Chapter 3: Structural Design and Testing Criteria

General Comments

Chapter 3 provides requirements and guidance on the determination of structural loads that a storm shelter must be designed to resist and provides specific instructions in dealing with issues particular to the structural design of a storm shelter. These include not only extremely high wind pressures but also a need to design for impact loads from flying debris and structural complications presented by a host building's elements connected to the shelter. Other issues dealt with include anchorage to the foundation, rain loads, flood loads, envelope components including impact-protective systems, openings, joints and penetrations.

Wind loads for storm shelters use wind speed maps. Due to differences in available data and modeling capabilities for the two storm types, different approaches were taken in developing shelter design wind speed maps for hurricanes and tornadoes. Hurricane wind speeds were determined using a probabilistic analysis consistent with the methods used for ASCE 7 wind maps, while tornado wind speeds were developed with a deterministic analysis used in FEMA P-361.

Contour maps of shelter design wind speeds for hurricanes are based on estimates of the 10,000-year mean recurrence interval speeds (i.e., wind speeds having a 0.5-percent chance of exceedance during a 50-year period), shown in Figure 304.2(2). In the most hurricane-prone parts of the continental United States between North Carolina and south Texas, hurricane shelter design wind speeds are equivalent to Saffir Simpson Category 5 hurricanes.

Zoned maps of shelter design wind speeds for tornadoes are based on geospatial analysis of tornado frequency and intensity, shown in Figure 304.2(1). The middle of the country, which typically experiences the most violent tornadoes (EF 5 on the Enhanced Fujita Scale), has a tornado shelter design wind speed of 250 mph. This area generally encompasses parts of the eastern High Plains, the Midwest, the Southeast, and the Ohio River Valley, including regions commonly referred to as “Tornado Alley” and Dixie Alley.”

SECTION 301
GENERAL

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

❖ Storm shelters are designed to provide a very high degree of occupant protection in a severe windstorm, even if the host building (if present) and nearby buildings are severely damaged.

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*.

❖ The unique requirements for storm shelter performance necessitate modifications to some of the ASCE 7 loads as described in Chapter 3, including changes to provisions for wind loads, rain loads, roof live loads, hydrostatic loads and flood loads. Where modifications to ASCE 7 provisions are made, all of the Chapter 3 requirements are more stringent than ASCE 7.

Chapter 3 additionally includes provisions for debris hazards, envelope component design and testing, connections of storm shelters to foundations or slabs, and penetrations of the storm shelter envelope.

ICC 500-2020 uses ASCE 7-16 as a referenced standard for loads. The wind load provisions of ASCE 7-16 have changed compared to ASCE 7-10, which was the referenced standard for ICC 500-2014. Explicit load combinations for storm shelters were added in the 2020 edition, as shown in Section 302.1. These combinations are in addition to the load combinations required by the applicable code.

Supplemental commentary on the history, development and application of ICC 500 structural design criteria is available in Chapter B3 of FEMA P-361, *Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms*, 4th edition.

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.

❖ This section is simply a pointer to the test procedures for pressure testing when it becomes necessary to determine adequacy for resistance to pressure by testing. Additional requirements for pressure testing are contained in Section 804. Section 306 also provides reference to Chapter 8 for impact testing procedures.

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.

❖ Load combinations are provided for Strength Design and Allowable Stress Design, for both tornado shelters and hurricane shelters. These combinations differ slightly from those found in the I-Codes and ASCE 7, to account for use/occupancy and environmental conditions anticipated during a tornado or hurricane.

Snow loads do not appear in any of the storm shelter load combinations because hurricanes and tornadoes are warm weather phenomena. Snow load effects are accounted for using the load combinations from the applicable code (Section 301.2).

The hurricane shelter load combinations include flood loads for shelters subject to the requirements of Section 402.1. These combinations account for both storm surge flooding and rainfall flooding. While flooding can occur in storms that produce tornadoes, the spatiotemporal correlation between tornadoes and flooding is much less than that between hurricane winds and flooding. Therefore, the tornado load combinations do not include flood loads. Tornado shelters are still subject to all applicable load combinations that include flood loads required by the applicable code, per Section 301.2.

Note that for roof live loads, the uniform loads from Section 303.3 are applied simultaneously with the debris impact loads, considering each laydown and falling debris hazard one at a time per Section 305.3.

Loads used in the load combination equations that are not modified in this chapter (e.g., dead load) are determined per ASCE 7.

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*:

$1.4D$ **(Equation 3-1)**

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

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

$1.2D + 1.0W_T + L_T + 0.5L_{rT}$ **(Equation 3-4)**

$0.9D + 1.0W_T$ **(Equation 3-5)**

For *hurricane shelters*:

$1.4D$ **(Equation 3-6)**

$1.2D + 1.6L + 0.5(L_{rH} \text{ or } R_H)$ **(Equation 3-7)**

$1.2D + 1.6(L_{rH} \text{ or } R_H) + (L \text{ or } 0.5W_H)$ **(Equation 3-8)**

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

$0.9D + 1.0W_H$ **(Equation 3-10)**

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:*

$1.2D + 1.0W_H + 2.0F_{aH} + L + 0.5(L_{rH} \text{ or } R_H)$ **(Equation 3-11)**

$0.9D + 1.0W_H + 2.0F_{aH}$ **(Equation 3-12)**

All other locations:

$1.2D + 0.5W_H + 1.0F_{aH} + L + 0.5(L_{rH} \text{ or } R_H)$ **(Equation 3-13)**

$0.9D + 0.5W_H + 1.0F_{aH}$ **(Equation 3-14)**

❖ See the commentary to Section 302.1. For a list of symbols and nomenclature, see Section 203.

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 3-15)**

$D + L_{rT}$ **(Equation 3-16)**

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

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

$D + 0.75L_T + 0.75(0.6W_T) + 0.75L_{rT}$ **(Equation 3-19)**

$0.6D + 0.6W_T$ **(Equation 3-20)**

For *hurricane shelters*:

$D + L$ **(Equation 3-21)**

$D + (L_{rH} \text{ or } R_H)$ **(Equation 3-22)**

$D + 0.75L + 0.75(L_{rH} \text{ or } R_H)$ **(Equation 3-23)**

$D + 0.6W_H$ **(Equation 3-24)**

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

$0.6D + 0.6W_H$ **(Equation 3-26)**

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 3-27)**

$D + 0.75L + 0.75(0.6W_H) + 0.75(L_{rH} \text{ or } R_H) + 1.5F_{aH}$ **(Equation 3-28)**

$0.6D + 0.6W_H + 1.5F_{aH}$ **(Equation 3-29)**

All other locations:

$D + 0.75L + 0.75(0.6W_H) + 0.75(L_{rH} \text{ or } R_H) + 0.75F_{aH}$ **(Equation 3-30)**

$0.6D + 0.6W_H + 0.75F_{aH}$ **(Equation 3-31)**

❖ See the commentary to Section 302.1. For a list of symbols and nomenclature, see Section 203.

SECTION 303 LOADS

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

❖ During even modest hurricanes and tornadoes, there is the potential for significant damage to typical roof coverings and debris accumulation on building roofs, with the corresponding increased likelihood for blockage of the primary or secondary, or both, drainage systems. Such potential blockage could lead to retention of more rainwater than anticipated and corresponding greater rain loads. The designer is cautioned to evaluate the environment surrounding the shelter, including nearby buildings and the host building (if present), for potential debris, and consider increasing the capacity of the secondary drainage system as needed.

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 Figure 303.1.1 or *approved* local weather data.

❖ The rainfall rate used for determination of rain loads on hurricane shelter roofs is an approximation of the 10,000-year mean recurrence interval (MRI) rainfall rate, determined by taking the 100-year, 1-hour rainfall rate and adding 6 inches (152.4 mm) per hour. The 6-inch-per-hour increment was based on a published extreme value analysis of the longest available rainfall records worldwide, each having 100–154 years of data (Koutsoyiannis 2004). Hawaii and Alaska rainfall rates are now included in Figure 303.1.1.

Rainfall rates shown in Figure 303.1.1 are from the 2021 *International Plumbing Code*® (IPC®). For locations not shown in Figure 303.1.1, approved local weather data, such as NOAA, local weather maps or analysis of local weather history, can be used. The following webpage provides point precipitation frequency estimates for the continental United States, Hawaii and Alaska: https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ok.

This webpage provides point precipitation frequency estimates for Puerto Rico and USVI: https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_pr.html.

This webpage provides point precipitation frequency estimates for the Pacific Islands (American Samoa, Guam and CMNI): https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_pi.html.

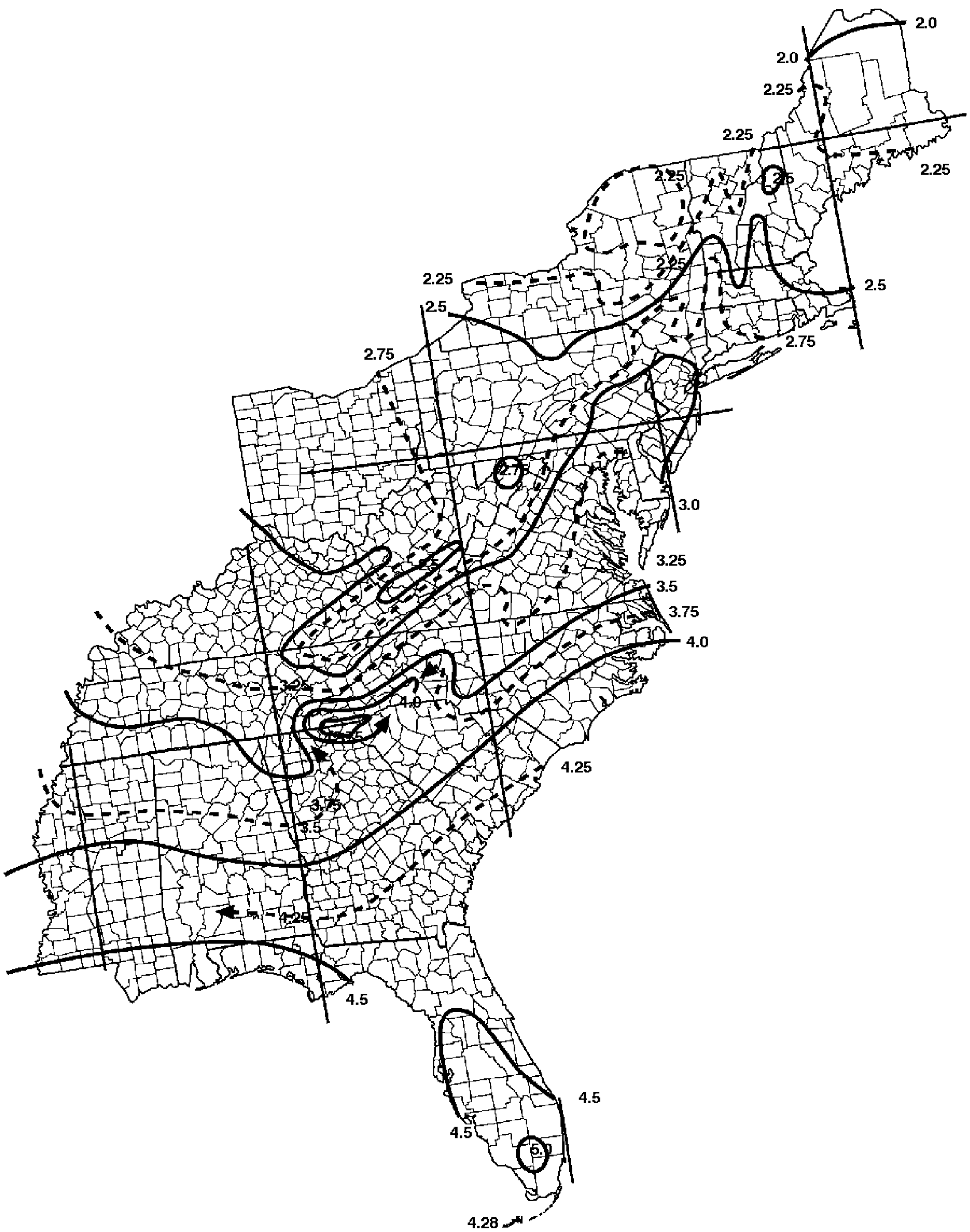
ICC 500 has no rain load or rainfall drainage (roof or site) requirements for tornado storm shelters, so the requirements of the applicable code govern.

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.

❖ Chapter 5 specifies the minimum required floor area per occupant for tornado and hurricane shelters, which is then used to determine the design occupant capacity. Given the short duration of tornado events, Chapter 5 allows for a dense packing of occupants in a community tornado shelter that is equivalent to the live loads specified for assembly occupancies in Section 1607 of the *International Building Code*® (IBC®) and Chapter 4 of ASCE 7. This would typically be a 100 psf load for a lobby, a space with movable seats (e.g., folding chairs) or other similar area. For a prefabricated shelter with fixed bench seating, a 60 psf live load consistent with an assembly area with fixed seating could be used. The assembly area live loads would govern over smaller live loads associated with the normal use of a space.

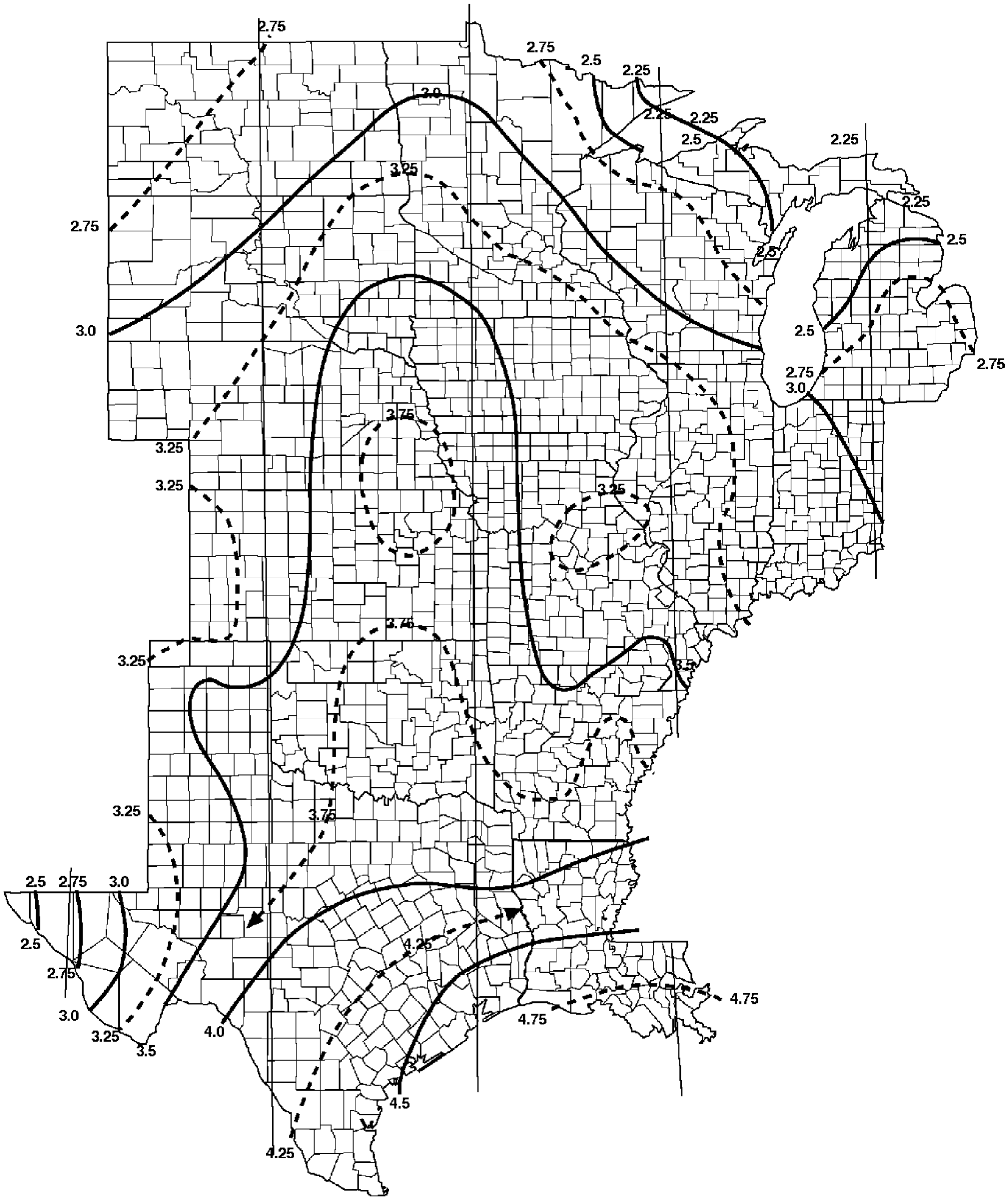
Community hurricane shelters are designed using a greater minimum required floor area per occupant. Hurricane events are longer in duration, so occupant comfort is more critical, and shelters need to accommodate cots or otherwise allow occupants to sleep. As a result, occupants in a hurricane shelter will generally be less densely packed and the corresponding live load may not exceed the normal use of the space.

Residential storm shelters are limited in both the size of the shelter and the total number of occupants. Often a residential storm shelter will be used only by the immediate members of the family occupying the home for which a storm shelter is installed. No minimum live load is specified for residential storm shelters, as the committee judged it unlikely for the standard 40 psf live load mandated by the *International Residential Code*® (IRC®), IBC and ASCE 7 for areas such as living rooms, great rooms, rec rooms and other spaces not considered sleeping areas to be exceeded.



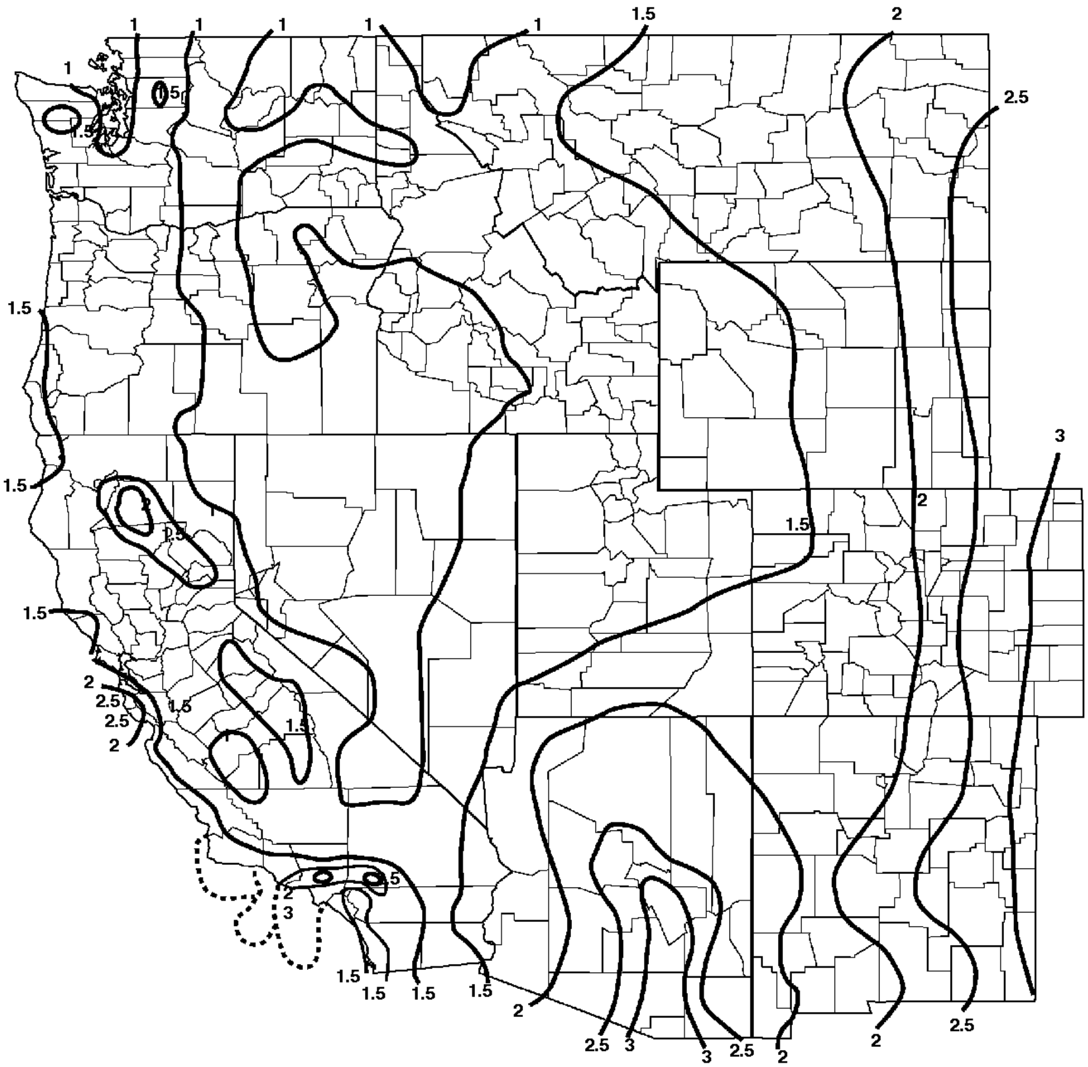
For SI: 1 inch = 25.4 mm.

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



For SI: 1 inch = 25.4 mm.

FIGURE 303.1.1—continued
100-YEAR, 1-HOUR RAINFALL (INCHES), CENTRAL UNITED STATES



For SI: 1 inch = 25.4 mm.

FIGURE 303.1.1—continued
100-YEAR, 1-HOUR RAINFALL (INCHES), WESTERN UNITED STATES