Storm Shelters: Selecting Design Criteria

FEMA

MAY 2007 TORNADO RECOVERY ADVISORY — *FEMA DR-1699-RA2*

Purpose and Intended Audience

The intended audience for this Tornado Recovery Advisory (RA) is anyone involved in the planning, policy-making, design, construction, or approval of tornado shelters, including designers, emergency managers, public officials, policy or decision makers, building code officials, and home or building owners. Homeowners and renters should also refer to the Tornado RA titled *Residential Sheltering: In-Residence and Stand-Alone Shelters.* The purpose of this advisory is to present information on different types of shelter design guidelines, code requirements, and other criteria that pertain to the design and construction of tornado shelters. There are various storm shelter criteria, each of which offers different levels of protection to its shelter occupants.

See these 2007 Tornado Recovery Advisories for information about sheltering from tornadoes:

- *Tornado Risks and Hazards in the Midwest United States* (Tornado RA1)
- *Residential Sheltering: In-Residence and Stand-Alone Shelters* (Tornado RA 3)

This Recovery Advisory Addresses:

- How shelter construction is different from typical building construction:
  - Structural systems
  - Windborne debris resistance
- Design criteria for different types of shelters
- Useful links and shelter resources

How Shelter Construction is Different from Typical Building Construction

A tornado shelter is typically an interior room, space within a building, or an entirely separate building, designed and constructed to protect its occupants from tornado wind forces and windborne debris. The level of occupant protection provided by a space specifically designed as a shelter is intended to be much greater than the protection provided by buildings that comply with the minimum requirements of building codes. The model building codes do not provide design and construction criteria for life safety for sheltering, nor do they provide design criteria for withstanding the forces of tornadoes.

Shelters typically fall into two categories: residential shelters and community (non-residential) shelters.

- Residential tornado shelters are constructed as in-residence or easily accessible external shelters. An ***in-residence shelter***, also called a "safe room," is a small, specially designed ("hardened") room, such as a bathroom or closet that is intended to provide a place of refuge for the people who live in the house. An ***external residential shelter*** is similar in function and design, but it is a separate structure installed outside of the house, either above or below ground. Refer also to the Tornado RA titled *Residential Sheltering: In-Residence and Stand-Alone Shelters.*
- A ***community shelter*** is intended to protect a large number of people, anywhere from 12 to as many as several hundred individuals. These shelters include not only public shelters, but also private shelters for businesses and other organizations.

The term "hardened" refers to specialized design and construction applied to a room or building to allow it to resist wind pressures and windborne debris impacts during a high-wind event and serve as a shelter.

Structural Systems

Community storm shelter being constructed to FEMA 361 criteria in Wichita, Kansas.

The primary difference in a building's structural system when designed for use as a shelter, versus conventional use, is the magnitude of the wind forces it is designed to withstand.

Buildings are designed to withstand a certain wind speed (termed "design [basic] wind speed") based on historic wind speeds documented for different areas of the country. The design wind speed used in conventional construction in the Midwest is a 90 mph, 3-second gust. By contrast, the design wind speed recommended by FEMA[1] for shelters in this same area is a 250 mph, 3-second gust to provide "near-absolute protection."[2]

Wind pressures are calculated as a function of the square of the design wind speed. As a result, the structural systems of a shelter are designed for forces several times higher than those used for typical building construction. Consequently, the structural systems used in shelters (and the connections between them) are very robust.

Windborne Debris Resistance

Windborne debris, commonly referred to as missiles, causes many of the injuries and much of the damage from tornadoes. Windows and the glazing in exterior doors of conventional buildings are not required to resist windborne debris, except for those in windborne debris regions (which are limited to hurricane-prone regions).[3] Debris protection includes impact-resistant glazing, which can either be laminated glass or polycarbonate, and coverings such as shutters. The ASCE 7 missile criteria were developed to minimize property damage and improve building performance; they were not developed to protect occupants. To provide occupant protection, the criteria used in designing shelters include substantially greater windborne debris loads.

> If glazing is present in a tornado shelter, it should be protected by an interior-mounted shutter that can be rapidly deployed by the shelter occupants.

The roof deck, walls, and doors of conventional construction are also not required by the building code to resist windborne debris. However, the roof deck and walls around a shelter space, and the doors leading into it, must resist windborne debris. Additional information regarding the different levels of windborne debris loads is provided below.

Design Criteria for Different Types of Shelters

Shelters provide different levels of protection depending on the design criteria used. The level of protection provided by a shelter is a function of the design wind speed (and resulting wind pressure) used in designing the shelter, and of the windborne debris load criteria.

Design wind speed and wind pressure criteria: The required design strength of the shelter is dictated by wind pressure criteria given by different guides, codes, and standards. The design wind pressure is a function of the design wind speed. In FEMA's shelter publications (see Useful Links on page 3), recommended design wind speeds range from 160 to 250 mph. However, the 2006 International Residential Code and the 2006 International Building Code, which establish the minimum requirements for residential and other building construction, include a design wind speed of 90 mph in the Midwest. The table on page 4 compares shelter design criteria options. The table on page 5 presents comparative data for two locations using the design criteria presented on page 4.

1. FEMA 361, *Design and Construction Guidance for Community Shelters* (July 2000), available online at http://www.fema.gov/library/viewRecord.do?id=1657.
2. "Near-absolute protection means that, based on our knowledge of tornadoes and hurricanes, a shelter built according to this guidance will protect its occupants from injury or death." FEMA 361, page 1-2, *Design and Construction Guidance for Community Shelters* (2000).
3. ASCE 7, American Society of Civil Engineers Standard 7, *Minimum Design Loads for Buildings and Other Structures* (2005).

Windborne debris load criteria: The table below presents windborne debris criteria given in current FEMA guidance and a proposed International Code Council standard. The table shows different test missiles and their corresponding momentum. The first entry in this table is the FEMA missile guidance for residential and community shelters. These parameters provide near-absolute protection.

Tornado and Hurricane Windborne Debris Criteria

Guidance, Code, or Standard Criteria for the Design Missile	Debris Test Speed (mph)	Large Missile Specimen	Momentum at Impact (lb_f-s)
Tornado Missile Testing Requirements			
FEMA 320 / FEMA 361	100	15# 2x4	68
International Code Council (ICC) Proposed Shelter Standard	100 (maximum) 80 (minimum)	15# 2x4 15# 2x4	68 55

NOTES:

lb_f-s – Pounds (force) seconds

Useful Links and Shelter Resources:

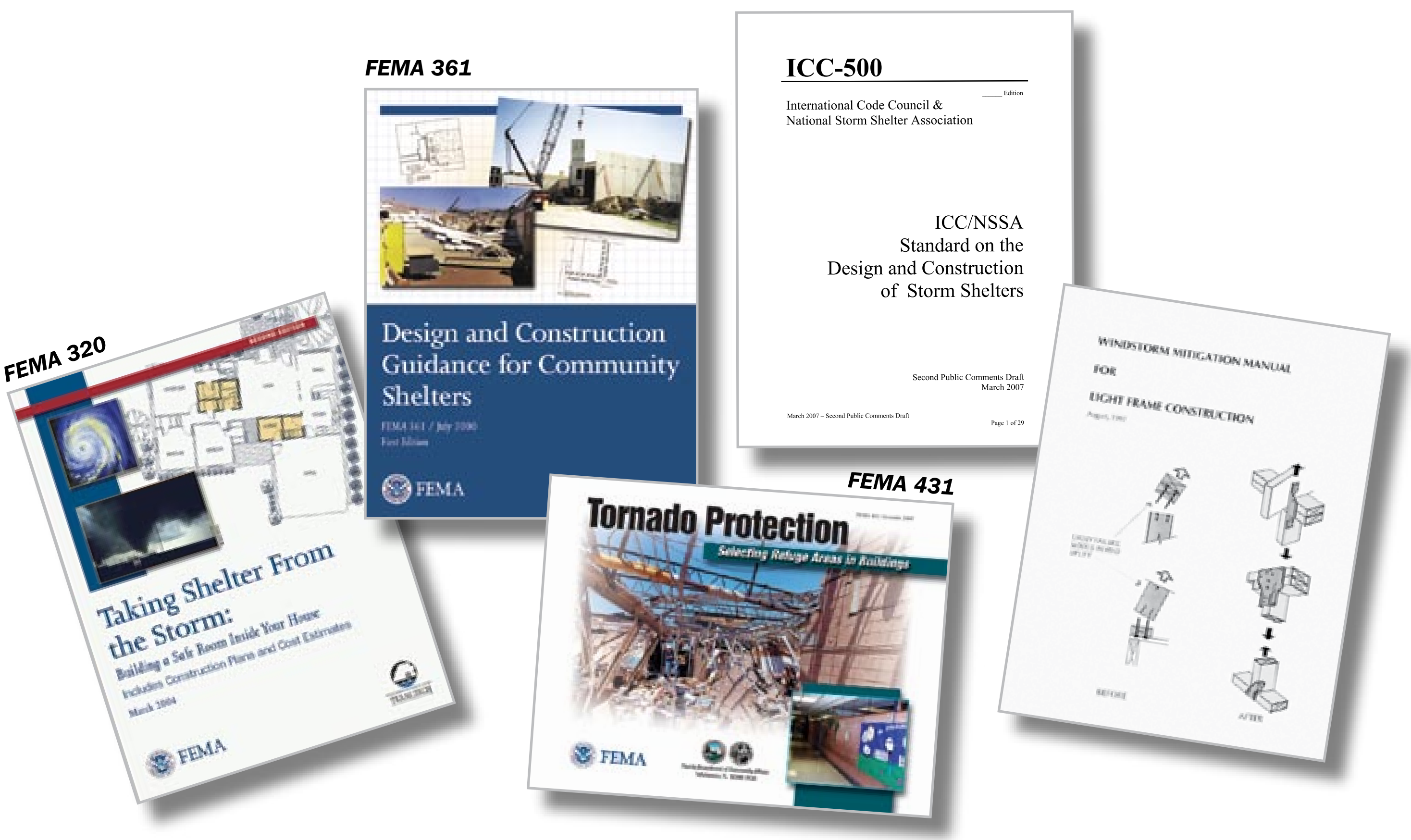
Taking Shelter From the Storm: Building a Safe Room Inside Your House (FEMA 320), FEMA, Washington, DC, Second Edition, March 2004.

Design and Construction Guidance for Community Shelters (FEMA 361), FEMA, Washington, DC, July 2000.

Tornado Protection: Selecting Refuge Areas in Buildings (FEMA 431), FEMA, Washington, DC, November 2003.

Standard on the Design and Construction of Storm Shelters, International Code Council and the National Storm Shelter Association (ICC-500), (Anticipated Release) Early 2008.

Windstorm Mitigation Manual for Light Frame Construction by David Wickersheimer, State Farm Fire and Casualty Company, FEMA Region V, Illinois.



Wind Shelter Design and Construction Codes, Standards, Guidance Comparison Table[1]

Title or Name of Document	Code, Reg, Standard, or Statute?	Wind Hazard	Wind Map[2]	Wind Design Coefficient Considerations[3,4]	Debris Impact Criteria[5]	Remarks
FEMA Shelter Publications: **FEMA 320** *Taking Shelter From the Storm: Building a Safe Room Inside Your House* (2004) **FEMA 361** *Design and Construction Guidance for Community Shelters*	FEMA guidance document, not a code or standard. "Best Practice" for high-wind shelters	Tornado and Hurricane	**FEMA 320:** Hazard map, but wind speeds not used for design **FEMA 361:** Map with four wind speed zones for design (wind mri is 10,000–100,000 years). This map is often referred to as the "FEMA 361 map."	**FEMA 320:** N/A – prescriptive design guidance for maximum hazard **FEMA 361:** Use FEMA 361 wind speed map with four zones. Calculate pressures using ASCE 7 methods and use I=1.0, K_d=1.0, Exposure C, no topographic effects, GCpi=+/-0.55 (this will account for atmospheric pressure change [APC])	Test all shelters with the representative missile: a 15-lb 2x4 at 100 mph (horizontal) and 67 mph (vertical)	**FEMA 320:** Intent is to provide "near-absolute protection." No certification is provided. **FEMA 361:** Intent is to provide "near-absolute protection." Shelter operations guidance is provided. Occupancy issues addressed. Wall section details provided. No certification is provided.
International Code Council/ National Storm Shelter Association (ICC/NSSA) High Wind Shelter Standard (ICC-500) – currently in development, tentatively available for adoption in January 2008.	Consensus standard for shelter design and construction, available for adoption in January 2008. To be incorporated by reference into the 2009 IBC and IRC.	Tornado and Hurricane	**Tornado:** Uses FEMA 361 map.	**Tornado:** Use FEMA 361 wind speed map. Calculate pressures using ASCE 7 methods and use I=1.0, K_d=1.0, Exposure as appropriate, no topographic effects, GCpi=+/-0.55 or +/-0.18+APC	Test shelters with representative missile (missile speed dependent on site design wind speed): **Tornado:** 15-lb 2x4 at 85–100 mph (horizontal) and 2/3 of this speed (vertical).	Intent is to provide a standard for the design and construction of high-wind shelters. Will not use term "near-absolute protection." Occupancy, ventilation, and use issues are also addressed. Shelter operations guidance is provided in the commentary only (commentary is a separate document—not a consensus document).
International Building Code (IBC)/ International Residential Code (IRC) 2000 and later/ASCE 7-98 and later.	Building code and design standards for regular (non-shelter) buildings. Some additional guidance is provided in commentary.	All but tornado	ASCE has its own wind speed map based on historical and probabilistic data; mri is 50 years in non-hurricane-prone regions.	Method is basis of most wind pressure calculation methods. All items in design process are site-specific. Use I=1.15 for critical and essential facilities.	None	The code requires increased wind design parameters only for buildings designated as critical or essential facilities.
Pre-2000 Building Codes	Building code and design standards for regular (non-shelter) buildings	All but tornado	Each of the older codes used their own published wind contour maps.	Typically these older codes provided a hurricane regional factor for design wind speeds, but little attention was paid to components and cladding.	None	These codes specified limited hazard-resistant requirements.
Areas of Refuge/ Last Resort	Guidance from FEMA and others for selecting best-available refuge areas	Tornado and Hurricane	None	None	None	Best available refuge areas should be identified in all buildings without shelters. FEMA 431, *Tornado Protection: Selecting Refuge Areas in Buildings,* provides guidance to help identify the best available refuge areas in existing buildings. Because best available refuge areas are not specifically designed as shelters, their occupants may be injured or killed during a tornado or hurricane.

TABLE NOTES:

1. The wind shelter guidance and requirements shown here are presented from highest to least amount of protection provided.
2. Mean recurrence intervals (mri) for wind speeds maps are identified by the code or standard that developed the map. Typically, the mri for non-shelter construction in non-hurricane-prone areas is 50 years and in hurricane-prone regions, approximately 100 years.
3. American Society of Civil Engineers (ASCE) 7-05 *Building Design Loads for Buildings and Other Structures* (2005) is the load determination standard referenced by the model building codes. The wind design procedures used for any shelter type in this table use one of the wind design methods as specified in ASCE 7-05, but with changes to certain design coefficients that are identified by the different codes, standards, or guidance summarized in this table.
4. From ASCE 7 method: I = importance factor; K_d = wind directionality factor; GCpi = internal pressure coefficient
5. Roof deck, walls, doors, openings, and opening protection systems must all be tested to show resistance to the design missile for the FEMA, ICC, and FL EHPA criteria.

The table below shows comparative data for a location in Kansas for the design criteria presented in the previous table. Where no guidance is provided for sheltering or basic construction, "N/A" (not applicable) is stated. Where there is no requirement, "Not required" is noted.

Design Criteria Comparison

Shelter Design Standard, Code, or Document	Data[1]	Example Location: Wichita, KS
FEMA 320/361	Design wind speed	250 mph
	Pressure on windward wall[2]	167 psf[3]
	Pressure on roof section[4]	401 psf (suction)
	Test missile momentum at impact	68 lbf –s[5]
ICC-500 (pending 1/08)	Design wind speed	250 mph
	Pressure on windward wall	167 psf
	Pressure on roof section	401 psf (suction)
	Test missile momentum at impact	68 lbf–s (tornado)
ASCE 7-05/IBC 2006 (ASTM E 1996)	Design wind speed	90 mph
	Pressure on windward wall	15 psf
	Pressure on roof section	36 psf (suction)
	Test missile momentum at impact	Not required
Pre-2000 Building Codes	Design wind speed	80 mph fastest-mile (100 mph 3-sec peak gust)
	Pressure on windward wall	16 psf
	Pressure on roof section	26 psf (suction)
	Test missile momentum at impact	Not required

NOTES:

1. Wind pressures were calculated based on a 40-foot x 40-foot square building, with a 10-foot eave height and a 10-degree roof pitch.
2. The wall pressures are Main Wind Force Resisting System (MWFRS) corner load.
3. psf – Pounds per square foot;
4. The given roof pressures are the wind loads for components and cladding at the corner of the roof (where pressures are highest) with an effective wind area of 40 square feet (sf).
5. lbf-s – Pounds (force) seconds