

301.4 Performance-based design for tornado loads. Where tornado loads are determined using a performance-based procedure, the tornado loads shall be in accordance with ASCE 7, Section 32.1.3, providing loads are not lesser in magnitude than required by this chapter.

301.5 Performance-based design for wind loads. Where wind loads are determined using a performance-based procedure, the wind loads shall be in accordance with ASCE 7, Section 26.1.3, providing loads are not lesser in magnitude than required by this chapter.

SECTION 302
LOAD COMBINATIONS

302.1 General. The *storm shelter* shall be designed to resist the load combinations specified in Section 302.2 or 302.3. *Storm shelters* that are designed as combination tornado and *hurricane shelters* shall comply with requirements for both sets of load combinations using either Section 302.2 or 302.3.

302.2 Strength design. Where strength design or load and resistance factor design (LRFD) is used, *storm shelters* and portions thereof shall be designed to resist the most critical effects resulting from the following combinations of factored loads. Each load combination shall also be investigated with one or more of the variable loads set to zero.

For *tornado shelters*:

$1.2D + 1.6L_T + 0.5L_{rT}$ **(Equation 3-1)**

$1.2D + 1.6L_{rT} + (L_T \text{ or } 0.5W_T)$ **(Equation 3-2)**

$1.2D + 1.0W_T + L_T + 0.5L_{rT}$ **(Equation 3-3)**

$0.9D + 1.0W_T$ **(Equation 3-4)**

For *hurricane shelters*:

$1.2D + 1.6L + 0.5(L_{rH} \text{ or } 1.0R_H)$ **(Equation 3-5)**

$1.2D + (1.6L_{rH} \text{ or } 1.0R_H) + (L \text{ or } 0.5W_H)$ **(Equation 3-6)**

$1.2D + 1.0W_H + L + 0.5(L_{rH} \text{ or } 1.0R_H)$ **(Equation 3-7)**

$0.9D + 1.0W_H$ **(Equation 3-8)**

In addition, for *hurricane shelters* subject to the requirements of Section 402.1 and located in:

Coastal high-hazard area or a *Coastal A Zone:*

$1.2D + 1.0W_H + 2.0F_{aH} + L + 0.5(L_{rH} \text{ or } 1.0R_H)$ **(Equation 3-9)**

$0.9D + 1.0W_H + 2.0F_{aH}$ **(Equation 3-10)**

All other locations:

$1.2D + 0.5W_H + 1.0F_{aH} + L + 0.5(L_{rH} \text{ or } 1.0R_H)$ **(Equation 3-11)**

$0.9D + 0.5W_H + 1.0F_{aH}$ **(Equation 3-12)**

302.3 Allowable stress design. Where allowable stress design (ASD, working stress design) is used, *storm shelters* and portions thereof shall be designed to resist the most critical effects resulting from the following combinations of loads. Each load combination shall also be investigated with one or more of the variable loads set to zero.

For *tornado shelters*:

$D + L_T$ **(Equation 3-13)**

$D + L_{rT}$ **(Equation 3-14)**

$D + 0.75L_T + 0.75L_{rT}$ **(Equation 3-15)**

$D + 0.6W_T$ **(Equation 3-16)**

$D + 0.75L_T + 0.75(0.6W_T) + 0.75L_{rT}$ **(Equation 3-17)**

$0.6D + 0.6W_T$ **(Equation 3-18)**

For *hurricane shelters*:

$D + (L_{rH} \text{ or } 0.7R_H)$ **(Equation 3-19)**

$D + 0.75L + 0.75(L_{rH} \text{ or } 0.7R_H)$ **(Equation 3-20)**

$D + 0.6W_H$ **(Equation 3-21)**

$D + 0.75L + 0.75(0.6W_H) + 0.75(L_{rH} \text{ or } 0.7R_H)$ **(Equation 3-22)**

$0.6D + 0.6W_H$ **(Equation 3-23)**

In addition, for *hurricane shelters* subject to the requirements of Section 402.1 and located in:

Coastal high-hazard area or a *Coastal A Zone:*

$D + 0.6W_H + 1.5F_{aH}$ **(Equation 3-24)**

$D + 0.75L + 0.75(0.6W_H) + 0.75(L_{rH} \text{ or } 0.7R_H) + 1.5F_{aH}$ **(Equation 3-25)**

$0.6D + 0.6W_H + 1.5F_{aH}$ **(Equation 3-26)**

All other locations:

$D + 0.75L + 0.75(0.6W_H) + 0.75(L_{rH} \text{ or } 0.7R_H) + 0.75F_{aH}$ **(Equation 3-27)**

$0.6D + 0.6W_H + 0.75F_{aH}$ **(Equation 3-28)**

SECTION 303
LOADS

303.1 Rain loads. Rain loads shall be determined in accordance with the *applicable code*.

303.1.1. Rainfall rate. For *hurricane shelter* roofs the rainfall rate shall be determined by adding 6 inches (152 mm) of rainfall per hour to the 100-year, 1-hour rainfall rate. The 100-year, 1-hour rainfall rate shall be determined from Figures 303.1.1(1) through 303.1.1(5) or *approved* local weather data.

303.2 Floor live loads. *Community tornado shelter* floors shall be designed for not less than the minimum uniform live loads for assembly occupancies in accordance with the *applicable codes*. *Community hurricane shelter* floors shall be designed for not less than the minimum uniform live load for the normal occupancy of the space.

303.3 Roof live loads. *Storm shelter* roofs shall be designed for minimum live loads specified in the *applicable code*, 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)

Where a *storm shelter* roof is subject to *laydown* or *falling debris hazards*, roof live loads shall also comply with Section 305.3.

303.3.1 Wheel loads. *Storm shelters* subject to vehicle loads shall be designed for vehicle loads in accordance with Section 1607 of the *International Building Code*, Section R301.5 of the *International Residential Code* or Section 4.10 of ASCE 7, as applicable.

303.4 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.

303.5 Flood loads. Where subject to the requirements of Section 402.1, *flood loads*, including wave action, shall be determined using a *flood elevation* not less than the minimum floor elevation in Section 402.6.

SECTION 304
TORNADO LOADS AND WIND LOADS

304.1 General. Tornado loads, W_T, wind loads for hurricanes, W_H, and wind loads for storms in Alaska, W_H, shall be determined in accordance with ASCE 7, Chapters 26 through 32, except as modified by this section. For tornado loads, the procedures from ASCE 7, Section 32.1.2 shall be applicable.

304.2 Design tornado speed. For *tornado shelters*, the design tornado speed, V_T, shall be in accordance with Figure 304.2.

304.3 Design wind speed. For *hurricane shelters*, the design wind speed, V_H, shall be in accordance with Figures 304.3(1) through 304.3(3). For *storm shelters* in Alaska, the design wind speed, V_H, shall be in accordance with Figure 304.3(4).

304.4 Tornado and wind directionality factors. The directionality factors for tornado loads, K_{dT} and the directionality factors for wind loads, K_d, shall be taken as 1.0.

304.5 Exposure category. For *hurricane shelters* that are located in Exposure Category B in accordance with ASCE 7, Section 26.7, Exposure C shall be used.

Exception: Wind loads for the main wind force-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 design wind speeds as determined from Section 304.3.

304.6 Enclosure classifications. Enclosure classifications for *storm shelters* shall be determined in accordance with ASCE 7, Chapter 26. For determining the enclosure classification for *community storm shelters*, the largest opening protected by an *impact-protective system* on a wall that receives positive external pressure shall be considered as an opening.

304.7 Tornado internal pressure coefficient for enclosed buildings. For *tornado shelters* classified as enclosed buildings, the internal pressure coefficient, GC_{piT}, shall be taken as ±0.18 where atmospheric pressure change (APC) venting area of 1 square foot (0.0929 m^2) per 1,000 cubic feet (28.3 m^3) of interior *storm shelter* volume is provided. APC venting shall consist of openings in the *storm shelter* roof having a pitch 10 degrees or less 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: An internal pressure coefficient of GC_{piT} = ±0.55 shall be used for *tornado shelters* where APC venting meeting the requirements of Section 304.7 is not provided.

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 for wind loads considering the *host building* and adjacent buildings to be destroyed and the *storm shelter* to be fully exposed.

304.9 Storm shelters connected to host buildings. Where a structural element 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 *storm 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 *storm shelters* shall be designed for the impact loads of wind-borne debris in accordance with Section 305.1.1 through 305.2.2.

305.1.1 Missile criteria for tornado shelters. The missile testing for all components of the *storm 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
MISSILE SPEED FOR TORNADO SHELTERS

DESIGN TORNADO SPEED	MISSILE SPEED AND 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 test missile for all components of the *storm 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 *storm shelter* surfaces shall be a minimum of 0.50 times the design wind speed. The speed of the test missile impacting horizontal surfaces shall be 0.10 times the design wind speed.

305.2 Testing for impacts. All components of the *storm shelter envelope* shall be tested for impact in accordance with Section 306 following the test procedures of Section 803.

Exception: Floors of the *storm shelter envelope* are not required to be tested for impact.

305.2.1 Inclined surfaces. *Storm shelter envelope* surfaces inclined 30 degrees (0.52 rad) or more from the horizontal shall be considered vertical surfaces. *Storm shelter envelope* surfaces inclined less than 30 degrees (0.52 rad) from the horizontal shall be considered horizontal surfaces.

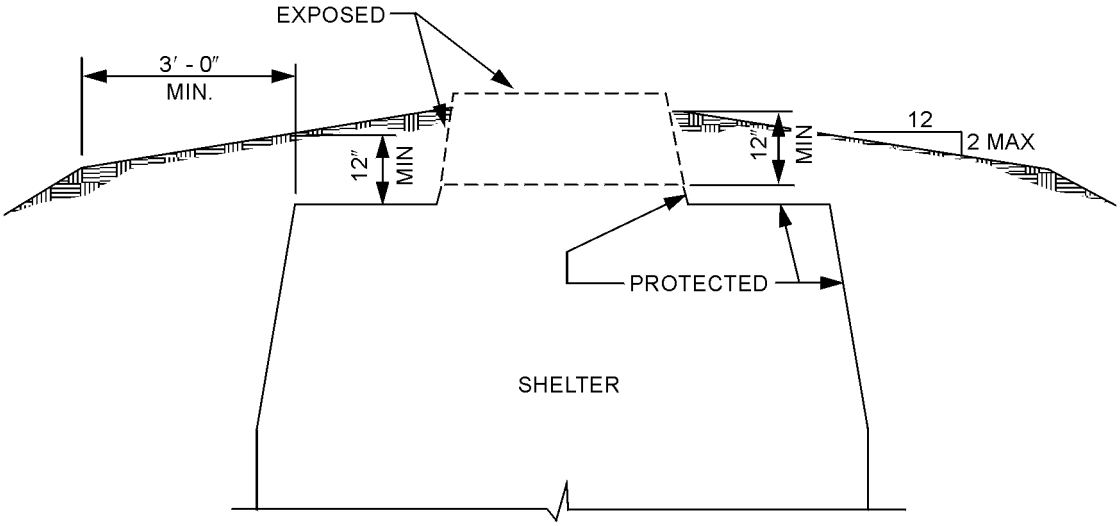
305.2.2 Soil-covered portions of storm shelters. Portions of soil-covered *storm shelters*, with less than 12 inches (305 mm) of soil cover protecting *storm shelter* horizontal surfaces, or with less than 36 inches (914 mm) of soil cover protecting *storm shelter* vertical surfaces, shall be tested for resistance to impact 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 *storm shelters* at a slope of not more than 2 inches per foot (167 mm/m) for a horizontal distance of not less than 3 feet (914 mm) from the exposed portions of the *storm shelter* or unexposed portions deemed to be protected by soil cover. See Figure 305.2.2 for an example.

305.3 Laydown and falling debris hazards. Where the roof of the *storm shelter* is within the laydown radius of a *laydown hazard* or the fall radius of a *falling debris hazard*, the *storm shelter* shall be designed to resist the impact loads from such hazards.

305.3.1 Laydown radius. The laydown radius shall be taken as the horizontal distance equal to the height of the *laydown hazard*.

305.3.2 Fall radius. The fall radius shall be taken as the horizontal distance equal to half the difference between the height of the *falling debris hazard* and the height of the roof of the *storm shelter* but need not exceed 30 feet (9144 mm).

305.3.3 Impact loads. Impact loads from *laydown* and *falling debris hazards* shall be determined using a minimum impact factor of 2.0 times the estimated weight of the debris hazard. Each *laydown* and *falling debris hazard* load shall be considered one at a time, applied simultaneously with the uniform live loads on the roof of the shelter in accordance with Section 303.3.



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

FIGURE 305.2.2
UNDERGROUND STORM SHELTER

SECTION 306
STORM SHELTER ENVELOPE COMPONENT DESIGN AND TESTING

306.1 Storm shelters meeting tornado impact test requirements. *Storm shelter envelope* components meeting impact test requirements for *tornado shelters* at the 250 mph (111.8 m/s) design tornado speed in accordance with Section 305.1.1 shall be considered acceptable for the impact test requirements for *hurricane shelters* provided the components meet the structural design load requirements for *hurricane shelters*.

306.2 Fire-resistance rating. The *storm shelter envelope* shall be fire-resistance rated in accordance with Section 603 and the *applicable code*.

306.3 Roof and wall assemblies. Roof and wall assemblies shall meet the impact criteria of Section 305.1, and the *design tornado pressure* and *design wind pressure* in accordance with Section 304.

306.4 Roof and wall openings. All openings in the *storm shelter envelope* shall be protected in accordance with Sections 306.4.1 through 306.4.4.2.2, as applicable.

306.4.1 Impact-protective systems. *Impact-protective systems* for use in the *storm shelter envelope* shall be tested, *listed* and *labeled* for impact in accordance with Section 803 and static and cyclic pressure in accordance with Sections 804 and 805. Any changes to *listed impact-protective systems,* such as a change of glazing, shall require evaluation by the listing agency or retesting of the entire assembly.

Exceptions:

1. Window assemblies and other glazed openings where the opening is protected on the exterior side by an *impact-protective system* are not required to be tested for impact.
2. Window assemblies and other glazed openings where the opening is protected on the interior side by an *impact-protective system* are not required to be tested for impact and static and cyclic pressure.
3. Nonoperable, permanently affixed shields or cowlings designed to resist the *design tornado pressure* or *design wind pressures* are not required to be tested for static and cyclic pressure in accordance with Sections 804 and 805.

306.4.1.1 Listing and labeling. *Impact-protective systems* shall be *listed* and *labeled* denoting compliance with this standard.

306.4.1.1.1 Marking. The following function and performance characteristics shall be provided on the *label* for each *impact-protective system* tested:

1. Manufacturer's identification reference or listing number for the assembly
2. Type of *impact-protective system,* such as window assembly, door assembly, shutter assembly or louver.
3. Hazard: hurricane, tornado or both.
4. Missile weight and speed.
5. *Design tornado pressure, design wind pressure,* or both.
6. Edition of ICC 500.

306.4.1.2 Installation. *Impact-protective systems* shall be installed in accordance with the manufacturer's listing and installation instructions.

306.4.1.3 Alternate anchorage for impact-protective systems. Where anchorage of *impact-protective systems* to the *storm shelter* structure is required by means other than those provided in the manufacturer's *listed* system, anchorage shall be designed for pull-out and shear to resist the tornado and wind loads in accordance with Section 304.

306.4.1.4 Impact-protective systems in tornado shelters. *Impact-protective systems* in *tornado shelters* shall be permanently affixed. All operable *impact-protective systems* shall include manual, nonpowered, deployment operation capabilities from inside the *storm shelter*.

306.4.1.5 Door undercut. Door assemblies in the *storm shelter envelope* shall be limited to a $^{3}/_{4}$-inch (19 mm) maximum undercut. (See example in Figure 306.4.1.5).

The gap at the meeting edge of a pair of side-swinging doors in the *storm shelter envelope* shall be $^{3}/_{16}$ inch (4.8 mm) maximum.

306.4.1.6 Louvers. Louvers shall be tested in accordance with Section 803.9.6 and shall be designed or configured such that debris particles shall impact at least two surfaces of the louver before passing through the *storm shelter envelope* and into the *protected occupant area*. Straight debris particle paths and elastic impacts are assumed in determining debris particle trajectories.

306.4.2 Alcove or baffled storm shelter entry systems. All protective elements of *alcove or baffled storm shelter entry systems* shall be tested for impact in accordance with Section 803.9.7.

306.4.3 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 $3^{1}/_{2}$ square inches (2258 mm^2) in area for rectangular penetrations or $2^{1}/_{2}$ inches (64 mm) in diameter for circular penetrations, shall be considered openings and shall be protected in accordance with Section 306.4. Penetrations of the *storm shelter envelope* shall not degrade the structural integrity of the *storm shelter* and impact resistance of the *storm shelter envelope*.

306.4.4 Joints, gaps or voids in storm shelter envelope. Joints, gaps or voids in a *storm shelter envelope* that open into the *protected occupant area* shall be considered openings and comply with the following:

1. Joints, gaps or voids shall be protected by permanent opening protection as *approved* by the engineer of record and the *authority having jurisdiction.*

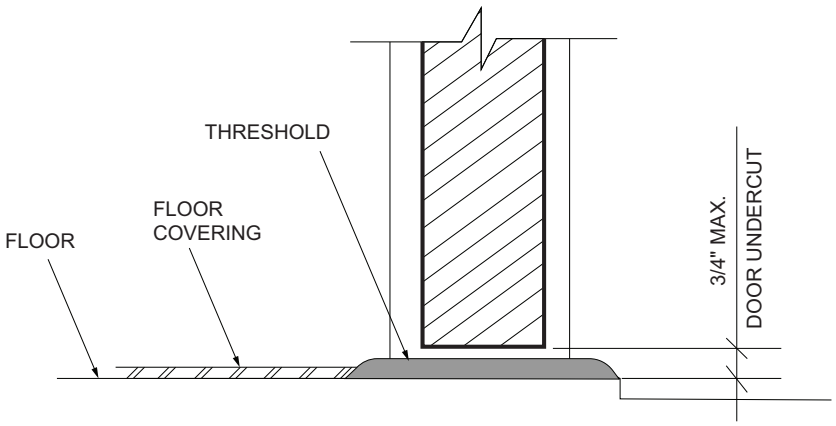


FIGURE 306.4.1.5
DOOR UNDERCUT

2. Joints, gaps or voids shall not allow a direct debris path through the *storm shelter envelope* into the *protected occupant area*. Debris particles shall impact at least two surfaces meeting the impact criteria of Section 305.1 prior to arriving at the *protected occupant area*. Straight debris particle paths and elastic impacts are assumed in determining debris particle trajectories.
3. Joints, gaps or voids that do not meet Item 1 or 2 shall comply with Section 306.4.1.5, 306.4.4.1 or 306.4.4.2.

306.4.4.1 Masonry control and expansion joints. Masonry control and expansion joints shall be a maximum of $^1/_2$ inch (12.7 mm) in width and shall be sealed with joint material that complies with TMS 602 for masonry or ASTM C920 for concrete.

306.4.4.2 Precast concrete construction joints. Precast concrete panel joints shall comply with Section 306.4.4.2.1 or 306.4.4.2.2.

306.4.4.2.1 Precast concrete wall panels. For wall panels 6 inches (152 mm) in thickness or greater, joints shall be a maximum of $^3/_4$ inch (19 mm) in width and shall be sealed on each face with a Type S joint material that complies with ASTM C920. The panel thickness shall be measured perpendicular to the joint and at 1 inch (25 mm) or less from the joint center.

306.4.4.2.2 Precast concrete roof panels. For roof panels 4 inches (102 mm) in thickness or greater, joints shall be a maximum of $^3/_4$ inch (19 mm) in width and shall be sealed on each face with a Type S joint material in accordance with ASTM C920. The panel thickness shall be measured perpendicular to the joint and at 1 inch (25 mm) or less from the joint center.

SECTION 307
CONNECTION OF STORM SHELTERS TO FOUNDATIONS OR SLABS

307.1 Connections of storm shelters to foundations systems. *Storm shelters* shall be designed to resist all loads specified in Chapter 3 and to transfer the resultant forces from their point of origin through the structure to the foundation system. Foundation shall be designed to transmit the resulting loads to the supporting soil. Anchorage to concrete foundation systems shall be in accordance with ACI 318.

307.1.1 Calculation of resistance. Structural stability of *storm shelters* shall be determined by engineering calculations for design tornado and wind loads. Where *storm shelters* are anchored to foundation systems and such top surfaces extending outward from the *storm shelter* walls are at grade, the top surfaces of the foundation systems shall not be considered to have wind uplift forces acting on them.

307.1.2 Elevated storm shelter foundation systems. Where *storm shelters* are constructed with the top of the supporting foundation system located at an elevation higher than the surrounding finished grade level, the structural stability of the *storm shelter* and elevated supporting foundation system shall be computed assuming that both are fully exposed to the *storm shelter* design tornado, wind and flood loads. Where applicable, and in accordance with the *applicable code*, the impacts of flood-borne debris on stability of the foundation system shall be considered.

307.2 Slabs-on-ground. Where slabs-on-ground are serving as part of the foundation system for the *storm shelter*, the slabs-on-ground shall be designed in accordance with ACI 318 to resist all loads specified in Chapter 3 and to transfer the resultant forces into the ground.

Exceptions:

1. Slabs-on-ground within a *storm shelter* not utilized to transfer tornado and wind forces acting on the *storm shelter* to the ground or to a foundation system supporting the *storm shelter* shall be designed in accordance with the *applicable code*.

2. Slabs-on-ground within a one- or two-family dwelling and supporting a *residential storm shelter* shall be designed in accordance with ACI 318 or ACI 332.

307.2.1 Joints in concrete slabs-on-ground. Design calculations for concrete slabs-on-ground shall include the effect of expansion joints, contraction joints or construction joints where such slabs-on-ground are utilized to resist loads from the supported *storm shelters*.

307.3 Existing slabs-on-ground supporting storm shelters. Replacement or strengthening of existing slabs-on-ground where a *storm shelter* is to be installed shall not be required where all of the following conditions apply:

1. *Community storm shelters* that are a single story in height with a footprint of 64 square feet (5.95 m^2) or less or *residential storm shelter*s.
2. The *storm shelter* is constructed out of concrete or concrete masonry.
3. Calculated soil pressure under the slabs-on-ground supporting the *storm shelter* walls does not exceed 2,000 psf (95.8 kN/m^2) for design loading conditions other than design storm events and 3,000 psf (143.7 kN/m^2) for design storm events.
4. The *storm shelter* is anchored at a minimum to the slab-on-ground at each corner of the structure and on each side of door openings in the shelter envelope.

For SI: 1 inch = 25.4 mm.

FIGURE 303.1.1(1)
100-YEAR, 1-HOUR RAINFALL (INCHES), EASTERN/CENTRAL UNITED STATES